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# Lifestyle, biological risk factors for non-communicable diseases in the midst of social inequalities and COVID-19

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# Lifestyle, biological risk factors for non-communicable diseases in the midst of social inequalities and COVID-19

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# Editorial: Lifestyle, biological risk factors for non-communicable diseases in the midst of social inequalities and COVID-19

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KEYWORDS

**non-communicable disease (NCD), COVID-19, social inequalities, risk factors, lifestyle**

Editorial on the Research Topic
Lifestyle, biological risk factors for non-communicable diseases in the midst of social inequalities and COVID-19

Poverty involves a variety of human deprivations, including those related to food consumption, education, security, health, dignity, and a decent job (1, 2). Relative poverty is defined as a person's failure to reach a minimal quality of life in comparison to others in the same location and time (3), while subjective poverty is a personal perspective of financial or material position (4). Poverty is the primary underlying cause of reduced food security and quality and quantity of consumed food, which exposes people to low dietary diversity and increases their risk of developing non-communicable diseases (NCDs).

The NCD profile is changing rapidly over time amongst rural South African populations due to COVID-19, poverty, and other psychosocial factors. The South African Development Plan highlights important recommendations for a 28% reduction in the prevalence of NCDs by the year 2030 in line with the requirements to meet the Sustainable Development Goal (SDG) target (5). Similarly, the World Heart Federation has set the year 2025 by which to have reduced NCD prevalence by 25% (6). However, the onset of the COVID-19 pandemic in early 2020 has already likely further compromised the efforts toward attaining the national and global targets. Some individuals and families have been pushed back to extreme poverty in low socioeconomic contexts. Therefore, efforts to tackle the triple burden of NCDs, poverty, and COVID-19 are urgent. Unfortunately, low literacy levels impact the triple burden of disease, and recommended lifestyle changes remain extremely low among individuals, families, and communities. Health promotion initiatives by medical experts, academics, and scholars are crucial if one wants to be successful in changing an individual's lifestyle. The community must look for novel and creative solutions to address demographic challenges such as overweight/obesity, hypertension, physical inactivity, smoking cessation, and alcohol abuse to maintain healthy-living lifestyles. Furthermore, to work toward alleviating the burden of NCD today, it is crucial to have a thorough understanding of the CVD risk factors, such as behavioral, clinical, and sub-clinical factors, as well as the resulting target organ damage.

Health professionals, academics, scholars, and community members gathered in the University of Limpopo and Kitty Village, Lephalale, during the period from 22 to 24 November 2022 from all parts of the world under the unique light of the 3rd Ellisras Longitudinal Study and Other Non-Communicable Diseases International Conference. The theme of the conference was “multi-morbidity, poverty, and COVID-19- are we winning?” New knowledge of NCDs acquired through laboratory and field work efforts and dedication was imparted. The series in this e-book Research Topic, among others, include a Research Topic of articles developed from selected abstracts presented at the 3rd ELSONCDIC and other sources such as Frontiers in Nutrition and Frontiers in Public Health.

In this Research Topic, there are 14 papers covering the above-mentioned topic. Four articles covered the section on **lifestyle choices and non-communicable disease risk factors**. A systematic review and meta-analysis reported a positive correlation between cumulative cortisol activity and adiposity-related complications, with cortisol levels being the only predictor of long-term stress among children. Furthermore, Ma et al. did not report any significant association between body mass index (BMI)/BMI z-score and the concentration of morning salivary cortisol and total daily cortisol output. Sekgala et al. (a) reported that the chances of developing metabolic syndrome (MetS), aberrant HDL-C, triglycerides, and hypertension were enhanced by alcohol consumption, sugar-sweetened drinks (SSBs), fried foods, and snacks from street food (SF) vendors. Furthermore, the body fat percentage and Clínica Universidad de Navarra-Body Adiposity Estimator (CUN-BAE) were the best discriminators of MetS, followed by the waist circumference, waist-to-height ratio, BMI, and the body roundness index (BRI) as the last discriminator. All the anthropometric measures demonstrated outstanding discriminatory abilities for predicting MetS, with c-statistics often larger than 0.8 [Sekgala et al. (b)]. Finally, gender disparity was detected in alcohol use by Mmereki et al., whereby adolescents aged 15–17 years and 18–21 years showed greater alcohol consumption than those aged 13–14 years.

Three manuscripts covered the section on **the COVID-19 pandemic and lifestyle.** Patients who previously only complied partially with treatment instructions before COVID-19 and who had an unstable disease condition were more susceptible to pandemics and epidemics and may require special care if such widespread outbreaks recur in the future (Jiao et al.). Participants affected by food insecurity (FI) had greater anxiety about poverty, COVID-19, and the health effect of FI on their lives. Additionally, the relationship between financial and physical wellbeing was found to be mediated by FI but not mental quality of life (QOL) indicators (Karam et al.). Male participants were most likely to follow an unhealthy lifestyle, such as drug use and smoking, while female participants were the most likely to be physically inactive (Sultana et al.).

**The poverty and risk of NCDs section was covered in three manuscripts.** It was found that a person’s physical health is greatly impacted by the length of their subjective poverty, particularly if they live in a rural area (Cao et al.). Householder smoking had a significant impact on the household’s likelihood of living in poverty, while having an NCD had a beneficial mediation effect (Yang et al.). Children from low-income backgrounds were shorter and leaner than those from high-income backgrounds, but they maintained their lean mass, which is an important trait for male reproduction. Due to lesser energy reserves and the avoidance of cardiometabolic expenses, their immune systems may have been compromised (Wells et al.).

The section on **nutrition and dietary patterns included two manuscripts.** On an interpersonal level, the best source of breastfeeding support was found to be mostly in the family. However, family interference also serves as a roadblock to breastfeeding. On the community level, family beliefs and practices are common among mothers. However, different traditional beliefs and societal and cultural norms divide them in the promotion or obstruction of breastfeeding. Intervention programs should concentrate on behavior modification to inform and prepare mothers to overcome controllable obstacles (Seabela et al.). Teenagers in Zambia were found to prefer four main dietary patterns: snacking, which includes eating sweets and snacks; vegetarianism, which includes eating pulses, fish, and vegetables; health consciousness, which includes eating fruits and eggs; and traditional, which includes eating cereal and meat. Teenagers also adhered to rather less common and healthier vegetarian and health-conscious dietary habits (Mukanu et al.).

Only one article was available in the section on the use of **a questionnaire to achieve valid estimates of any health measure, HIV antiretroviral therapy, and increased endothelial biomarkers**. Decision-makers and researchers in the health profession should be mindful that question-order biases can alter results from two questionnaires with questions that have the same words but a different order or clustering, rendering the comparison of the results from the two questionnaires invalid. The results imply that when evaluating the scale of a subjective health-related phenomenon exposed to significant ambiguity (e.g., the perceived danger of occasional and frequent drug use), the responses may greatly depend on the question ordering when using two or more consecutive or adjacent items (Pérez-Romero et al.). After adjustments for CVD risk factors, HIV status was linked to higher levels of endothelial dysfunction biomarkers when compared to a HIV-negative control (Hanser et al.).

## Summary

Urbanization is associated with increased changes in lifestyle and diet. Therefore, it is hypothesized to contribute to the increase of CVD worldwide, especially during the COVID-19 pandemic phase. Furthermore, susceptibility to hunger, food insecurity, poverty, negative socioeconomic factors, and unhealthy lifestyles have also contributed to the global increase in CVD prevalence. Lifestyle changes that encourage the cessation of risky behavior should be promoted and will eventually benefit individuals and communities. Influential lifestyle changes begin with the acquisition of accurate knowledge through personal interaction with health experts, scholars, and academics who disseminate health information to different sectors of the community.

## Author contributions

KM wrote the first draft and sent it to AK, BN-C, and HK for critical review and input. The article's submission was reviewed and approved by all the authors. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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# Association of Householder Smoking With Poverty and the Mediating Effect of NCDs in Relatively Underdeveloped Regions in China

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**Background:** Studies have not provided clear enough evidence on the direct association between cigarette smoking and poverty. This study aims to assess the association of householder smoking with near-poverty households, and the potential mediating effect of NCDs.

**Methods:** A cross-sectional survey was conducted from November 2019 to October 2020 in relatively underdeveloped regions in China. In total, 2,409 households were investigated in areas under the jurisdiction of 24 primary health care (PHC) institutions of eight provinces. Pearson's $\chi^2$-test was performed, and multivariable logistic regression and extended probit regression models were fitted to examine the association between householder smoking and near-poverty households. Moreover, generalized structural equation modeling was used to explore the mediating effect of NCDs.

**Results:** After adjusting for all other potential confounding factors, compared with households headed by never-smokers, households headed by smokers exhibited significantly elevated risks of being near poverty, with an odds ratio of 2.01 (95% CI: 0.48–0.91). We also found that living in rural areas and having a low education level both had a negative effect on being near poverty. Additionally, NCDs had a significantly positive mediating effect, with a 31.57% effect of householder smoking on near-poverty status mediated by NCDs; the indirect effect was estimated to be 0.17 (95% CI: 0.04–0.31).

**Conclusions:** Householder smoking significantly elevated the risk of the household being near poverty, and suffering NCDs had a positive mediating effect.

**Keywords: cigarette smoking, poverty, noncommunicable diseases (NCDs), extended probit regression, generalized structural equation model**

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## INTRODUCTION

Cigarette smoking is a major public health problem and remains the leading preventable cause of death and disability in China and other countries, killing more than 8 million people a year around the world (1). In 2020, it was estimated that there were approximately 1.3 billion tobacco users worldwide, with the vast majority living in low- and middle-income countries or in more disadvantaged socioeconomic groups (1, 2). China is the world's largest producer and consumer of tobacco, accounting for more than 44% of the world's total cigarette consumption (3). It is estimated that one million people die of tobacco-related diseases in China every year, with the majority of those individuals in their productive years. Unfortunately, this number is estimated to exceed three million per year by the end of 2050 if the smoking epidemic is not controlled (4, 5).

Additionally, even though the global percentage of people living in extreme poverty declined from 36% in 1990 to 10% in 2015, more than 700 million people now live in extreme poverty (6). "End poverty in all its forms everywhere" is the first goal of United Nations Sustainable Development. Studies have found that noncommunicable diseases (NCDs), associated with mortality and prolonged disability, have negative impacts at the individual, community, and societal levels (7) and could expose individuals to poverty through lost productivity, unemployment and long-term medical expenses (8, 9). Meanwhile, studies have also found that cigarette smoking is one of the main risk factors driving the growing epidemic of NCDs, including cancers and cardiovascular and respiratory diseases (10, 11). However, early studies have not provided clear enough evidence on the direct association between cigarette smoking and poverty. Evidence is accordingly required to clarify the association of cigarette smoking with poverty and its underlying mechanisms, underpinning the rationale for integrating tobacco control policies with poverty alleviation strategies.

At the macro level, multiple studies have demonstrated that tobacco use imposes an economic burden through a reduction in productivity and an increase in the cost of medical treatment (12). For example, Pearce et al. (13) reported that in 2012, tobacco use contributed to an estimated USD 7.9 billion, USD 402 million, and USD 138 million in lost productivity in China, Brazil, and South Africa, respectively. Cigarette smoking accounted for approximately USD 289-332.5 billion in medical expenses over the period 1964–2014 in the United States (14), while in Indonesia, tobacco-related treatment costs were estimated at nearly USD 2.2 billion (15). The Directorate General for Health and Consumers study (16) reported that the estimated costs attributed to cigarette smoking in the European Union amounted to approximately USD 714.9 billion in 2009, and a global estimated economic burden of smoking was approximately USD 1.44 trillion in 2012 (17).

At the micro level, there have been few studies about cigarette smoking and poverty. Liu et al. (18) estimated cigarette smoking's impact on poverty through excessive medical spending and direct spending on cigarettes. Wei et al. (19) conducted a population-based study and demonstrated that smoking can significantly reduce the income of Chinese urban residents, resulting in immense negative impacts on society. In the traditional Chinese family structure, the householder is often male and males have much higher smoking rates than females (5). Moreover, householders often shoulder a heavy burden and play a central role in households' economic status. However, to our knowledge, no study has assessed the association between householder smoking and poverty and its underlying mechanisms. To fill this research gap, we conducted a cross-sectional study and assessed the association of householder smoking with near-poverty households and the mediating effect of NCDs in relatively underdeveloped regions in China.

# METHODS

## Study Design and Participants

We conducted a cross-sectional questionnaire-based survey in relatively underdeveloped regions in China from November 2019 to October 2020, and the participants were enrolled using a stratified multistage sampling method. According to per capita GDP levels, we first chose 12 cities/counties that had relatively lower per capita GDP in eight province-level regions in China (North China: Fuping and Pingshan in Hebei Province; Central China: Nanyang in Henan Province, Macheng and Qichun in Hubei Province; Eastern China: Linqing and Wuli in Shandong Province; Southwest China: Luzhou in Sichuan Province, Kaili in Guizhou Province; Northwest China: Yulin in Shanxi Province; Northeast China: Harbin and Wuchang in Heilongjiang Province). Then, in each city/county, two primary health care (PHC) institutions were randomly selected as our investigation units, for a total of 24 PHC institutions.

Next, with the coordination of local health professionals in PHC institutions, approximately 100 households were selected in areas under the jurisdiction of each PHC institution. The participants were not sampled randomly but were directly selected based on the following: (1) living in local communities for at least 6 months; (2) willing to participate in this study; (3) the householder was aged over 40; (4) near-poverty households and nonpoor households were included; and (5) smokers and never-smokers were included.

## Data Collection and Measures

The selected householders had a face-to-face interview with the local health professionals of the PHC institutions, and prior to the interview, investigators received professional training to ensure data collection quality. A validated interviewer-administered questionnaire was used to obtain information about the household's basic situation (household income, size of household and residence location), demographic characteristics of the householder (sex, age, education level, marital status, and income level), and the householder's smoking status, whether the householder suffered from NCDs or not and so on. All measures were self-reported in the study.

## Poverty Status

In 2019, the Chinese government defined the poverty as yearly per capita income <3,747 Yuan (or US $1.49 per day). In our study, we further defined near-poverty as 200% of the poverty level definition (7,494 Yuan) and categorized household poverty status as near-poverty (yearly per capita income <7,494 Yuan) or nonpoor (yearly per capita income of 7,494 Yuan or above).

## Smoking Status

Smoking status was categorized as smoker (including current smoker and former smoker) or never-smoker. Participants were asked: "Have you smoked in the last month?" When the respondent answered "yes", the individual was categorized as a "current smoker"; if the respondent answered "no", he or she was then asked, "have you ever smoked?" If the respondent answered "yes", the individual was considered to be a "former smoker"; if the answers to both questions were "no", the respondent was considered a never-smoker.

## Noncommunicable Diseases (NCDs)

Noncommunicable disease status were determined by the following question: "Have you ever been diagnosed with noncommunicable diseases, such as hypertension, diabetes, COPD, CHD, strokes, cancer and so on?" Respondents who replied "yes" were categorized as having NCDs.

## Respondent Characteristics

We controlled for an array of demographic and socioeconomic statuses that have been previously shown to be associated with cigarette smoking and poverty. The basic household situation included the household's residential location (rural or urban) and household size (number of household members). Demographic characteristics of the householder included the following: sex (male or female); age group (40–50 years, 50–60 years, 60–70 years, ≥70 years); educational level (illiterate, primary, junior high, senior high/vocational, college and above), marital status (single, married, divorced/widowed) and alcohol use (yes or no). We also asked, "Does raising cigarette prices influence tobacco use?" (yes or no). All covariates were categorical variables.

## Statistical Analysis

The database was established using Epidata 3.1 and transferred into Stata/MP 16.0 software for analysis. Categorical (nominal/ordinal) variables were described using frequencies and percentages. Pearson's $\chi^2$-test was performed to assess differences in the characteristics between near-poverty and nonpoor households for the categorical variables. Both univariate and multivariate logistic regression models were used to determine the association between householder smoking and near-poverty households. The covariates were adjusted in the multivariable logistic regression model. Moreover, to accommodate endogenous covariates, we fitted an extended probit regression model (20) using the response to "Does raising cigarette prices influence tobacco use?" as the instrumental variable of smoking status to examine the association. In addition, we used generalized structural equation modeling to evaluate the mediating effect of NCDs.

# RESULTS

## Demographic Characteristics

The study included 1,595 households from rural areas and 814 households from urban areas. Of the 2,409 households, 430 (17.85%) households were near-poverty, and 1,979 (82.15%) households were nonpoor. A total of 1,183 (49.11%) householders were never-smokers, while 1,226 (50.89%) householders were smokers. The ages of the householders ranged from 40 to 80 years, with an average age of 55.52 ± 10.42 years. **Table 1** compares the basic household situations and the householders' demographic characteristics according to poverty status. Near-poverty households were more likely to be in rural areas and to have only one member in the household. For householders from near-poverty households, the smoking rate was higher than that in householders from nonpoor households (60.00 vs. 48.91%, $P < 0.001$). NCDs were reported to be more prevalent among near-poverty householders (51.16%) than nonpoor householders (30.32%). Furthermore, near-poverty householders tended to be older, to be single or divorced/widowed, and to have a lower education level. In terms of householder sex, there were no considerable differences between the two categories of households (84.19 vs. 84.13% male).

## Association of Householder Smoking With Near-Poverty Household

**Table 2** shows the association of householder smoking with near-poverty status among households in relatively underdeveloped regions of China. The results of Models 1–3 all suggest that householder smoking significantly increased the risk of households being near poverty ($P < 0.05$). As shown in Models 1–2, compared to households headed by never-smokers, households headed by smokers had an approximately 50% increase in the probability of household being near poverty, with odds ratios of 1.57 (95% CI: 1.27–1.94) and 1.49 (95% CI: 1.14–1.95), respectively. In Model 3, we found that the correlation between the errors of our two equations was significantly negative, so the unobservable factors that increased the householder smoking rates decreased the probability of households being near poverty. The results of Model 3 revealed that households headed by smokers had a two times higher risk of being near poverty than households headed by never-smokers, with an odds ratio of 2.01 (95% CI: 0.48–0.91).

**Table 3** presents the average treatment effect (ATE) of householder smoking on near-poverty status and the average potential-outcome means (PO means) of the two smoking status based on Model 3. When all householders were never-smokers, we estimated that the average probability of households being near poverty was 12.14% (95% CI: 0.10–0.14), which would rise to 25.23% (95% CI: 0.22–0.28) when all householders were smokers. The average probability of households being near poverty increased by 12.99% (95% CI: 0.09–0.17) when all householders were smokers vs. when all householders were never-smokers.

Moreover, households in rural areas had higher odds of being near poverty than households in urban areas (OR = 0.70,

**TABLE 1 |** The sociodemographic characteristics of near-poverty and nonpoor households.

| Characteristics | Near-poverty N(%) | Nonpoor N(%) | $\chi^2$ | *P* value |
|---|---|---|---|---|
| Smoking status | | | 17.37 | <0.001 |
| Never-smoker | 172 (40.00) | 1,011 (51.09) | | |
| Smoker | 258 (60.00) | 968 (48.91) | | |
| Residence location | | | 132.41 | <0.001 |
| Urban | 43 (10.00) | 771 (38.96) | | |
| Rural | 387 (90.00) | 1,208 (61.04) | | |
| Household size* | | | 97.37 | <0.001 |
| 1 | 101 (23.60) | 151 (7.68) | | |
| 2 | 118 (27.57) | 665 (33.84) | | |
| 3–4 | 128 (29.91) | 777 (39.54) | | |
| ≥5 | 81 (18.93) | 372 (18.93) | | |
| Sex | | | <0.001 | 0.978 |
| Male | 362 (84.19) | 1,665 (84.13) | | |
| Female | 68 (15.81) | 314 (15.87) | | |
| Age group | | | 91.89 | <0.001 |
| 40–50 years | 83 (19.30) | 749 (37.85) | | |
| 50–60 years | 129 (30.00) | 642 (32.44) | | |
| 60–70 years | 124 (28.84) | 394 (19.91) | | |
| ≥70 years | 94 (21.86) | 194 (9.80) | | |
| Education level* | | | 430.36 | <0.001 |
| Illiterate | 129 (30.07) | 86 (4.36) | | |
| Primary | 165 (38.46) | 412 (20.90) | | |
| Junior high | 109 (25.41) | 741 (37.60) | | |
| Senior high/vocational | 24 (5.59) | 424 (21.51) | | |
| College and above | 2 (0.47) | 308 (15.63) | | |
| Marital status* | | | 226.06 | <0.001 |
| Single | 62 (14.45) | 25 (1.26) | | |
| Married | 280 (65.27) | 1,759 (88.93) | | |
| Divorced/Widowed | 87 (20.28) | 194 (9.81) | | |
| NCDs | | | 54.28 | <0.001 |
| Yes | 210 (51.16) | 600 (30.32) | | |
| No | 220 (48.84) | 1,379 (69.68) | | |

**There were missing data, and the variables of household size, education level and marital status had 16, 9 and 2 missing data points, respectively.*

95% CI: −0.56 to −0.15). Additionally, we also found that the higher the education level of the householder was, the lower the predictive probability of the household being near poverty in both rural and urban areas. However, regarding different education levels, households headed by smokers all had higher probabilities of being near poverty than households headed by never-smokers (**Figure 1**).

## Mediating Effect of NCDs Between Householder Smoking and Near-Poverty Status

**Figure 2** presents the path diagram of the generalized structural equation model estimation used to evaluate the mediating effect of NCDs between householder smoking and near-poverty status. As shown in **Table 4**, smokers had an increased risk of suffered from NCDs compared with never-smokers, and the direct effect of smoking on NCDs was estimated to be 0.33 (95% CI: 0.13–0.53). Householders who had NCDs had an increased probability of being near poverty, and the direct effect was estimated to be 0.53 (95% CI: 0.28–0.77). There was a significant positive indirect effect of householder smoking on households being near-poverty status (coefficient: 0.17; 95% CI: 0.04–0.31). In addition, we also observed that the direct and total effects of householder smoking on near-poverty status were estimated to be 0.38 (95% CI: 0.14–0.62) and 0.55 (95% CI: 0.28–0.82), respectively, which were both significant. Overall, we estimated that 31.57% of the total effect was mediated by NCDs.

# DISCUSSION

In this study, we observed a strong association between householder smoking and household being near-poverty status that persisted after adjusting for basic household

**TABLE 2 |** Unadjusted and adjusted odds ratios of the association of near-poverty status with householder smoking.

| Variable | Model 1 OR (95% CI) | Model 2 OR (95% CI) | Model 3 OR (95% CI) |
|---|---|---|---|
| **Poverty status** | | | |
| Smoking status (Ref.: Never-smoker) | | | |
| Smoker | 1.57 (1.27–1.94) *** | 1.49 (1.14 to 1.95) ** | 2.01 (0.48 to 0.91) *** |
| Residence location (Ref.: Rural) | | | |
| Urban | | 0.50 (0.33 to 0.74) *** | 0.70 (−0.56 to −0.15) *** |
| Age group (Ref.: 40–50 years) | | | |
| 50–60 years | | 1.18 (0.84 to 1.65) | 1.11 (−0.08 to 0.28) |
| 60–70 years | | 1.17 (0.81 to 1.69) | 1.10 (−0.10 to 0.30) |
| ≥70 years | | 1.18 (0.76 to 1.83) | 1.124 (−0.12 to 0.36) |
| Sex (Ref.: male) | | | |
| Female | | 0.87 (0.56 to 1.36) | 1.18 (−0.08 to 0.41) |
| Education level (Ref.: illiterate) | | | |
| Primary | | 0.33 (0.23 to 0.49) *** | 0.52 (−0.87 to −0.43) *** |
| Junior high | | 0.13 (0.08 to 0.19) *** | 0.31 (−1.42 to −0.94) *** |
| Senior high/vocational | | 0.06 (0.03 to 0.11) *** | 0.21 (−1.86 to −1.25) *** |
| College and above | | 0.01 (0.01 to 0.05) *** | 0.12 (−2.73 to −1.57) *** |
| Marital status (Ref.: single) | | | |
| Married | | 0.10 (0.05 to 0.18) *** | 0.27 (−1.65 to −1.00.) *** |
| Divorced/widowed | | 0.22 (0.11 to 0.44) *** | 0.42 (−1.25 to −0.51) *** |
| **Smoking status** | | | |
| Influence or not (Ref.: NO) | | | |
| Yes | | | 18.47 (2.43 to 3.41) *** |
| Sex (Ref.: male) | | | |
| Female | | | 0.33 (−1.28 to −0.92) *** |
| Corr (e. smoking status, e. poverty status) | | | 0.67 (−0.53 to −0.24) *** |

*Model 1 is unadjusted. Model 2 is adjusted for residence location, education level, marital status and provinces. Based on Model 2, Model 3 was fitted using the response to the question about higher cigarette prices influencing tobacco use as the instrumental variable, with sex was also adjusted in the auxiliary model.*
*The estimated results for the variable province are not shown in the table.*
*** $p < 0.01$; *** $p < 0.001$.*

**TABLE 3 |** Estimates of ATE of householder smoking on being near poverty and PO means of the two smoking status.

| | Margin | Unconditional standard errors | z | *P* value | 95% CI |
|---|---|---|---|---|---|
| **PO mean** | | | | | |
| Smoking status | | | | | |
| Never-smoker | 0.1223766 | 0.0097019 | 12.61 | <0.001 | 0.10–0.14 |
| Smoker | 0.2522712 | 0.0166563 | 15.15 | <0.001 | 0.22–0.28 |
| **ATE** | | | | | |
| Smoking status | | | | | |
| (Smoker vs. never-smoker) | 0.1298946 | 0.0214413 | 6.06 | <0.001 | 0.09–0.17 |

situation and sociodemographic factors. In line with previous studies (19, 21), our results indicated that householder smoking elevated the probability of households being near poverty after adjustment for relevant covariates and potential confounds, which contributed evidence on the direct association between householder smoking and near-poverty status at the micro level.

Moreover, our study revealed a higher impact of smoking on poverty than in a previous study (19). Possible reasons are as follows. First, near-poverty status was used as the income criterion in this study, which was defined as 200% of the poverty level definition. Second, the study was conducted in relatively underdeveloped regions in China, particularly rural regions where residents have higher rates of smoking and poverty than residents of urban areas (22). Third, participants interviewed in this study were aged over 40, and studies have shown that adverse effects of smoking are cumulative and delayed, which would be gradually shown after smokers become middle-aged (14, 18). Meanwhile, we also found that the effect of householder smoking on household near-poverty status was more significant

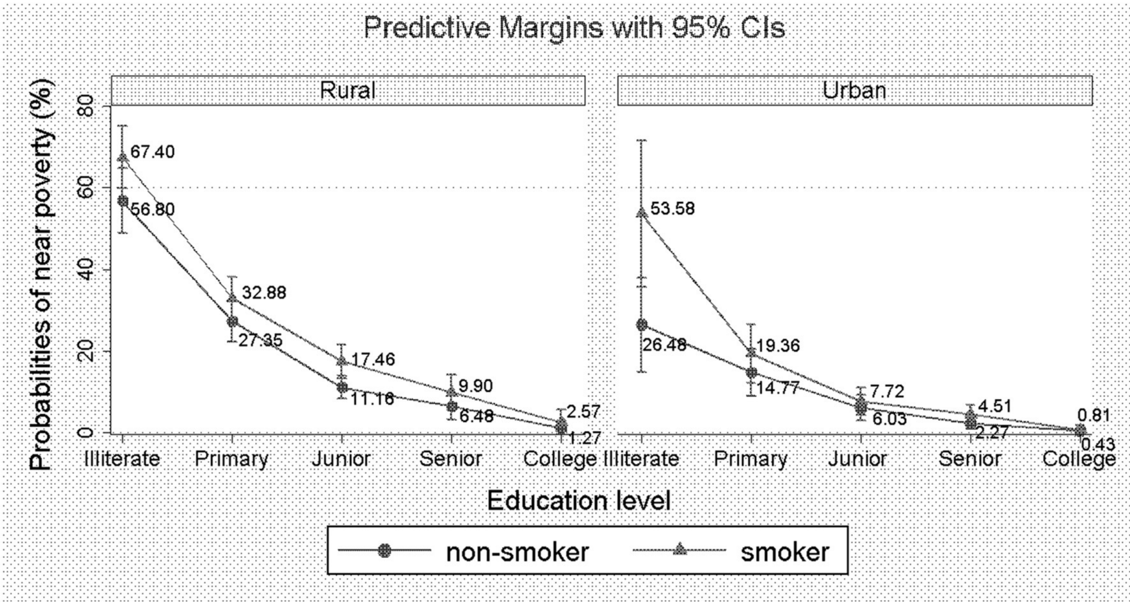


**FIGURE 1 |** Predictive probabilities of being near poverty across different education levels and smoking status.

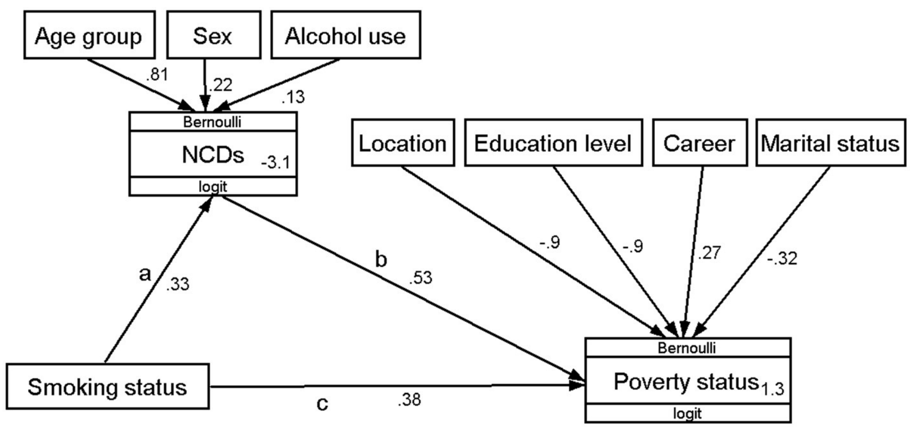


**FIGURE 2 |** Path diagram of generalized structural equation model estimation of the mediating effect of NCD's between householder smoking and near-poverty status. Path c is the direct effect before taking into account the effect of NCDs. Path a and b make up the mediating pathway, with the mediating effect usually being described in the literature as the product of co-efficient (ab). Age group, sex, and alcohol use were adjusted as confounding variables of NCDs. Residence location, education level, career, and marital status were adjusted as the confounding variables of being near poverty.

in households with householders aged over 50 than in households with householders under 50 years old.

The purchasing of cigarettes imposes a financial burden on low-income smokers and their families, but tobacco-related diseases, such as NCDs, exact an even greater cost and plunge those already on the margins into poverty. This study revealed that NCDs had a significantly positive mediating effect between householder smoking and household being near-poverty status, which offered evidence to consider the underlying mechanisms of the observed association. Potential explanations include the toxic effects of smoking on the human body, including but not limited to endothelial dysfunction, inflammation, and cancer, leading to a higher chance of developing NCDs (23, 24). Furthermore, NCDs result in reduced workforce participation and productivity, which has a direct bearing on household income (12, 19). Additionally, it has been suggested that NCDs significantly increase outpatient and hospitalization rates and medical expenditures, diverting household funds from basic necessities such as food, education and health care and further increasing the risk of poverty (25, 26). However, the causality of householder smoking and poverty is complex, and further studies should be carried out to provide more evidence.

Our study indicated that cigarette smoking has a strong association with near-poverty status, so from a policy perspective,

**TABLE 4 |** Generalized structural equation model estimation results of the mediating effect of NCDs between householder smoking and near-poverty status.

| | Coefficient | Standard errors | z | *P* value | 95% CI |
|---|---|---|---|---|---|
| **Direct effects** | | | | | |
| Poverty status | | | | | |
| NCDs | 0.5276675 | 0.1240981 | 4.25 | <0.001 | 0.28–0.77 |
| Smoking status | 0.3779753 | 0.1235824 | 3.06 | 0.002 | 0.14–0.62 |
| NCDs | | | | | |
| Smoking status | 0.3305322 | 0.1023171 | 3.23 | 0.001 | 0.13–0.53 |
| **Indirect effects** | | | | | |
| Poverty status | | | | | |
| Smoking status | 0.1744111 | 0.0678039 | 2.57 | 0.010 | 0.04–0.31 |
| **Total effects** | | | | | |
| Poverty status | | | | | |
| Smoking status | 0.5523864 | 0.1387412 | 3.98 | <0.001 | 0.28–0.82 |

controlling tobacco use and reducing smoking prevalence are not only important public health issues but are also closely related to poverty alleviation. As the most populated developing country in the world, China has made remarkable progress in poverty alleviation; however, problems of "sickness poor" and "poverty due to illness" remain the biggest barriers to consolidating achievements in poverty alleviation. Therefore, it is recommended to integrate tobacco control strategies with national poverty alleviation policies, which will be helpful in overcoming economic and political obstacles in the implementation of existing tobacco control measures. Additionally, we also found that NCDs mediated the association between householder smoking and near-poverty status, so it is recommended to strengthen health education and expand the coverage of medical insurance, which will be useful to lighten near-poverty households' financial burden and solve near-poverty households' inclination toward poverty because of illness. Furthermore, worldwide evidence has shown that raising tobacco taxes had the single greatest impact on the reduction of tobacco consumption (27, 28), and studies have demonstrated that low-income smokers were more price-sensitive and could reap greater health gains from increased taxes and higher prices of cigarettes (29, 30). It is also recommended to gradually increase the tobacco tax rate and prices to curb the tobacco epidemic.

We also noted that a low educational level of the householder was significantly associated with a higher probability of being near poverty. Previous studies have shown that less-educated individuals and individuals with lower socioeconomic status were more likely to be smokers (31, 32). In addition, studies have demonstrated that individuals with lower socioeconomic status also benefitted less from smoking prevention information (33, 34). Therefore, interventions aimed at preventing addiction to smoking among lower-educated individuals and individuals with lower socioeconomic status are recommended, including improving the educational and cognitive levels of individuals in relatively underdeveloped regions and promoting publicity campaigns about the hazards of smoking. In addition, due to lower awareness about the hazards of smoking and the benefits of smoking cessation aids and smoking cessation programs, individuals with lower socioeconomic status were less likely to quit smoking (35, 36). Hence, in future smoking cessation interventions, smokers with lower education and socioeconomic status should be given more attention.

The strengths of our study include the nationally representative survey. A broad range of data from relatively underdeveloped regions in China was collected, supplementing the empirical research conclusions on the relationship between householder smoking and household being near-poverty status. Moreover, in the study of the effects of householder smoking on near-poverty status, data endogeneity was unavoidable, and an extended probit regression model with the instrumental variable was used to overcome endogeneity problems. In addition, we used generalized structural equation modeling to evaluate the mediating effect of NCDs, providing evidence to consider the underlying mechanisms of the association between householder smoking and near-poverty households. However, there are also several limitations in this study. First, this study is a retrospective self-reported survey, and recall bias may be inevitable; however, prior studies have found that self-reported smoking status and health conditions had reasonable validity (37, 38). Second, the analysis was based on cross-sectional analyses, which limited our ability to make causal inferences about the association of householder smoking with being near poverty, and longitudinal association should be explored in future studies. Third, although we attempted to adjust several potential confounders, the analysis of the relationship of smoking and NCDs might miss potential important confounding variables due to lack of information such as diet and physical activity information.

## CONCLUSIONS

In conclusion, householder smoking significantly elevated the risk of households being near poverty, and suffering NCDs had a positive mediating effect between householder smoking and near-poverty status. We also found that a lower educational level and living in rural areas were significantly associated with a higher probability of being near poverty.

## What Is Already Known on This Subject?

- At the macro level, tobacco use imposes an economic burden through a reduction in productivity and an increase in the cost of medical treatment.
- At the micro level, few studies estimate the impact of cigarette smoking on poverty by reducing the income of Chinese urban residents and excessive medical spending.

## What This Study Adds?

- At the micro level, householder smoking significantly elevated the risk of households being near poverty.
- Suffering from NCDs has a positive mediating effect on the relationship between householder smoking and households being near poverty.

## DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because data involves personal privacy issues. Requests to access the datasets should be directed to HY, yanghuimin85@126.com.

## ETHICS STATEMENT

This study was approved by the Ethics Committee of the Capital Institute of Pediatrics, Beijing (ID: SHERLL2020017). The patients/participants provided their written informed consent to participate in this study.

## AUTHOR CONTRIBUTIONS

CJ, BC, and HY conceptualized the study. The questionnaire was developed by CJ, BC, and AG and refined with input from HY. Data collection in the field was coordinated by BC and AG and supervised by HY and JS. HY, JS, and XC contributed substantially to data analyses and interpretation of the results under the guidance of CJ. HY drafted the manuscript. CJ and BC revised the manuscript critically for intellectual content. All authors approved the final version of the manuscript.


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# Associations Between Different Cortisol Measures and Adiposity in Children: A Systematic Review and Meta-Analysis

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This study examined associations between hair, salivary, serum, and urinary cortisol concentration with adiposity-related indicators in children, and explored their potential effects modification by age, sex, cortisol measurement method, and country developmental context. We systematically searched PubMed, Web of Science, and Embase for studies examining at least one of the four aforementioned cortisol with objectively measured adiposity-related outcomes in children. Meta-analyses of cross-sectional studies revealed that hair cortisol concentration was associated with fat mass index (FMI)-standard deviation score (SDS)/FMI z-score (pooled-β = 0.04, 95% CI: 0.01, 0.08) and BMI/BMI z-score (pooled-β = 0.15, 95% CI: 0.06, 0.25), and these associations were significant among children aged ≤ 12 years (pooled-β = 0.15, 95% CI: 0.05, 0.26) and >12 years (pooled-β = 0.13, 95% CI: 0.04, 0.22), children from developed countries (pooled β = 0.12, 95% CI: 0.03, 0.21) and developing countries (pooled-β = 0.193, 95% CI: 0.188, 0.198), and in studies extracting cortisol *via* LC-MS/MS (pooled-β = 0.18, 95% CI: 0.06, 0.29) but not ELISA (pooled-β = 0.08, 95% CI: −0.06, 0.22). Meta-analyses of both cohort and cross-sectional studies revealed non-significant associations of morning salivary cortisol concentration and total daily cortisol output with BMI/BMI z-score. Serum cortisol concentration was not associated with BMI or waist circumference. Meta-analysis of urinary cortisol concentration and adiposity was hindered by insufficient data. These findings further corroborate understanding of chronic stress' physiological contribution to increased pediatric obesity risk.

**Systematic Review Registration:** [https://www.crd.york.ac.uk/prospero/#recordDetails], identifier [CRD42020215111].

**Keywords: hair cortisol concentration, salivary cortisol, serum cortisol, urinary cortisol, obesity, children**

# INTRODUCTION

Childhood obesity persists as a global public health crisis (1–4). Recent research has identified stress as an important risk factor for childhood adiposity (5–8). Stress is a negative emotional experience accompanied by predictable biochemical, physiological, cognitive, and behavioral changes directed toward altering the stressful event or accommodating to its effects (7); such changes may further serve to increase childhood obesity risk (7). Measurement of stress is inherently complex and requires consideration of multiple dimensions, including the social, psychological, and physiological (9). Given the inherent limitations of using subjective, self-reported measures for stress, considerable literature has established the use of physiological biomarkers for the objective assessment of stress for research. However, associations between physiological measures of stress and adiposity-related indicators in children are inconsistent, preventing a unified understanding of the stress processes in childhood obesity and subsequent design of related interventions.

The hypothalamic-pituitary-adrenal (HPA) axis is the most widely studied physiological stress system. When an individual perceives stress, a physiological cascade occurs in the HPA axis, and its main downstream hormone "cortisol" has been viewed as the "gold standard" biomarker with which to assess stress (6, 10). Alterations in HPA axis may be reflected in changes in the level and diurnal trajectory of cortisol secretion (11). Cortisol can facilitate obesity by stimulating unhealthy eating behaviors and promoting fat deposition (7). Moreover, visceral adipose tissue itself is rich in 11β-hydroxysteroid dehydrogenase type I, which converts inactive cortisone to cortisol (12). Therefore, a potential bidirectional relationship between cortisol and adiposity outcomes may exist. However, in this study, our primary focus will be placed on examinations of cortisol on adiposity outcomes in children.

It is possible for laboratories to utilize blood, urine, saliva, and hair to measure cortisol (13). For many years, cortisol was obtained primarily from serum or urine, but more recent approaches have sampled saliva and hair for less invasive monitoring of HPA functioning, and each measure reflects bodily cortisol levels. Serum cortisol concentration measures the total cortisol (14). Salivary cortisol concentration is usually used to assess the circadian rhythm of cortisol (e.g., cortisol awakening response) and the secretion of cortisol under stress-induced conditions (e.g., the total output of cortisol) (15). Urine samples will generally capture HPA activity over a period of only 24 h or less. In contrast, hair cortisol concentration (HCC) have increasingly been used to assess the long-term presence and/or accumulation of cortisol in children (16, 17).

More research is needed to evaluate and understand the associations between different cortisol measures for stress with adiposity-related outcomes in children. However, the literature on such associations is very limited (18–20). To date, only one systematic review (of $n$ =26 studies) has provided the evidence on associations between HCC and obesity in children, finding a modest positive correlation between HCC and anthropometric measures including body mass index (BMI), BMI z-score, waist circumference (WC), and body fat (21). However, the meta-analyses of reviewed studies did not exclude those relying on self-reported weight status and did not distinguish between cross-sectional and longitudinal studies. Moreover, studies have suggested that individual (e.g., age and sex) and environmental contextual factors (e.g., country development status) may modify associations between cortisol and adiposity outcomes in children (22). For example, a study found that association between cortisol and increased BMI were stronger in early adolescence than in late adolescence (23). Another study showed that altered cortisol balance modified the net lipogenetic/lipolytic in various adipose tissue depots in a sex-dependent manner in the periphery, therefore contributing to the differential associations between cortisol and adiposity outcomes (24). Furthermore, lower socio-economic status of a country was a predictor of higher cortisol levels and obesity risk (25, 26). These findings indicate that these background factors may modify the associations between cortisol and adiposity-related outcomes in children. Interestingly, no studies have heretofore examined how different cortisol measures may vary in their associations with obesity by different sociodemographic or socio-economic factors in children.

Therefore, this systematic review and meta-analysis aimed to examine associations of different cortisol measures – hair, saliva, serum, and urine – with various adiposity-related outcomes in children, and to further explore the potential modification of these associations by external contextual factors including child age, sex, cortisol measurement method, and country developmental context. These findings will synthesize the body of evidence surrounding associations between different cortisol measures and pediatric obesity, and advance the understanding of child stress biomarker research.

# METHODS

This study was developed and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and other recommended practice standards (e.g., Johnson and Hennessy, 2019).

## Literature Search

A systematic search was performed in three electronic bibliographic databases-PubMed, Web of Science, and Embase-for relevant studies published from inception to October 2021. We developed a search strategy for databases based on keywords of seminal articles we had previously identified. Search strategies included all combinations of terms related to cortisol, anthropometric measures, and children (**Supplementary Table 1**).

Hand searching of references was conducted to uncover any potentially overlooked studies. Articles identified from the reference lists were further screened and evaluated using the same study criteria. Reference searching was repeated on all newly identified articles until no additionally relevant articles were found.

## Study Selection

Studies that met all of the following criteria were included: (1) was cross-sectional, case-control, or longitudinal; (2) studied children under 18 years old without mental disorders or any diagnosed chronic conditions (e.g., hypertension, cardiovascular disease); (3) examined naturally occurring cortisol, assayed from either urine, saliva, hair or blood, as exposure variables; (4) analyzed objectively measured adiposity-related outcomes; (5) reported statistical associations between cortisol and adiposity-related outcomes; (6) were published in English; and (7) were peer-reviewed publications. When multiple articles reported on the same data, the article with the largest sample size and results most relevant to this review was retained. Two authors assessed all identified studies for eligibility independently and disagreements were resolved through discussion.

## Data Extraction and Preparation

A standardized form was developed to collect information from selected studies. Data extracted included that on: (1) the study (e.g., first author, publication year, study design, cortisol measure[s] used, adiposity-related outcome[s] assessed, the country site of study, and the country site's developmental context [developed vs. developing]), (2) the sample (e.g., participant age, sex, race/ethnicity), and (3) effect sizes. Acceptable adiposity-related outcomes included BMI/BMI z-score/BMI-standard deviation score (BMI-SDS), waist circumference (WC), percentage body fat (PBF), fat mass index (FMI)-SDS/FMI z-score, free fat mass index (FFMI), and waist to height ratio (WtHR), and truncal distribution of fat mass (TDFM). Data were extracted independently by two authors and discrepancies were resolved through discussion.

## Study Quality Assessment

Two authors independently assessed the quality of eligible articles using the U.S. National Heart, Lung, and Blood Institute's Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (27). This assessment tool rates studies based on 14 criteria. For each criterion, a score of one was assigned for "yes" and zero otherwise (i.e., "no," "not applicable," "not reported," or "cannot determine"). Overall quality was rated based on the total score of the scale, with 0–3, 4–7, and 7–14 reflecting poor, fair, and good quality, respectively. Discrepancies on study quality ratings were also resolved through discussion (**Supplementary Table 2**).

## Statistical Analysis

A meta-analysis was performed to estimate the pooled associations between different cortisol measures and adiposity-related outcomes in children. Study heterogeneity was assessed using the $I^2$ index and Tau-squared ($T^2$). The level of heterogeneity represented by $I^2$ was interpreted as modest ($I^2 \leq 25\%$), moderate ($25\% < I^2 \leq 50\%$), substantial ($50\% < I^2 \leq 75\%$), or considerable ($I^2 > 75\%$) (28). A random-effects model was applied because of assumed clinical and methodological heterogeneity among the studies (29).

Pre-specified subgroup analyses were conducted to test potential modifying effects of age, sex, country developmental context (i.e., developed vs. developing), and cortisol measurement method [i.e., enzyme-linked immunosorbent assay (ELISA) vs. liquid chromatography tandem-mass spectrometry (LC-MS/MS) vs. chemiluminescence immunoassay (CLIA) vs. electrochemiluminescence immunoassay (ECLIA) vs. Radioimmunoassay (RIA) vs. dissociation-enhanced lanthanide fluorescence immunoassay (DELFIA) vs. a time-resolved fluorescence immunoassay (TRFIA)]. Sensitivity analyses were conducted to investigate the influence of a single study on the overall pool estimation by omitting one study at a time.

Publication bias was assessed by visual inspection for symmetry/asymmetry of contour-enhanced funnel plots and Egger's tests. All statistical analyses were conducted in Stata 14 with specific meta-analysis commands (i.e., metan and metareg) (College Station, TX, United States). All analyses used two-sided tests and $p < 0.05$ was considered statistically significant.

# RESULTS

## Study Selection

The search identified 8,627 articles of which 38 (31 cross-sectional articles and seven longitudinal articles) were included in this systematic review, with a sample size of 18,667 children. Twenty-four articles were included in the meta-analysis (**Figure 1**). For testing potential modifying effects, nine (20, 30–37) of the 24 articles were further divided into 18 separate studies given differences in age, sex, indicators of adiposity, and cortisol measurement method, thus, in sum, 33 separated studies were included for meta-analysis. Study characteristics are shown in **Table 1**.

## Hair Cortisol Concentration and Adiposity-Related Outcomes Among Children

Nineteen articles encompassing 11,067 children reported on associations between HCC and adiposity-related outcomes, with three longitudinal articles, 11 articles among children aged ≤ 12 years old, 16 from developed countries, 13 using 3 cm hair samples, and ten extracting cortisol by ELISA and eight by LC-MS/MS. All articles measured BMI/BMI z-score/BMI-SDS, and six of them also measured WC, PBF, FMI-SDS/FMI z-score, and WtHR (**Table 1**).

Unadjusted correlations ($r$) between HCC and WC were significant ($n$ = 4 studies, pooled-$r$ = 0.16, 95% CI: 0.03, 0.28; **Figure 2C**). Similar unadjusted correlations were found for studies extracting HCC by ELISA ($n$ = 3 studies, pooled-$r$ = 0.19, 95% CI: 0.03, 0.40) and for studies by CLIA ($n$ = 1 study, $r$ = 0.14, 95% CI: 0.03, 0.25). However, the unadjusted correlations between HCC and BMI/BMI z-score/BMI-SDS were not significant (**Figure 2D**). Significant unadjusted correlations between HCC and BMI/BMI z-score were found for girls ($n$ = 2 studies, pooled-$r$ = 0.20, 95% CI: 0.07, 0.34) but not for boys ($n$ = 1 study, $r$ = 0.13, 95% CI: −0.03, 0.29; **Table 2**).

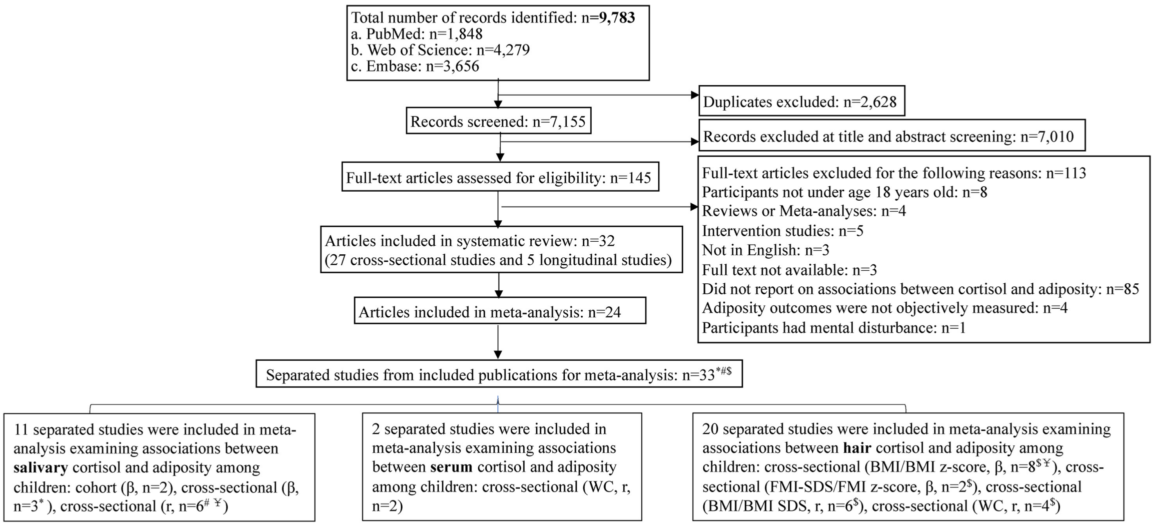


**FIGURE 1 |** Flowchart of the literature search and study selection procedures. *Included articles were divided into separate studies by different age groups. #Included publications were divided into separate studies by gender. $Included articles were divided into separate studies by different indicators of adiposity. ¥Included articles were divided into separate studies by different measurement of cortisol.

In meta-analyses, the pooled adjusted associations from cross-sectional studies revealed that HCC was positively associated with FMI-SDS/FMI z-score ($n$ = 2 studies, pooled-β = 0.04, 95% confidence interval [CI]: 0.01, 0.08) and BMI/BMI z-score ($n$ = 8 studies, pooled-β = 0.15, 95% CI: 0.06, 0.25; **Figures 2A,B**). Such adjusted associations varied by cortisol measurement method. Significant effects were found for studies extracting HCC by LC-MS/MS ($n$ = 3 studies, pooled-β = 0.18, 95% CI: 0.06, 0.29) but not for those by ELISA ($n$ = 5 studies, pooled-β = 0.08, 95% CI: −0.06, 0.22). Similar adjusted associations were observed for children aged ≤ 12 years old ($n$ = 6 studies, pooled-β = 0.15, 95% CI: 0.05, 0.26) and children > 12 years old ($n$ = 2 studies, pooled-β = 0.13, 95% CI: 0.04, 0.22), and for studies from developing countries ($n$ = 2 studies, pooled-β = 0.193, 95% CI: 0.188, 0.198) and those from developed countries ($n$ = 6 studies, pooled-β = 0.12, 95% CI: 0.03, 0.21; **Table 2**).

## Salivary Cortisol Concentration and Adiposity-Related Outcomes Among Children

Sixteen articles with 3,462 children examined associations between salivary cortisol concentration and adiposity-related outcomes, including 13 cross-sectional articles and five longitudinal articles (two articles reported both cross-sectional and longitudinal results). Fourteen of the 16 articles examined children ≤ 12 years old, twelve articles took place in developed countries, five articles examined cortisol as AUCi (area-under-the-curve-increase) and two reported AUCg (area under the curve with respect to ground), and eleven articles used ELISA for cortisol extraction. All these articles measured BMI/BMI z-score and four also measured WC and PBF (**Table 1**).

In meta-analyses, the total daily cortisol output of salivary cortisol (as AUCi) was positively correlated with BMI among all children ($n$ = 4 studies, pooled-$r$ = 0.25, 95% CI: 0.04, 0.46) in cross-sectional studies (**Figure 3B**). Age and country developmental context modified such unadjusted correlations. Significant correlations were found for studies among children aged ≤ 12 years old ($n$ = 3 studies, pooled-$r$ = 0.30, 95% CI: 0.02, 0.61) but not for children > 12 years old ($n$ = 1 study, $r$ = 0.15, 95% CI: −0.06, 0.37), and for studies from developed countries ($n$ = 3 studies, pooled-$r$ = 0.30, 95% CI: 0.02, 0.61) but not for the study from developing country ($n$ = 1 study, $r$ = 0.15, 95% CI: −0.06, 0.37). The significant pooled correlations were similar for studies extracting salivary cortisol using ELISA ($n$ = 3 studies, pooled-$r$ = 0.33, 95% CI: 0.09, 0.58) and using TRFIA ($n$ = 1 study, $r$ = 0.07, 95% CI: 0.01, 0.14), and for study among boys ($n$ = 1 study, $r$ = 0.30, 95% CI: 0.03, 0.57) and girls ($n$ = 2 studies, pooled-$r$ = 0.10, 95% CI: 0.04, 0.16; **Table 3**).

However, the adjusted association between salivary cortisol concentration (as AUCi) and BMI z-score was non-significant ($n$ = 3 studies, pooled-β = 0.52, 95% CI: −0.45, 1.49; **Figure 3A**). The associations were also non-significant stratifying by cortisol measurement method (LC-MS/MS vs. ELISA) and country developmental context (developing country vs. developed country; **Table 3**).

Regarding morning salivary cortisol, neither its correlations with BMI/BMI z-score from two cross-sectional studies (pooled-$r$ = 0.10 95% CI: $r$ = −0.06, 0.26) nor the adjusted associations from two cohort studies were significant (pooled-β = −0.19, 95% CI: −0.31, −0.07; **Table 3** and **Figures 3C,D**).

## Serum Cortisol Concentration and Adiposity-Related Outcomes Among Children

Six cross-sectional articles encompassing 4,265 children examined associations between serum cortisol concentration

TABLE 1 | Summary of main characteristics of 33 studies reporting on associations between hair, salivary, serum, and/or urinary cortisol concentration with adiposity-related outcomes in children.

| First author, Publication year; Country and development context | Study design | Sample size (% Girls) | Age (years, Mean ± SD, Range) | Race/Ethnicity | Cortisol measure | | Adiposity outcomes | | Effect size/Associations between cortisol and adiposity/Covariates |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Measure source | Measurement method | Measures | Method of ascertainment | |
| **Hair cortisol** | | | | | | | | | |
| 1[1] Vehmeijer et al. (55); Netherlands (Developed) | Cohort | 2,042 (52.5%) | 5.90 (5.70–8.00) | European and non-European | Hair, 3 cm | LC-MS/MS | BMI-SDS | BMI was calculated based on measured weight and height. BMI-SDS was generated based on Dutch reference growth charts | Increase of BMI SDS (β = 0.06, 95% CI: 0.02, 0.09) per quintile of hair cortisol Covariates included: (1) Child's: Sex and age, maternal pre-pregnancy BMI, psychological distress during pregnancy (2) Maternal: Educational level and marital status at 6 years, child's ethnicity, hair color and television watching time |
| 1[2] Vehmeijer et al. (55); Netherlands (Developed) | Cohort | 2,042 (52.5%) | 5.90 (5.70–8.00) | European and non-European | Hair, 3 cm | LC-MS/MS | FMI-SDS | FMI was measured by DXA | Increase of FMI-SDS (β = 0.05, 95% CI: 0.02, 0.08) per quintile of hair cortisol Covariates included: (1) Child's: Sex and age, maternal pre-pregnancy BMI, psychological distress during pregnancy (2) Maternal: Educational level and marital status at 6 years, child's ethnicity, hair color and television watching time |
| 1[3] Vehmeijer et al. (55); Netherlands (Developed) | Cohort | 2,042 (52.5%) | 5.90 (5.70–8.00) | European and non-European | Hair, 3 cm | LC-MS/MS | Overweight vs. Non-overweight | BMI was calculated by measuring weight and height. Weight status was defined based on the International Obesity Task Force cut-offs, the age- and sex- specific cut-off points | Increased risk for overweight or obesity of (OR = 1.18, 95% CI: 1.07, 1.29) per quintile of hair cortisol Covariates included: (1) Child's: Sex and age, maternal pre-pregnancy BMI, psychological distress during pregnancy (2) Maternal: Educational level and marital status at 6 years, child's ethnicity, hair color and television watching time |
| 2[1] Bethancourt et al. (56); Bolivia (Developing) | Cross-sectional | 167 (53.2%) | 9.70 (6.00–15.00) | Not reported | Hair, 1.5 cm | ELISA | BMI z-score | BMI was calculated based on measured weight and height. BMI z-score was generated based on the WHO reference values and macros | Increase of −0.02 BMI z-score (SE = 0.02, *p* = 0.26) per 20% increase of hair cortisol Covariates included: Maternal: Community and household of residence, age, household adult equivalents, household income, self-reported perceived social status |

(Continued)

**TABLE 1** | (Continued)

| First author, Publication year; Country and development context | Study design | Sample size (% Girls) | Age (years, Mean ± SD, Range) | Race/Ethnicity | Cortisol measure | | Adiposity outcomes | | Effect size/Associations between cortisol and adiposity/Covariates |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Measure source | Measurement method | Measures | Method of ascertainment | |
| 2[2] Bethancourt et al. (56); Bolivia (Developing) | Cross-sectional | 167 (53.2%) | 9.70 (6.00–15.00) | Not reported | Hair, 1.5 cm | ELISA | Body fat percentage | Body fat percentage was measured using a Tanita BF-680W bioelectric impedance scale | Increase of −0.29 percentage of body fat (SE = 0.12, $p = 0.01$) per 20% increase of hair cortisol<br>Covariates included: Maternal: Community and household of residence, age, household adult equivalents, household income, self-reported perceived social status |
| #3[1] Petimar et al. (57); United States (Developed) | Cohort | 491 (NR) | 7.80–13.10 | White | Hair, ≥3 cm | LC-MS/MS | BMI z-score | BMI was calculated based on measured weight and height. BMI z-score was generated based on US CDC growth charts (2000) | Associations between log hair cortisol concentration (HCC) and BMI z-score: β = 0.00, 95% CI: −0.08, 0.07<br>Covariates included: Child's: Age, sex, birthweight-for-sex-and-gestational age *z* score, second-hand smoke exposure, mid-childhood pubertal development score, and early childhood BMI z-score<br>Maternal: enrollment age, maternal education, pre-pregnancy BMI, maternal smoking during pregnancy, household income |
| #3[2] Petimar et al. (57); United States (Developed) | Cohort | 493 (NR) | 7.80–13.10 | White | Hair, ≥3 cm | LC-MS/MS | Waist circumference | Waist circumference was measured | Associations between log HCC and WC: β = −0.04, 95% CI: −0.83, 0.74<br>Covariates included: Child's: Age, sex, birthweight-for-sex-and-gestational age *z* score, second-hand smoke exposure, mid-childhood pubertal development score, and early childhood BMI z-score<br>Maternal: enrollment age, maternal education, pre-pregnancy BMI, maternal smoking during pregnancy, household income |
| #3[3] Petimar et al. (57); United States (Developed) | Cohort | 491 (NR) | 7.80–13.10 | White | Hair, ≥3 cm | LC-MS/MS | Waist to height ratio (WtHR) | WtHR was calculated based on measured waist and height | Associations between log HCC and WtHR: β = 0.002, 95% CI: −0.003, 0.007<br>Covariates included: Maternal: enrollment age, education, pre-pregnancy BMI, maternal smoking during pregnancy, household income Child's: Age, sex, birth weight-for-sex-and-gestational age *z* score, second-hand smoke exposure, mid-childhood pubertal development score, and early childhood waist to height ratio |

*(Continued)*

**TABLE 1** | (Continued)

| First author, Publication year; Country and development context | Study design | Sample size (% Girls) | Age (years, Mean ± SD, Range) | Race/Ethnicity | Cortisol measure | | Adiposity outcomes | | Effect size/Associations between cortisol and adiposity/Covariates |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Measure source | Measurement method | Measures | Method of ascertainment | |
| 4 Bryson et al. (58); Australia (Developed) | Cross-sectional | 297 (60.6%) | 3.10 ± 0.10 | Not reported | Hair, 3 cm | ELISA | BMI z-score | BMI was calculated based on measured weight and height. BMI z-score was generated based on Cole's international criteria (Cole, Bellizzi, 2000) | Associations between HCC and BMI z-score: β = 0.76, 95% CI: 0.51, 1.12, $p = 0.16$<br>Covariates included: Age, gender, season of assessment, site of hair collection, randomized controlled trial randomization status |
| 5 Baan et al. (59); Netherlands (Developed) | Cross-sectional | 298 (45.64%) | 12.60–13.20 | Not reported | Hair, 3 cm | LC-MS/MS | BMI z-score | BMI was calculated based on measured weight and height. BMI z-score was generated based on the 1997 Dutch nationwide growth study | Associations between log HCC and BMI z-score: β = 0.13, 95% CI: 0.04, 0.22, $p = 0.01$<br>No covariates were reported |
| 6[1] Smith et al. (36); Australia (Developed) | Cross-sectional | 128 (68.0%) | 8.44 ± 0.34 | Not reported | Hair, 3 cm | ELISA | Waist circumference | Waist circumference was measured | Correlation between log HCC and WC: $r = 0.015$<br>No covariates were reported |
| 6[2] Smith et al. (36); Australia (Developed) | Cross-sectional | 128 (68.0%) | 8.44 ± 0.34 | Not reported | Hair, 3 cm | ELISA | BMI | BMI was calculated based on measured weight and height | Correlation between log HCC and BMI: $r = -0.047$<br>No covariates were reported |
| 7 Evans et al. (19); Sweden (Developed) | Cross-sectional | 92 (NR) | 10 | Dutch | Hair, 3 cm | LC-MS/MS | BMI | BMI was calculated based on measured weight and height | Correlation between HCC and BMI: $r = 0.01$<br>No covariates were reported |
| #8 Distel et al. (18); United States (Developed) | Cohort | 52 (61%) | 6–10 | Mexican | Hair, NR | ELISA | BMI | BMI was calculated based on measured weight and height | Associations between HCC and BMI: β = 4.62, 95% CI: 1.41, 7.83, $p < 0.01$<br>Covariates included: Age and food insecurity |
| 9 Sun et al. (60); China (Developing) | Cross-sectional | 1,000 (57.9%) | 8.97 ± 0.86 | Han Chinese | Hair, ≥10 mg | ELISA | BMI | BMI was calculated based on measured weight and height | Associations between HCC and BMI: β = 0.17, 95% CI: 0.05, 0.29<br>Covariates included: PRS polygenic risk score |
| 10 Lu et al. (34); China (Developing) | Cross-sectional | 85 (45.9%) | 11.40 ± 0.30 | Chinese, not otherwise specified | Hair, 3 cm | LC-MS/MS | BMI z-score | BMI was calculated based on measured weight and height. BMI z-score was defined as the number of standard deviation units from the mean or reference value | Associations between log HCC and BMI: β = 0.193, 95% CI: 0.19, 0.20, $p = 0.004$<br>No covariates were reported |
| 11 Papafotiou et al. (35); Greece (Developed) | Cross-sectional | 50 (100%) | 7.60 ± 1.30 | Greek | Hair, 3 cm | LC-MS/MS | BMI z-score | BMI was calculated based on measured height and weight. BMI z-score was generated based on Cole' s international criteria (Cole, Bellizzi, 2000) | Correlations between HCC and BMI z-score: $r = 0.327$, $p = 0.025$<br>No covariates were reported |

*(Continued)*

**TABLE 1** | (Continued)

| First author, Publication year; Country and development context | Study design | Sample size (% Girls) | Age (years, Mean ± SD, Range) | Race/Ethnicity | Cortisol measure | | Adiposity outcomes | | Effect size/Associations between cortisol and adiposity/Covariates |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Measure source | Measurement method | Measures | Method of ascertainment | |
| 12[1] Gerber et al. (32); Switzerland (Developed) | Cross-sectional | 318 (53.1%) | 7.26 ± 3.51 | Not reported | Hair, 3 cm | CLIA | BMI | BMI was calculated based on measured weight and height | Correlations between HCC and BMI: $r = 0.16$, $p < 0.01$, $r = 0.13$ for boys, $r = 0.16$ for girls ($p < 0.05$)<br>No covariates were reported |
| 12[2] Gerber et al. (32); Switzerland (Developed) | Cross-sectional | 318 (53.1%) | 7.26 ± 3.51 | Not reported | Hair, 3 cm | CLIA | Body fat percentage | Percentage body fat was calculated based on measured skinfold | Correlations between HCC and PBF: $r = 0.14$, $p < 0.01$, $r = 0.12$ for boys, $r = 0.16$ for girls ($p < 0.05$)<br>No covariates were reported |
| 12[3] Gerber et al. (32); Switzerland (Developed) | Cross-sectional | 318 (53.1%) | 7.26 ± 3.51 | Not reported | Hair, 3 cm | CLIA | Waist circumference | Waist circumference was measured | Correlations between HCC and WC: $r = 0.14$, $p < 0.01$, $r = 0.18$, $p < 0.05$ for boys, $r = 0.11$ for girls<br>No covariates were reported |
| 13 Rippe et al. (25); Netherlands (Developed) | Cross-sectional | 2,484 (51.7%) | 6.20 ± 0.70 | Danish-Caucasian Western and other European | Hair, 3 cm | LC–MS/MS | BMI | BMI was calculated based on measured weight and height | Associations between log HCC and BMI: (95% CI) = 0.025 (0.02, 0.03; $p = 0.001$)<br>No covariates were reported |
| 14 Olstad et al. (61); Australia (Developed) | Cross-sectional | 30 (43.3%) | 14.30 ± 3.90 | Not reported | Hair, 3 cm | ELISA | BMI z-score | BMI was calculated based on measured weight and height. BMI z-score was generated based on the CDC growth charts of U.S (2000) | Associations between HCC and BMI z-score: $\beta = 0.20$, 95% CI: −0.85, 1.25, $p = 0.694$<br>Covariates included: (1) Childs's: Age (2) Maternal: BMI, education |
| 15[1] Noppe et al. (20); Netherlands (Developed) | Cross-sectional | 2,953 (51.9%) | 6.20 ± 0.60 | European and non-European, not otherwise specified | Hair, 3 cm | LC–MS/MS | BMI | BMI was calculated based on measured weight and height | Associations between HCC and BMI: $\beta = 0.19$, 95% CI: 0.12, 0.26<br>Covariates included: Child's: Age, sex, ethnicity, and topical glucocorticoid use |
| 15[2] Noppe et al. (20); Netherlands (Developed) | Cross-sectional | 2,953 (51.9%) | 6.20 ± 0.60 | European and non-European, not otherwise specified | Hair, 3 cm | LC–MS/MS | FMI-SDS | Fat mass index was measured by DXA | Associations between HCC and FMI: $\beta = 0.05$, 95% CI: 0.01, 0.09<br>Covariates included: Child's: Age, sex, ethnicity, and topical glucocorticoid use |
| 16 Murray et al. (62); Australia (Developed) | Cross-sectional | 95 (52.6%) | 9.50 ± 0.34 | Not reported | Hair, 3 cm | ELISA | BMI | BMI was calculated based on measured weight and height | Correlations between HCC and BMI: $r = -0.26$<br>No covariates were reported |
| 17[1] Larsen et al. (33); Denmark (Developed) | Cross-sectional | 317 (NR) | 5 (4–7) | Danish, not otherwise specified | Hair, 1–2 cm | ELISA | BMI z-score | BMI was calculated based on measured weight and height. BMI z-score was generated using the Lambda-Mu-Sigma method | Associations between HCC and BMI z-score: $\beta = 0.01$, 95% CI: −0.04, 0.07, $p = 0.70$<br>Covariates included: Child's: Intervention status, gender, physical activity, maternal education level, and age |

*(Continued)*

**TABLE 1** | (Continued)

| First author, Publication year; Country and development context | Study design | Sample size (% Girls) | Age (years, Mean ± SD, Range) | Race/Ethnicity | Cortisol measure | | Adiposity outcomes | | Effect size/Associations between cortisol and adiposity/Covariates |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Measure source | Measurement method | Measures | Method of ascertainment | |
| 17[2] Larsen et al. (33); Denmark (Developed) | Cross-sectional | 280 (NR) | 5 (4–7) | Danish, not otherwise specified | Hair, 1–2 cm | ELISA | FMI z-score | FMI was measured by BIA-method, and calculated based on an equation described by Goran et al. (1996) in young Children | Associations between HCC and FMI z-score: β = 0.03, 95% CI: −0.03, 0.08, $p = 0.32$<br>Covariates included: Child's: Intervention status, gender, physical activity, maternal education, and age |
| 17[3$] Larsen et al. (33); Denmark (Developed) | Cross-sectional | 280 (NR) | 5 (4–7) | Danish, not otherwise specified | Hair, 1–2 cm | ELISA | FFMI z-score | FFMI was calculated by subtracting FFM from body weight. FMI was measured by BIA-method | Associations between HCC and FMI z-score: β = −0.01, 95% CI: −0.07, 0.05, $p = 0.69$<br>Covariates included: Child's: Intervention status, gender, physical activity, maternal education, and age |
| 17[4$] Larsen et al. (33); Denmark (Developed) | Cross-sectional | 309 (NR) | 5 (4–7) | Danish, not otherwise specified | Hair, 1–2 cm | ELISA | Waist circumference | BMI was calculated based on measured weight and height. BMI z-score was generated using the Lambda-Mu-Sigma method | Associations between HCC and WC: β = 0.10, 95% CI: −0.09, 0.30, $p = 0.30$<br>Covariates included: Child's: Intervention status, gender, physical activity, maternal education, and age |
| 17[5$] Larsen et al. (33); Denmark (Developed) | Cross-sectional | 308 (NR) | 5 (4–7) | Danish, not otherwise specified | Hair, 1–2 cm | ELISA | WtHR | WtHR was calculated based on measured waist circumference and height | Associations between HCC and WtHR: β = −0.001, 95% CI: −0.003, 0.002, $p = 0.52$<br>Covariates included: Child's: Intervention status, gender, physical activity, maternal education, and age |
| 18[1] Veldhorst et al. (37); Netherlands (Developed) | Cross-sectional | 40 (75%) | 8–12 | Caucasian, no-Caucasian | Hair, 1 cm | ELISA | BMI-SDS | BMI was calculated based on measured weight and height. BMI SDS was generated based on the 2010 Dutch nationwide growth study | Correlations between log HCC and BMI-SDS: $r = 0.407$, $p < 0.01$<br>No covariates were reported |
| 18[2] Veldhorst et al. (37); Netherlands (Developed) | Cross-sectional | 40 (75%) | 8–12 | Caucasian, no-Caucasian | Hair, 1 cm | ELISA | Waist circumference | Waist circumference was measured | Correlations between log HCC and WC: $r = 0.43$, $p < 0.01$<br>No covariates were reported |
| 19[1] Noppe et al. (63); Netherlands (Developed) | Cross-sectional | 128 (50.8%) | 8.40 (4.25–14.13) | Not reported | Hair, 3 cm | ELISA | Waist circumference | Waist circumference was measured | Correlations between log HCC and WC: $r = 0.19$, $p = 0.04$<br>No covariates were reported |
| 19[2] Noppe et al. (63); Netherlands (Developed) | Cross-sectional | 128 (50.8%) | 8.40 (4.25–14.13) | Not reported | Hair, 3 cm | ELISA | WtHR | WtHR was calculated based on measured waist circumference and height | Correlations between log HCC and WtHR: $r = 0.19$, $p = 0.04$<br>No covariates were reported |
| 19[3*] Noppe et al. (63); Netherlands (Developed) | Cross-sectional | 128 (50.8%) | 8.40 (4.25–14.13) | Caucasian | Hair, 3 cm | ELISA | BMI | BMI was calculated based on measured weight and height | NR |

*(Continued)*

TABLE 1 | (Continued)

| First author, Publication year; Country and development context | Study design | Sample size (% Girls) | Age (years, Mean ± SD, Range) | Race/Ethnicity | Cortisol measure | | Adiposity outcomes | | Effect size/Associations between cortisol and adiposity/Covariates |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Measure source | Measurement method | Measures | Method of ascertainment | |
| **Salivary cortisol** | | | | | | | | | |
| 1[1] Pruszkowska-Przybylska et al. (64); Poland (Developing) | Cross-sectional | 73 (100%) | 8.92 (7–11) | Not reported | Saliva (8 a.m.–2 p.m.) | ELISA | Body fat percentage | Body fat percentage was measured using the BIA-method | Association between salivary cortisol and FM% was β = −0.089, SE = 0.12, $p = 0.462$<br>Covariates included: Child's: Vitamin D concentration<br>Maternal: Education, 2D:4D digit ratio, socio-economic status |
| 1[2] Pruszkowska-Przybylska et al. (64); Poland (Developing) | Cross-sectional | 73 (100%) | 8.92 (7–11) | Not reported | Saliva (8 a.m.–2 p.m.) | ELISA | BMI z-score | BMI was calculated based on measured weight and height. The calculated method of BMI z-score was not reported | Association between salivary cortisol and BMI z-score was β = −0.027, SE = 0.117, $p = 0.818$<br>Covariates included: Child's: Vitamin D concentration<br>Maternal: Education, 2D:4D digit ratio, socio-economic status |
| 1[3] Pruszkowska-Przybylska et al. (64); Poland (Developing) | Cross-sectional | 60 (0%) | 8.92 (7–11) | Not reported | Saliva (8 a.m.–2 p.m.) | ELISA | Body fat percentage | Body fat percentage was measured using the BIA-method | Association between salivary cortisol and FM% was β = −0.091, SE = 0.137, $p = 0.511$<br>Covariates included: Child's: Vitamin D concentration<br>Maternal: Education, 2D:4D digit ratio, socio-economic status |
| 1[4] Pruszkowska-Przybylska et al. (64); Poland (Developing) | Cross-sectional | 60 (0%) | 8.92 (7–11) | Not reported | Saliva (8 a.m.–2 p.m.) | ELISA | BMI z-score | BMI was calculated based on measured weight and height. The calculated method of BMI z-score was not reported | Association between salivary cortisol and BMI z-score was β = −0.148, SE = 0.134, $p = 0.273$<br>Covariates included: Child's: Vitamin Concentration<br>Maternal: Education, 2D:4D digit ratio, socio-economic status |
| 2[1] Dai et al. (65); United States (Developed) | Cross-sectional | 689 (53.0%) | 9.20 (SD = 0.41) | Caucasian, not otherwise specified | Saliva (waking, 30 mins post-waking) | ELISA | Body composition | Body composition was indexed by BMI and waist-to-hip ratio. BMI was calculated based on measured weight and height | Salivary cortisol was associated with body composition: β = −0.20, SE = 0.05, $p < 0.01$<br>Covariates included: Child's: Sex, age, race, socioeconomic, and medication use |
| 2[2] Dai et al. (65); United States (Developed) | Longitudinal | 647 (55.0%) | 10.53 (SD = 0.52) | Caucasian, not otherwise specified | Saliva (waking, 30 mins post-waking) | ELISA | Body composition | Body composition was indexed by BMI and waist-to-hip ratio. BMI was calculated based on measured weight and height | Salivary cortisol at baseline was associated with body composition at follow-up: β = 0.00, SE = 0.02, $p > 0.05$<br>Covariates included: Child's: Sex, age, race, socioeconomic, and medication use |
| 3 Pruszkowska-Przybylska et al. (66); Poland (Developing) | Cross-sectional | 132 (56.8%) | 6–13 | Not reported | Saliva (8 a.m.–2 p.m.) | ELISA | Fat mass percentage | Fat mass was measured by BIA-method | Salivary cortisol was associated with fat mass percentage β = −0.17, SE = 0.076, $p = 0.026$<br>No covariates were reported |

*(Continued)*

**TABLE 1** | (Continued)

| First author, Publication year; Country and development context | Study design | Sample size (% Girls) | Age (years, Mean ± SD, Range) | Race/Ethnicity | Cortisol measure | | Adiposity outcomes | | Effect size/Associations between cortisol and adiposity/Covariates |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Measure source | Measurement method | Measures | Method of ascertainment | |
| 4[X] Marceau et al. (52); United States (Developed) | Cohort | 361 (43%) | 4.50–9 | White, African, American, Hispanic, Latino, Multiethnic, other | Saliva (morning) | DELFIA | BMI | BMI was calculated based on measured weight and height | Associations between morning salivary cortisol and BMI: β = −1.34, 95% CI: −2.28, −0.4, $p < 0.05$<br>No covariates were reported |
| 4[z] Marceau et al. (52); United States (Developed) | Cohort | 361 (43%) | 4.50–9 | White, African, American, Hispanic, Latino, Multiethnic, other | Saliva (evening) | DELFIA | BMI | BMI was calculated based on measured weight and height | Associations between evening salivary cortisol and BMI: β = −0.52, 95% CI: −3.52, 2.48<br>No covariates were reported |
| 5[1]*Lynch et al. (51); United States (Developed) | Cross-sectional | 147 (57.1%) | 10–12 | African American, Asian, Caucasian, Hispanic | Saliva (mid-morning) (9:30 A.M.–11:00 A.M.) | ELISA | Waist Circumference | Waist circumference was measured | NR |
| 5[2]* Lynch et al. (51); United States (Developed) | Cross-sectional | 147 (57.1%) | 10–12 | African American, Asian, Caucasian, Hispanic | Saliva (mid-morning) (9:30 A.M.–11:00 A.M.) | ELISA | BMI | BMI was calculated based on measured weight and height | NR |
| 6 Lu et al. (34); China (Developing) | Cross-sectional | 85 (45.9%) | 11.4 0 ± 0.30 | Chinese, not otherwise specified | Saliva cortisol (lnAUCi, TSST-C) | LC-MS/MS | BMI z-score | BMI was calculated based on measured weight and height. BMI z-score is defined as the number of standard deviation units from the mean or reference value | Associations between salivary cortisol lnAUCi and BMI: β = 0.051, 95% CI: −1.74, 1.84<br>No covariates were reported |
| 7[1] Papafotiou et al. (35); Greece (Developed) | Cross-sectional | 50 (100%) | 7.60 ± 1.30 | Greek | Saliva (AUCg) | ECLIA | BMI z-score | BMI was calculated based on measured height and weight. BMI z-score was generated based on Cole' s international criteria (Cole, Bellizzi, 2000) | Correlations between salivary cortisol (AUCg) and BMI z-score: $r = 0.352$, $p = 0.016$<br>No covariates were reported |
| 7[2x] Papafotiou et al. (35); Greece (Developed) | Cross-sectional | 50 (100%) | 7.60 ± 1.30 | Greek | Saliva (morning) | ECLIA | BMI z-score | BMI was calculated based on measured height and weight. BMI z-score was generated based on Cole' s international criteria (Cole, Bellizzi, 2000) | Correlations between morning salivary cortisol and BMI-Z score: $r = 0.321$, $p = 0.031$<br>No covariates were reported |
| 7[3z] Papafotiou et al. (35); Greece (Developed) | Cross-sectional | 50 (100%) | 7.60 ± 1.30 | Greek | Saliva (evening) | ECLIA | BMI z-score | BMI was calculated based on measured height and weight. BMI z-score was generated based on Cole' s international criteria (Cole, Bellizzi, 2000) | Correlations between salivary cortisol and BMI z-score: $r = 0.413$, $p = 0.006$<br>No covariates were reported |

*(Continued)*

**TABLE 1 |** (Continued)

| First author, Publication year; Country and development context | Study design | Sample size (% Girls) | Age (years, Mean ± SD, Range) | Race/Ethnicity | Cortisol measure | | Adiposity outcomes | | Effect size/Associations between cortisol and adiposity/Covariates |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Measure source | Measurement method | Measures | Method of ascertainment | |
| 8 Chu et al. (49); China (Developing) | Cross-sectional | 110 (50.9%) | 4–5 | Chinese, not otherwise specified | Saliva (morning) | LC-MS/MS | BMI | BMI was calculated based on measured weight and height | Correlations between salivary cortisol and BMI: $r = 0.\ 001$, $p = 0.\ 426$<br>No covariates were reported |
| 9[1] Lu et al. (45); China (Developing) | Cross-sectional | 87 (44.8%) | 12–13 | Chinese, not otherwise specified | Saliva (AUCi, after TSST-C) | ELISA | BMI | BMI was based on measured weight and height | Correlations between salivary cortisol (AUCi) and BMI: $r = 0.15$<br>No covariates were reported |
| 9[2$] Lu et al. (45); China (Developing) | Cross-sectional | 87 (44.8%) | 12–13 | Chinese, not otherwise specified | Saliva (AUCi, after TSST-C) | ELISA | Body fat percentage | Percentage body fat was measured by BIA-method | Correlations between salivary cortisol (AUCi) and PBF: $r = 0.15$<br>No covariates were reported |
| 10[x] Ruttle et al. (23); United States (Developed) | Cohort | 323 (NR) | 11–18 | Largely Caucasian | Saliva (morning) | ELISA | BMI | BMI was calculated based on measured weight and height | Associations between morning salivary cortisol and BMI: $\beta = -0.17$, 95% CI: −0.29, −0.05, $p < 0.01$<br>Covariates included: Child sex and pubertal status, maternal BMI |
| 10[y] Ruttle et al. (23); United States (Developed) | Cohort | 323 (NR) | 11–18 | Largely Caucasian | Saliva (afternoon) | ELISA | BMI | BMI was calculated based on measured weight and height | Associations between afternoon salivary cortisol and BMI: $\beta = -0.15$, 95% CI: −0.27, −0.03, $p < 0.01$<br>Covariates included: Child sex and pubertal status, maternal BMI |
| 10[z] Ruttle et al. (23); United States (Developed) | Cohort | 323 (NR) | 11–18 | Largely Caucasian | Saliva (evening) | ELISA | BMI | BMI was calculated based on measured weight and height | Associations between evening salivary cortisol and BMI: $\beta = -0.12$, 95% CI: −0.24, −0.002, $p < 0.01$<br>Covariates included: Child's sex and pubertal status, maternal BMI |
| 11[1$] Miller et al. (46); United States (Developed) | Cross-sectional | 218 (50.9%) | 4.40 ± 0.58 | White, Black, Biracial, Hispanic/Latino | Saliva (AUC, Stress-elicitation challenge tasks) | ELISA | BMI z-score | BMI was calculated based on measured weight and height. BMI z-score was calculated based on US Centers for Disease Control reference growth curves for age and sex | Associations between salivary cortisol (AUC) and BMI z-score: $\beta = -0.17$, 95% CI: −0.31, −0.03, $p = 0.018$<br>Covariates included: Child's: Age, sex, ethnicity<br>Maternal: Overweight and family income-to-needs ratio |
| 11[2$] Miller et al. (62); United States (Developed) | Cohort | 115 (NR) | 4.40 ± 0.58 | White, Black, Biracial, Hispanic/Latino | Saliva (AUC, Stress-elicitation challenge tasks) | ELISA | Change of BMI z-score | BMI was calculated based on measured weight and height. BMI z-score was calculated based on US Centers for Disease Control reference growth curves for age and sex | Associations between salivary cortisol (AUC) and change of BMI-Z score: $\beta = 0.002$, 95% CI: −0.004, 0.008, $p = 0.410$<br>Covariates included: Child's: Age, sex, ethnicity<br>Maternal: Overweight and family income-to-needs ratio |
| 12[c] Francis et al. (31); United States (Developed) | Cross-sectional | 32 (NR) | 5–7 | White, Black, others | Saliva (AUCi, TSST-C) | ELISA | BMI z-score | BMI was extracted from medical record | Associations between salivary cortisol (AUCi) and BMI z-score: $\beta = 0.07$, 95% CI: −0.32, 0.46<br>Covariates included: Child's: Eating in the absence of hunger<br>Parental: Combined education |

*(Continued)*

**TABLE 1** | (Continued)

| First author, Publication year; Country and development context | Study design | Sample size (% Girls) | Age (years, Mean ± SD, Range) | Race/Ethnicity | Cortisol measure | | Adiposity outcomes | | Effect size/Associations between cortisol and adiposity/Covariates |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Measure source | Measurement method | Measures | Method of ascertainment | |
| 12[d] Francis et al. (31); United States (Developed) | Cross-sectional | 11 (NR) | 8–9 | White, Black, others | Saliva (AUCi, TSST-C) | ELISA | BMI z-score | BMI was extracted from medical record | Associations between salivary cortisol (AUCi) and BMI z-score: β = 1.38, 95% CI: 0.46, 2.30, $p < 0.01$<br>Covariates included: Child's: Eating in the absence of hunger<br>Parental: Combined education |
| 13[a$] Hill et al. (50); United States (Developed) | Cohort | 153 (0%) | 9.60 ± 0.90 | Caucasian, African American | Saliva (morning) | ELISA | Change in BMI z-score | BMI was calculated based on measured weight and height | Correlations between morning salivary cortisol and change in BMI z-score: $r = 0.15$, $p = 0.009$<br>No covariates were reported |
| 13[b$] Hill et al. (50); United States (Developed) | Cohort | 163 (100%) | 9.60 ± 0.90 | Caucasian, African American | Saliva (morning) | ELISA | Change in BMI z-score | BMI was calculated based on measured weight and height | Correlations between morning salivary cortisol and change in BMI z-score: $r = -0.015$ |
| 14[a] Dockray et al. (30); United States (Developed) | Cross-sectional | 56 (0%) | 11.44 | Hispanic, Hispanic, African American, Asian American | Saliva cortisol (lnAUCi, TSST-C) | ELISA | BMI | BMI was calculated based on measured weight and height | Correlations between saliva cortisol lnAUCi and BMI: $r = 0.29$, $p < 0.05$<br>No covariates were reported |
| 14[b] Dockray et al. (30); United States (Developed) | Cross-sectional | 55 (100%) | 10.49 | Hispanic, Hispanic, African American, Asian American | Saliva cortisol (logAUCi, TSST-C) | ELISA | BMI | BMI was calculated based on measured weight and height | Correlations between saliva cortisol logAUCi and BMI: $r = 0.52$, $p < 0.01$<br>No covariates were reported |
| 15 Barat et al. (48); France (Developed) | Cross-sectional | 19 (63.2%) | 6–13 | Not reported | Saliva (morning) | RIA | Truncal distribution of fat mass (TDFM) | TDFM was assessed with dual energy X-ray absorptiometry | Correlations between morning salivary cortisol and TDFM: $r = 0.38$ for total children, $r = -0.33$ for boys, $r = 0.53$ for girls<br>No covariates were reported |
| 16 Rosmalen et al. (47); Netherlands (Developed) | Cross-sectional | 894 (100%) | 10–12 | Not reported | Saliva (AUCi, normal condition) | TRFIA | BMI | BMI was calculated based on measured weight and height | Correlation between salivary cortisol (AUCi) and BMI: $r = 0.072$, $p = 0.042$<br>No covariates were reported |
| **Serum cortisol** | | | | | | | | | |
| 1[1] Gallagher et al. (67); Greek (Developed) | Cross-sectional | 2,665 (49.5%) | 9–13 | Not reported | Serum | ELISA | Visceral fat | Visceral fat was measured by BIA method | Serum cortisol was associated with visceral fat: β = −0.04, 95% CI: −0.1, −0.07, $p = 0.01$<br>Covariates included: Child's: Sex, tanner stage, total daily energy intake and total steps per day<br>Maternal: Education |
| 1[2] Gallagher et al. (67); Greek (Developed) | Cross-sectional | 2,665 (49.5%) | 9–13 | Not reported | Serum | ELISA | BMI | BMI was calculated based on measured weight and height | Serum cortisol was associated with visceral fat: β = −0.03, 95% CI: −0.1, 0.0, $p = 0.06$<br>Covariates included: Child's: Sex, tanner stage, total daily energy intake and total steps per day<br>Maternal: Education |

*(Continued)*

**TABLE 1** | (Continued)

| First author, Publication year; Country and development context | Study design | Sample size (% Girls) | Age (years, Mean ± SD, Range) | Race/Ethnicity | Cortisol measure | | Adiposity outcomes | | Effect size/Associations between cortisol and adiposity/Covariates |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Measure source | Measurement method | Measures | Method of ascertainment | |
| 1[3] Gallagher et al. (67); Greek (Developed) | Cross-sectional | 2,665 (49.5%) | 9–13 | Not reported | Serum | ELISA | BMI z-score | BMI z-score was calculated based on WHO 2007 growth reference for age | Serum cortisol was associated with BMI z-score: β = −0.01, 95% CI: −0.0, 0.0, $p = 0.11$)<br>Covariates included: Child's: Sex, tanner stage, total daily energy intake and total steps per day<br>Maternal: Education |
| 2* Koester-Weber et al. (68); Multi-Centre in Europe (Developed) | Cross-sectional | 927 (55%) | 14.90 ± 1.20 | Not reported | Serum | ELISA | Overweight vs. Non-overweight | BMI was calculated by measuring weight and height. Overweight: BMI > 25 Kg/$m^2$, Obesity: BMI > 30 kg/$m^2$ | NR |
| 3[1$] Hillman et al. (53); United States (Developed) | Cross-sectional | 218 (100%) | 14.90 ± 2.20 | White, Black, Other | Serum (afternoon and AUCi) | RIA | BMI z-score | BMI was calculated based on measured weight and height. BMI z-score was generated based on the CDC growth charts of U.S (2000) | Associations between serum cortisol (AUCi) and BMI z-score: β = −0.02, 95% CI: −0.04, −0.003, $p = 0.02$<br>No covariates were reported |
| 3[2$] Hillman et al. (53); United States (Developed) | Cross-sectional | 218 (100%) | 14.90 ± 2.20 | White, Black, Other | Serum (afternoon and AUCi) | RIA | BMI | BMI was calculated based on measured weight and height | Associations between serum cortisol (AUCi) and BMI: β = −0.06, 95% CI: −0.156, 0.03, $p = 0.20$<br>Covariates included: Child's: Age, race, Tanner stage, and socio-economic status |
| 3[3$] Hillman et al. (53); United States (Developed) | Cross-sectional | 218 (100%) | 14.90 ± 2.20 | White, Black, Other | Serum (afternoon and AUCi) | RIA | Body fat percentage | Percentage body fat was measured by DXA | Associations between serum cortisol (AUCi) and PBF: β = −0.05, 95% CI: −0.17, 0.08, $p = 0.49$<br>Covariates included: Child's: Age, race, and socio-economic status |
| 4[1] Adam et al. (69); United States (Developed) | Cross-sectional | 211 (43.6%) | 10.80–11.10 | Latino | Serum | RIA | BMI | BMI was calculated based on measured weight and height | Correlations between serum cortisol and BMI: $r = 0.06$<br>No covariates were reported |
| 4[2] Adam et al. (69); United States (Developed) | Cross-sectional | 211 (43.6%) | 10.80–11.10 | Latino | Serum | RIA | Waist circumference | Waist circumference was measured | Correlations between serum cortisol and WC: $r = -0.03$<br>No covariates were reported |

*(Continued)*

**TABLE 1** | (Continued)

| First author, Publication year; Country and development context | Study design | Sample size (% Girls) | Age (years, Mean ± SD, Range) | Race/Ethnicity | Cortisol measure | | Adiposity outcomes | | Effect size/Associations between cortisol and adiposity/Covariates |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Measure source | Measurement method | Measures | Method of ascertainment | |
| 5 Weigensberg et al. (70); United States (Developed) | Cross-sectional | 205 (42.4%) | 11.10 ± 1.70 | Latino | Serum | RIA | Waist circumference | Waist circumference was measured | Correlations between serum cortisol and WC: $r = 0.02$<br>No covariates were reported |
| 6 Barat et al. (48); France (Developed) | Cross-sectional | 39 (43.6%) | 6–13 | Not reported | Serum | RIA | Truncal distribution of fat mass (TDFM) | TDFM was assessed with dual energy X-ray absorptiometry | Correlations between morning salivary cortisol and TDFM: $r = 0.17$ for total children, $r = 0.33$ for boys, $r = 0.40$ for girls<br>No covariates were reported |
| **Urine cortisol** | | | | | | | | | |
| 1[1$] Hillman et al. (53); United States (Developed) | Cross-sectional | 218 (100%) | 14.90 ± 2.20 | White, Black, Other | Urine free cortisol (afternoon) | RIA | BMI | BMI was calculated based on measured weight and height. BMI z-score was generated based on the CDC growth charts of U.S (2000) | Associations between urine cortisol and BMI: $\beta = 3.54$, 95% CI: 1.12, 5.97, $p = 0.005$<br>Covariates included: Child's: Age, race, Tanner stage, and socio-economic status |
| 1[2$] Hillman et al. (53); United States (Developed) | Cross-sectional | 218 (100%) | 14.90 ± 2.20 | White, Black, Other | Urine free cortisol (afternoon) | RIA | BMI z-score | BMI was calculated based on measured weight and height | Associations between urine cortisol and BMI z-score: $\beta = 0.56$, 95% CI: 0.16, 0.96, $p = 0.007$<br>Covariates included: Child's: Race, Tanner stage, and socio-economic status |
| 1[3$] Hillman et al. (53); United States (Developed) | Cross-sectional | 218 (100%) | 14.90 ± 2.20 | White, Black, Other | Urine free cortisol (afternoon) | RIA | Body fat percentage | Percentage body fat was measured by DXA | Associations between urine cortisol and PBF: $\beta = 2.60$, 95% CI: −0.65, 5.85, $p = 0.12$<br>Covariates included: Child's: Age, race, and socio-economic status |
| 2$ Barat et al. (48); France (Developed) | Cross-sectional | 28 (50%) | 6–13 | Not reported | Urine free cortisol morning | RIA | Truncal distribution of fat mass (TDFM) | TDFM was assessed with dual energy X-ray absorptiometry | Correlation between urine cortisol and TDFM was: $r = -0.28$ for total children, $r = 0.09$ for boys and $r = 0.25$ for girls<br>No covariates were reported |

*BMI, body mass index; WC, waist circumference; PBF, percentage body fat; BMI-SDS, BMI standard deviation score; SDS, standard deviation score; FMI, fat mass index; FFMI, free fat mass index; WtHR, waist to height ratio; CDC, Centers for Disease Control and Prevention; CI, confidence interval; M, mean; NR, not reported;β, beta coefficient; ELISA, enzyme-linked immunosorbent assay; CLIA, chemiluminescence immunoassay; HPLC-MS/MS, high-performance liquid chromatography-tandem mass spectrometry; LC-MS/MS, liquid chromatography tandem mass spectrometry; ECLIA, electrochemiluminescence immunoassay; RIA, radioimmunoassay; DELFIA, dissociation-enhanced lanthanide fluorescence immunoassay; TRFIA, a time-resolved fluorescence immunoassay; TSST-C, Trier Social Stress Test for Children; AUC, area under the curve with respect to ground; AUCi, saliva cortisol area-under-the-curve-increase.*

*[#]The two cohort studies that showed associations between hair cortisol and weight status were not included in the meta-analysis because the explanation of effect size (β) is different.*

*[#]These studies were not included in the meta-analysis because the meaning of effect size (β) was different as those of the other studies.*

**These studies were not included in the meta-analysis because the effect sizes were not reported.*

*[$]These studies were not included in the meta-analysis because the studies reported the homologous association < 2.*

*a and b: The studies data was extracted from one publication by gender, a for boys and b for girls, respectively.*

*c and d: The studies data was extracted from one publication in the age groups.*

*x, y, and z: Study data were extracted from one publication according to different measurement times – x for morning, y for afternoon and z for evening. In meta-analysis, we only included the association between morning cortisol and weight status.*

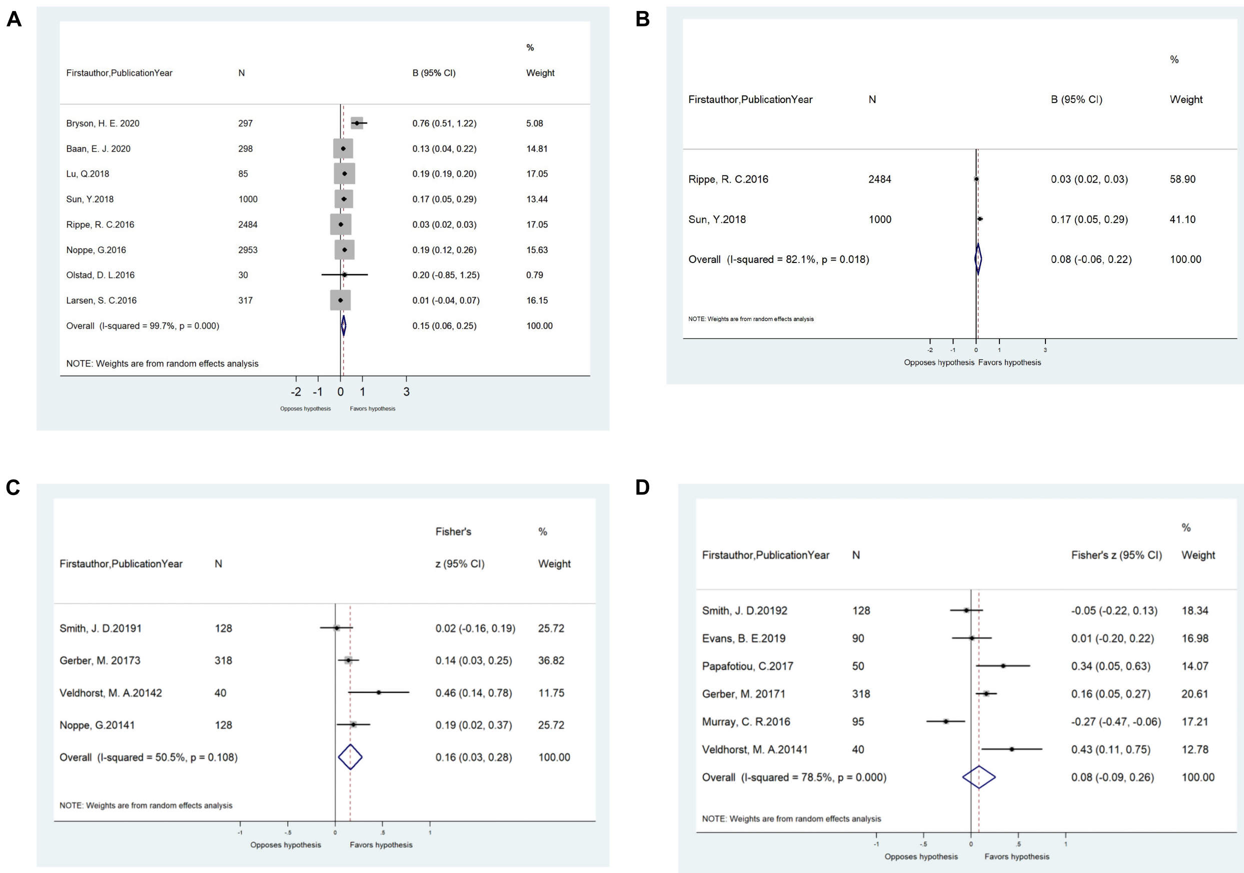


**FIGURE 2 | (A)** Meta-analysis of the adjusted associations (β, 95% CI) between hair cortisol and BMI/BMI z-score in cross-sectional studies (*n* = 8). **(B)** Meta-analysis of the adjusted associations (β, 95% CI) between hair cortisol and FMI-SDS/FMI z-score in cross-sectional studies (*n* = 2). **(C)** Meta-analysis of the unadjusted correlations (*r*, 95% CI) between hair cortisol and waist circumference in cross-sectional studies (*n* = 4). **(D)** Meta-analysis of the unadjusted correlations (*r*, 95% CI) between hair cortisol and BMI/BMI z-score/BMI-SDS in cross-sectional studies (*n* = 6). BMI, body mass index; BMI SDS, BMI standard deviation scores.

and adiposity-related outcomes. All were based in developed countries. Three articles were among children aged ≤ 12 years old and four articles extracted cortisol by RIA. Two articles measured BMI/BMI z-score, while others measured WC, PBF, visceral fat, and TDFM (**Table 1**). Pooled results showed that serum cortisol concentration was not correlated with WC (pooled-$r = -0.01$, 95% CI: −0.10, 0.09) from two cross-sectional studies (**Table 4** and **Figure 4**). Meta-analysis of serum cortisol concentration and other adiposity-related outcomes were not possible due to insufficient statistical data.

## Urinary Cortisol Concentration and Adiposity-Related Outcomes Among Children

Two articles of 246 children examined associations between urinary cortisol and adiposity-related outcomes. Both were from developed countries and extracted cortisol by RIA. One study measured TDFM while the other measured BMI/BMI z-score and PBF (**Table 1**). Of the two articles, one reported that the correlations between urinary cortisol and TDFM was $r = 0.14$ (−0.24, 0.49) for all children and by sex, for boys: $r = 0.09$, and for girls: $r = 0.25$. The other article reported that urinary cortisol to be positively associated with BMI (β = 3.54, 95% CI: 1.12, 5.97) and BMI z-score (β = 0.56, 95% CI: 0.16, 0.96), but not with PBF (β = 2.60, 95% CI: −0.65, 5.85). Further subgroup meta-analysis was not possible because necessary statistics were not available.

## Sensitivity Analysis and Assessment of Publication Bias

Respective sensitivity analyses were conducted to examine associations of HCC, salivary cortisol, and serum cortisol concentration with adiposity-related outcomes. Only when the study by Chu et al., 2017 was removed from the meta-analyses of cross-sectional studies did the non-significant correlations between morning salivary cortisol concentration and BMI/BMI z-score become significant ($r = 0.35$, 95% CI: 0.10, 0.60; **Supplementary Table 3**). The Egger's tests and funnel plots indicated no publication bias within our evaluated study parameters (**Table 2** and **Supplementary Figure 1**).

**TABLE 2 |** Overall and sub-group meta-analysis of the associations between hair cortisol concentration and adiposity-related outcome(s) among children based on 20 included studies.

| Sample | Adiposity-related outcome(s) | N of studies | Effect size (β , 95% CI) | *P*-value | Heterogeneity $I^2$ (%) | $\chi^2$ | *P*-value | Tau-squared | *P*-value (Egger's test)[e] |
|---|---|---|---|---|---|---|---|---|---|
| (1) Cross-sectional studies (β , 95% CI) | | | | | | | | | |
| Overall | FMI-SDS/FMI z-score | 2 | 0.08 (−0.06, 0.22) | 024 | 82.1 | 5.60 | 0.02 | 0.01 | – |
| Overall[a] | BMI/BMI z-score | 8 | **0.15 (0.06, 0.25)** | 0.002 | 99.7 | 2,200.16 | <0.001 | 0.01 | 0.69 |
| Age group | | | | | | | | | |
| ≤12 years | BMI/BMI z-score | 6 | **0.15 (0.05, 0.26)** | <0.001 | 99.8 | 2,199.92 | <0.001 | 0.01 | |
| >12 years | BMI/BMI z-score | 2 | **0.13 (0.04, 0.22)** | 0.004 | 0 | 0.02 | 0.90 | <0.001 | |
| Country developmental context | | | | | | | | | |
| Developed countries | BMI/BMI z-score | 6 | **0.12 (0.03, 0.21)** | <0.001 | 88.4 | 43.22 | <0.001 | 0.01 | |
| Developing countries | BMI/BMI z-score | 2 | **0.193 (0.188, 0.198)** | <0.001 | 0 | 0.14 | 0.71 | <0.001 | |
| Measurement method | | | | | | | | | |
| LC-MS/MS | BMI/BMI z-score | 3 | **0.18 (0.06, 0.29)** | 0.002 | 99.8 | 2186.67 | <0.001 | 0.01 | |
| ELISA | BMI/BMI z-score | 5 | 0.08 (−0.06, 0.22) | 0.26 | 65.1 | 5.74 | 0.06 | 0.01 | |
| (2) Cross-sectional studies (*r*, 95% CI) | | | | | | | | | |
| Overall[a,c] | Waist circumference | 4 | **0.16 (0.03, 0.28)** | 0.01 | 50.5 | 6.07 | 0.11 | 0.01 | 0.449 |
| Measurement method | | | | | | | | | |
| ELISA | Waist circumference | 3 | **0.19 (0.03, 0.40)** | 0.01 | 67.0 | 6.06 | 0.05 | 0.02 | |
| CLIA[d] | Waist circumference | 1 | **0.14 (0.03, 0.25)** | – | – | – | – | – | |
| Overall[c] | BMI/BMI z-score/BMI-SDS | 6 | 0.08 (−0.09, 0.26) | 0.35 | 78.5 | 23.29 | <0.001 | 0.04 | 0.918 |
| Measurement method | | | | | | | | | |
| ELISA | BMI/BMI z-score/BMI-SDS | 3 | 0.02 (−0.32, 0.35) | 0.93 | 84.5 | 12.88 | 0.002 | 0.07 | |
| LC-MS/MS | BMI/BMI z-score/BMI-SDS | 2 | 0.16 (−0.16, 0.48) | 0.33 | 69.8 | 3.31 | 0.07 | 0.04 | |
| Sex[b] | | | | | | | | | |
| Boys[d] | BMI/BMI z-score | 1 | 0.13 (−0.03, 0.29) | – | – | – | – | – | |
| Girls | BMI/BMI z-score | 2 | **0.21 (0.06, 0.36)** | 0.003 | 13.9 | 1.16 | 0.28 | <0.001 | |

*FMI, fat mass index; BMI, body mass index; SDS, standard deviation score; ELISA, Enzyme-Linked Immunosorbent Assay; LC–MS/MS, liquid chromatography tandem mass spectrometry; CLIA, chemiluminescence immunoassay.*

*We had searched two cohort studies that reported the associations (β, 95% CI) between hair cortisol concentration and adiposity, one of the studies showed that the associations between hair cortisol concentration and BMI: β (95% CI) = 4.62 (1.41, 7.83) ($p < 0.01$), the other one's effective size has different meaning. Thus, we were unable to perform a meta-analysis.*

[a] *These studies did not report the associations between cortisol and adiposity for boys and girls, respectively. Thus, we did not do the subgroups analysis across genders, country context, or age groups.*

[b] *Among the six studies showed association (r) between hair cortisol concentration and weight status, only one reported the association for boys and girls. We divided the article into two studies and one study only showed the association for girls.*

[c] *These studies were all from developed countries and the participants were ≤12 years old, thus, we did not perform sub-group meta-analysis across country context and age groups.*

[d] *In the sub-group meta-analysis, only one study was included and the effect size was the one reported in the original study.*

[e] *The Egger's tests was used to indicate the existence of publication bias. If p-value < 0, it was indicated that publication bias was existed, otherwise, no publication bias existed. Numbers in bold indicate significance.*

# DISCUSSION

This is the first systematic review and meta-analysis to synthesize and evaluate the associations between different cortisol measures and adiposity-related outcomes in children. We found that most of our included studies examined the associations of either HCC or salivary cortisol concentration with adiposity-related outcomes, and most studies were from developed countries. However, results from our meta-analysis indicated that only HCC, the cortisol measure that serves as an indicator of long-term stress and cumulative cortisol activity, was positively associated with objectively measured adiposity-related outcomes (i.e., FMI-SDS/FMI z-score, BMI, BMI z-score) in children. Salivary, serum, and urinary cortisol measures were not consistently associated with these adiposity-related outcomes, especially after adjustment for covariates, and/or lacked sufficient data for meta-analyses.

For HCC, meta-analysis of results from cross-sectional studies showed it to be robustly and positively associated with objectively measured adiposity-related outcomes in children, including FMI-SDS/FMI z-score and BMI/BMI z-score. The age- (≤12 years vs. >12 years) and country developmental context-stratified (developing countries vs. developed countries) analyses also supported these positive adjusted associations. Our meta-analyses result also revealed HCC to be positively correlated with WC without adjusting for covariates. These observations support the role of chronic stress or chronically elevated levels of cortisol in the development and maintenance

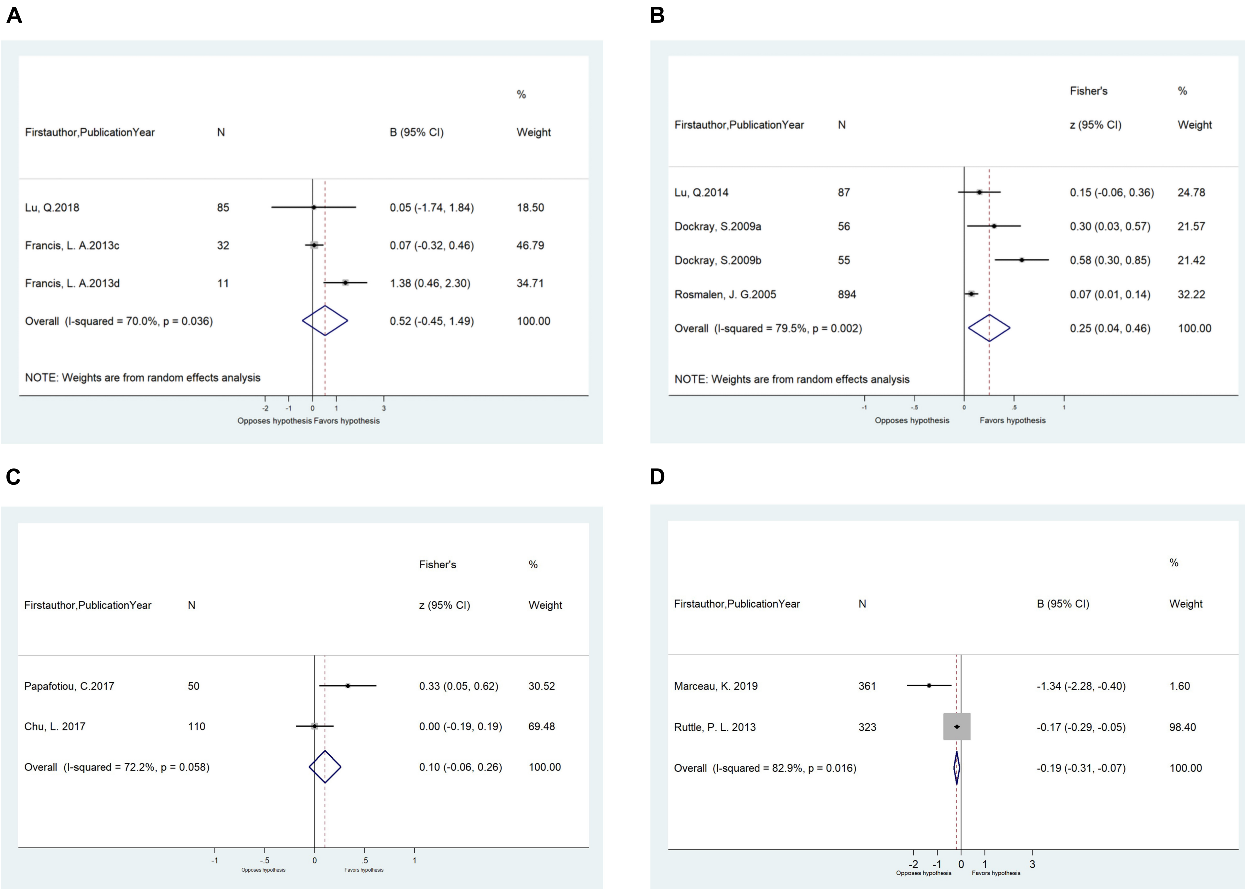


**FIGURE 3 | (A)** Meta-analysis of the associations (β, 95% CI) between salivary cortisol (lnAUCi) and BMI z-score in cross-sectional studies (*n* = 3). **(B)** Meta-analysis of the unadjusted correlations (*r*, 95% CI) between salivary cortisol (log AUCi) and BMI in cross-sectional studies (*n* = 4). **(C)** Meta-analysis of the unadjusted correlations (*r*, 95% CI) between morning salivary cortisol and BMI/BMI z-score in cross-sectional studies (*n* = 2). **(D)** Meta-analysis of the longitudinal adjusted effects (β, 95% CI) of morning salivary cortisol on BMI in longitudinal studies (*n* = 2). BMI, body mass index.

of both general and central obesity in children. These findings are consistent with the results of a previous systematic review (21). Cortisol increases fat accumulation *via* glucocorticoid receptors, which have a particularly high density in visceral adipose tissue (38). Moreover, cortisol can increase food intake, especially of energy dense "comfort foods"(39), which can further contribute to increased obesity risk. The positive pooled effect sizes between HCC and adiposity-related outcomes corroborate the importance of considering chronic stress exposures over more acute stress measures when designing or evaluating childhood obesity interventions as well as in treating obesity (7).

Notably, our meta-analyses revealed the novel importance of HCC measurement method, the choice of which modified adjusted cross-sectional associations between HCC and BMI/BMI z-score in children. Only HCC extracted by LC-MS/MS, not ELISA, was associated with BMI/BMI z-scores. Immunoassays such as ELISA tend to yield higher but less accurate HCC than LC-MS/MS, possibly because ELISA overestimate steroid content given antibody cross-reactivity (40). Rather, LC-MS/MS offers superior specificity and sensitivity with its multi-analyte capabilities, making it the preferred method for HCC analysis in high-quality clinical research (41). Additionally, thanks to the high sensitivity for cortisol in hair provided by mass spectrometers, only small samples of hair are needed to run LC-MS/MS, which is conducive for large epidemiological studies among pediatric populations. Future studies should measure HCC by LC-MS/MS, and more longitudinal work is necessary to examine long-term associations.

Twelve of the 17 studies measuring HCC used hair 3 cm proximal to the scalp. Based on an average hair growth rate of 1 cm per month, such samples can reflect the cumulative cortisol and cortisone secretion of HPA axis in the previous 3 months (42). It follows then that most studies using HCC are, either consciously or not, accounting for chronic stress over the past 3-months in children. Other studies have also suggested that researchers could retrospectively examine cortisol production for a particular preceding time period when stress could have been more salient (43). However, other studies have observed HCC to decrease gradually along the length of hair shaft as distal hair samples may suffer

**TABLE 3 |** Overall and sub-group meta-analysis of the associations between salivary cortisol concentration and adiposity-related outcomes among children based on 11 included studies.

| Sample | Adiposity outcomes | N of studies | Effect size (β , 95% CI) | *P* value | Heterogeneity | | | | *P*-value (Egger's test)[c] |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | $I^2$ (%) | $\chi^2$ | *P*-value | Tau-squared | |
| 1. Total daily output of salivary cortisol (lnAUCi or logAUCi, cross-sectional studies) | | | | | | | | | |
| (1) Salivary cortisol (lnAUCi; β , 95% CI)[a] | BMI z-score | 3 | 0.52 (−0.45, 1.49) | 0.29 | 70.0 | 6.66 | 0.04 | 0.48 | 0.655 |
| Measurement method | | | | | | | | | |
| LC-MS/MS[b] | BMI z-score | 1 | 0.05 (−1.74, 1.84) | 0.96 | – | – | – | – | |
| ELISA | BMI z-score | 2 | 0.66 (−0.62, 1.93) | 0.31 | 84.9 | 6.60 | 0.01 | 0.73 | |
| Country developmental context | | | | | | | | | |
| Developing country[b] | BMI z-score | 1 | 0.05 (−1.74, 1.84) | 0.96 | – | – | – | – | |
| Developed country | BMI z-score | 2 | 0.66 (−0.62, 1.93) | 0.31 | 84.9 | 6.60 | 0.01 | 0.73 | |
| (2) Salivary cortisol (logAUCi; *r*, 95% CI) | BMI | 4 | **0.25 (0.04, 0.46)** | 0.02 | 79.5 | 14.6 | 0.002 | 0.03 | 0.147 |
| Measurement method | | | | | | | | | |
| ELISA | BMI | 3 | **0.33 (0.09, 0.58)** | <0.001 | 65.6 | 5.82 | 0.06 | 0.03 | |
| TRFIA[b] | BMI | 1 | **0.07 (0.01, 0.14)** | 0.03 | – | – | – | – | |
| Sex | | | | | | | | | |
| Boys[b] | BMI | 1 | **0.30 (0.03, 0.57)** | 0.03 | – | – | – | – | |
| Girls | BMI | 2 | 0.31 (−0.19, 0.80) | 0.002 | 92.0 | 12.49 | <0.001 | 0.12 | |
| Country developmental context | | | | | | | | | |
| Developed countries | BMI | 3 | **0.30 (0.02,0.61)** | <0.001 | 86.2 | 14.47 | 0.001 | 0.06 | |
| Developing countries[b] | BMI | 1 | 0.15 (−0.06, 0.37) | <0.001 | – | – | – | – | |
| Age group | BMI | | | | | | | | |
| ≤12 years | BMI | 3 | **0.30 (0.02, 0.61)** | <0.001 | 86.2 | 14.47 | 0.001 | 0.07 | |
| >12 years | BMI | 1 | 0.15 (−0.06, 0.37) | 0.17 | – | – | – | – | |
| (3) Morning salivary cortisol (*r*, 95% CI, cross-sectional studies) | BMI/BMI z-score | 2 | 0.15 (−0.17, 0.47) | 0.367 | 72.2 | 3.59 | 0.06 | 0.04 | – |
| (4) Morning salivary cortisol (β , 95% CI, cohort studies | BMI | 2 | −**0.66 (**−**1.79, 0.47)** | 0.25 | 82.9 | 5.86 | 0.02 | 0.57 | – |

*BMI, body mass index; AUCi, saliva cortisol area-under-the-curve-increase; LC-MS/MS, liquid chromatography tandem mass spectrometry; ELISA, enzyme-linked immunosorbent assay; TRFIA, a time-resolved fluorescence immunoassay.*

[a]*Age of the children in the three studies were ≤12 years, and they did not report the association between salivary cortisol concentration and BMI/BMI z-score for boys or girls. Thus, we did not do the subgroups analysis across gender and age groups.*

[b]*In the sub-group meta-analysis, only one study was included, so the data reported in the original study was presented.*

[c]*The Egger's tests was used to indicate the existence of publication bias. If p-value < 0, it was indicated that publication bias was existed, otherwise, no publication bias existed. Numbers in bold indicate significance.*

more insults (e.g., repeated water and soap exposure) (44). Future study designs should consider these attributes and explore ways to incorporate HCC measures so as to capture cortisol levels encompassing several months. This will serve to further elucidate associations between chronic stress and childhood obesity.

In contrast to the long-term inference enabled by HCC, salivary cortisol concentration is more reflective of HPA reactivity and the stress response facilitated by laboratory settings (30). Seven (30, 31, 34, 35, 45–47) of the 13 studies (23, 30, 31, 34, 35, 45–52) used $AUC_i$ to assess increases in salivary cortisol after administering the Trier Social Stress Test for Children (TSST-C) (53). Though $AUC_i$ of salivary cortisol was correlated with BMI prior to adjusting for covariates, the adjusted associations were not significant for cross-sectional or longitudinal studies, for studies that measured salivary cortisol by ELISA or LC-MS/MS or for studies from developing or developed countries.

Rather than AUCi of salivary cortisol, the other six studies (23, 48–52) measured morning salivary cortisol to indicate the cortisol awakening response (54). However, we found neither unadjusted nor adjusted associations between morning salivary cortisol concentration and adiposity-related outcomes to be significant. These findings suggest that both cortisol awakening response and cortisol reactivity to acute stress challenge tasks are not associated with adiposity-related outcomes in children. Correspondingly, recent longitudinal studies found that obesity predicted greater changes in cortisol awakening response and cortisol reactivity to challenge in early to middle childhood, not that cortisol awakening response and cortisol reactivity predicted increased likelihood of obesity over the same time period (31). In our review, only four of the 13 included studies

**TABLE 4 |** Overall meta-analysis of the correlations (*r*, 95% CI) between serum cortisol concentration and waist circumference among children based on cross-sectional studies.

| | | | | | Heterogeneity | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Sample** | **Adiposity outcome(s)** | **N of studies** | **Correlations (*r*, 95% CI)** | ***P*-value** | **$I^2$ (%)** | **$\chi^2$** | ***P*-value** | **Tau-squared** | ***P*-value Egger's test)[a]** |
| Overall | Waist circumference | 2 | −0.01 (−0.10, 0.09) | 0.91 | 0 | 0.26 | 0.61 | <0.001 | – |

[a]*The Egger's tests was used to indicate the existence of publication bias. If p-value < 0, it was indicated that publication bias was existed, otherwise, no publication bias existed.*

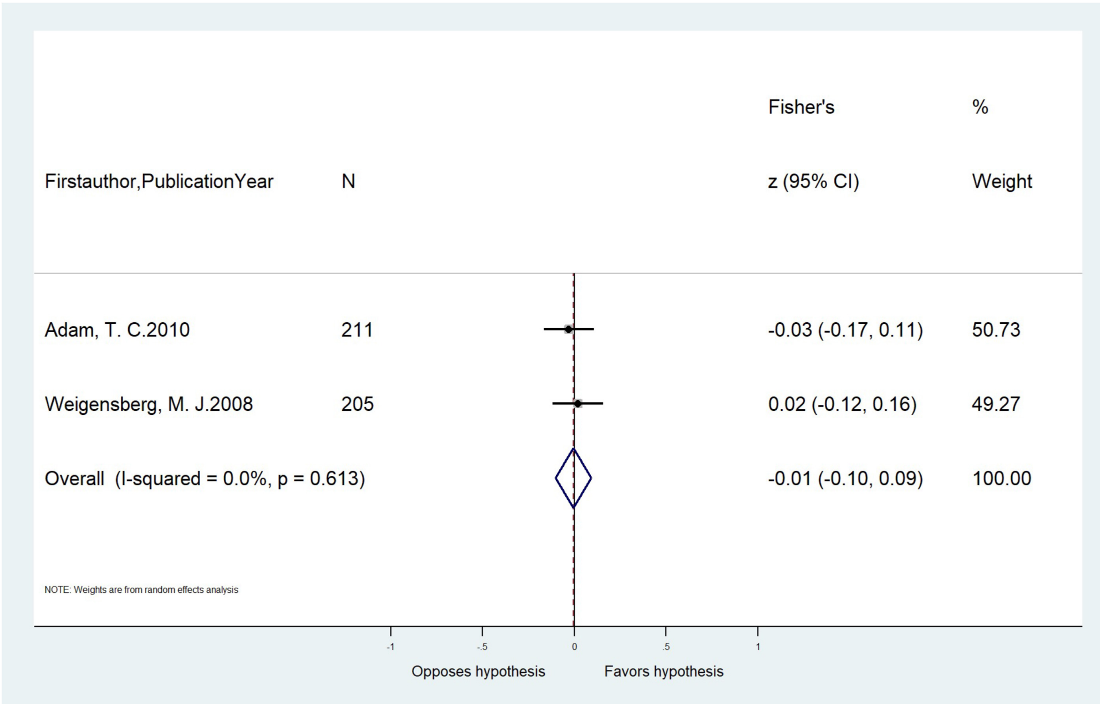


**FIGURE 4 |** Meta-analysis of the unadjusted correlations (*r*, 95% CI) between serum cortisol concentration and waist circumference in cross-sectional studies (*n* = 2).

were longitudinal, precluding similar inferences on the direction of these associations. More longitudinal studies are needed to understand these associations.

Given the current evidence base, serum cortisol concentration was not observed to be correlated with WC and BMI in children. For urinary cortisol and adiposity-related outcomes, limited studies and data precluded further meta-analyses. However, we did have two studies examine these associations, both supporting significant positive associations between urinary cortisol and BMI (34). Still, these studies' cross-sectional designs and solitary existence demonstrate the need for more efforts to confirm serum and urinary cortisol associations in childhood obesity.

The present systematic review and meta-analysis expands the knowledge base concerning stress biomarker utility in pediatric adiposity research by providing pooled effect sizes for different cortisol measures against objectively measured adiposity-related outcomes. These findings may help health professionals and policymakers better understand how different cortisol measures reflect underlying stress processes and how stress may contribute to adiposity in children. This review also comprehensively investigated the effects of potential moderators on cortisol-adiposity associations, such as age, sex, cortisol measurement method, and country development context. These latter findings provide insights on how to measure HCC more precisely, and how to better understand obesogenic effects of stress in different socio-demographic and economic contexts. Furthermore, examining the pooled effect sizes separately using unadjusted and adjusted models provides a more comprehensive picture of the cortisol with adiposity.

Nonetheless, some limitations should be considered in the interpretation of our results. First, sex-stratified analyses of adjusted associations between HCC and adiposity-related outcomes were not possible given limited statistics available. Second, the generalizability of our findings is limited as we included only studies published in English, most of our included studies were from developed countries, and we excluded studies focusing on children with mental disorders or chronic diseases. Third, most studies were observational in nature, precluding causal interpretations. Fourth, while our findings provide insights on physiological stress processes and adiposity-related outcomes, the sources of stress could not be identified beyond chronicity and acuteness and are thus unable to inform actionable recommendations for childhood obesity prevention efforts; such can be the efforts of future work. Fifth, the number of studies included in some subgroup analyses were small as only limited eligible studies were available, especially for salivary and serum cortisol; more studies utilizing these biomarkers are needed. Last, as several original studies with <50 participants were included in the meta-analysis, the small samples reduced the power to find significant associations between cortisol and adiposity-related outcomes.

After consideration of the four cortisol measures of hair, saliva, serum, and urine in children, this study provides important evidence supporting a positive relationship between HCC and objectively measured adiposity-related outcomes. Similar findings were found for children aged ≤12 years and >12 years, and for children from developing and developed countries. These findings provide direct evidence of the physiological stress processes that contribute to increased risk of adiposity-related outcomes in children, and corroborate the need to focus on chronic stress in childhood obesity intervention efforts.

## DATA AVAILABILITY STATEMENT

The original contributions presented in this study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding authors.

## AUTHOR CONTRIBUTIONS

LuM and LeM designed the research. XL, LuM, NY, and MC conducted the literature search, data screening, and extraction. XL performed the meta-analysis. LuM, XL, and DTC drafted the manuscript. LeM and DTC provided administrative support for the project and had primary responsibility for the final manuscript. All authors read and approved the final manuscript. All authors revised the manuscript, critically helped in the interpretation of results, provided relevant intellectual input, and approved the submitted version.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2022.879256/full#supplementary-material

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# Financial Wellbeing and Quality of Life Among a Sample of the Lebanese Population: The Mediating Effect of Food Insecurity

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**Background:** Lebanon is undergoing multiple overlapping crises, affecting the food security, financial well-being, and quality of life (QOL) of its residents.

**Objective:** The primary objective was to assess the food insecurity (FI) status of a sample of the Lebanese population. The second objective was to explore factors related to QOL parameters and evaluate the mediating effect of food security between financial well-being and QOL.

**Methods:** The study was cross-sectional and enrolled 412 participants recruited online using the snowball sampling technique. The survey included questions related to sociodemographic and economic characteristics of Lebanese households and validated scales to assess FI, QOL measures, financial well-being, and fear of COVID-19.

**Results:** Almost 43% of the study participants reported being food insecure, with 31% experiencing mild FI, 10% moderate FI, and 1.5% severe FI. Compared to food-insecure participants, food secure participants had a significantly higher income (58.5% vs. 39.2%, $p < 0.001$), a university education level (96.6% vs. 88.1%, $p = 0.002$), an average perceived financial status (83.9% vs. 65.9%), higher financial well-being scores (5.14 vs. 3.19, $p < 0.001$), and lower crowding index (0.94 ± 0.4 vs. 1.09, $p = 0.002$). Multivariate analysis showed that FI was not associated with physical (Beta = −1.48, 95% CI: −3.10; 0.13) and mental (Beta = −1.46, 95% CI −3.68; 0.75) QOL, after adjusting for other demographic and socioeconomic correlates. This association remained non-significant when introducing the financial well-being variable to the model. Mediation analyses showed that the FI variable mediated the association between financial well-being and physical QOL (Beta = 0.19, 95% CI: 0.02; 0.36), but not the mental QOL (Beta = −0.02, 95% CI: −0.20; 0.14).

**Conclusion:** Food insecurity was prevalent in our study sample, and it mediated the association between financial well-being and physical, but not mental, QOL parameters. These findings call for evidence-based policies and programs to help improve the food security and well-being of Lebanese households amidst these unprecedented circumstances.

**Keywords: food insecurity, quality of life, financial wellbeing, Lebanon, physical health, mental health**

## INTRODUCTION

Lebanon once considered the Switzerland of the Levant, and its capital, Beirut, the "Paris of the Middle East" (1), are facing an escalating humanitarian juncture arising due to multiple concurrent crises: a massive economic collapse, the August 4 tragic Beirut Port blast, and the ongoing COVID-19 pandemic (2). These overlapping crises continue to have serious repercussions on the country's economic viability, political stability, and the food and health security of its population.

According to a report published by the World Bank (3), the economic and financial hardship that Lebanon has been undergoing in the last 2 years was ranked among the top three most severe crises globally since the mid-nineteenth century. The currency in Lebanon lost its value in a dramatic way, the income of 1,500,000 LBP (Lebanese Pounds) was worth 1,000 USD prior to the crises, and have declined significantly reaching 60 USD at the time when paper was released. In parallel, people have limited access to their savings in the banks and can retrieve from it small monthly amount in foreign currencies. This left the population in Lebanon with financial instability and inability to cope with emergencies. Alongside the economic crisis, unprecedented price inflation for all commodities, including food and beverages, reached up to 483% in January 2022, after being 438.65% in December 2021, according to the Central Administration of Statistics (4). In 2020, the United Nations estimated that over 50% of the Lebanese population was at risk of failing to access basic food needs (5). The collapse of the financial system, the weak welfare programs, and the ever-increasing economic, social, and political challenges facing Lebanon since 2019, have all threatened the food security and health of its residents (6, 7).

Food insecurity (FI), defined by the Food and Agriculture Organization (FAO) as the lack of physical, economic, and social access to safe, sufficient, and nutritious food (8), affects physical and mental health, both considered dimensions of quality of life (QOL), along with social health, material wellbeing, and development and activity (9, 10). FI has been associated with multiple nutrition-related health outcomes, including, but not restricted to, dietary inadequacies, obesity, poor general health, and a myriad of chronic health conditions among adults (11, 12). In addition to its physical health effects, FI has also been associated with poor mental health outcomes related to its degree, with severe FI being associated with extreme chronic stress (13) and a higher risk of anxiety and depression (14). Multiple potential mechanisms can explain the association of FI and poor mental health, such as the increased physical stress caused by poor nutrition and nutrient insufficiency, the psychological stress caused by the anxiety of not obtaining enough food, or the social stress, including isolation and shaming (15).

Scientific evidence published since the start of COVID-19 highlighted the myriad of adverse effects of the pandemic on health outcomes, including increased psychological stressors and poor mental health outcomes. Studies showed that populations globally were undergoing panic, fear, and phobia that extended beyond the fear of being infected or infecting others to anxiety about loss of jobs, lower incomes, and lack of access to food and other basic amenities. This issue was particularly pronounced among vulnerable populations residing in low-to-middle-income countries (LMICs) with limited social protection programs (14, 16–18).

In Lebanon, the COVID-19 pandemic coupled with economic and financial hardships, and political instability, has adversely impacted the food security of the population and their physical and mental health (19, 20). Recent studies have highlighted the compromised mental health of Lebanese, an essential pillar of quality of life (QOL) (20), reflected by increased incidences of post-traumatic stress disorders and depression symptoms following the Beirut blast (16, 20). A recent Lebanese study conducted between November and December 2020 among 1,133 Lebanese participants found that food insecurity is an immediate problem for households in Beirut and many governorates in Lebanon (19). Another recent study that aimed to evaluate the impact of the pandemic and economic crises on FI in Lebanon revealed that FI was estimated to reach 36 to 39% post-crises, on average (21).

Theoretically, it is known that financial constraint is related to FI (22) and it is an indicator of the quality of life and wellbeing (23). In turn, FI was found in the scientific literature to be related to physical (11, 12) and poor mental health (13, 14). However, in the absence of a framework, exploring the relationships between these factors (financial wellbeing, FI and QOL), it was interesting to study these associations. Also, to our knowledge, no study showcased the association of FI with the QOL parameters among the Lebanese population and none have explored if FI in Lebanon, amidst the multiple crises, was directly affecting mental (wellbeing, anxiety, depression) and physical QOL, or if QOL parameters are affected by other underlying causes including, but not restricted, to past traumas, fear of COVID-19, and fear of poverty. Therefore, this study aimed to present a better understanding of the association between these variables that affect to a great extent the Lebanese population. The primary objective of the current study was to assess the food security status of a sample of the Lebanese population amidst

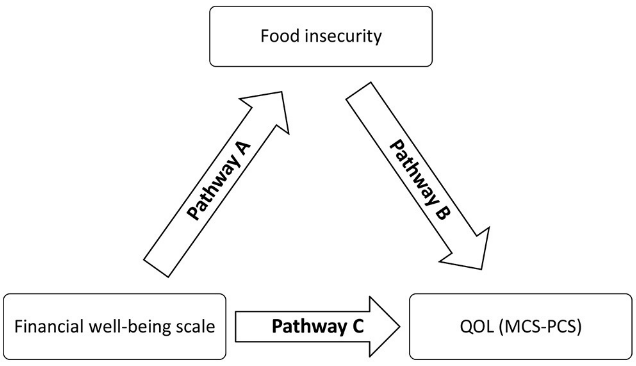


**FIGURE 1 |** The framework showing the mediation pathways between financial wellbeing, food insecurity, and quality of life.

multiple overlapping crises in the country. The second objective was to explore factors related to physical and mental QOL and to evaluate the mediating effect of food security between financial wellbeing and QOL.

# MATERIALS AND METHODS

## Study Design and Population

This study was cross-sectional and enrolled 412 Lebanese adults from all governorates recruited online between October and December 2021, using the snowball sampling technique, which is a non-probability sampling technique. Selected participants were asked to enroll future subjects for the study by sharing the questionnaire with their peers and contacts via social media sites. An anonymous self-administered Arabic questionnaire was developed and shared by the researchers on several social media platforms (WhatsApp, Facebook, Instagram, and Linkedin). Non Lebanese living in Lebanon, Lebanese living abroad and participants younger than 18 years old were excluded from the study.

## Ethics Approval

The study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures were approved by the Modern University of Business and Science Ethics Committee (approval reference MU-20211005-26, Oct 2021).

## Sample Size Calculation

The Epi Info™ software (Centers for Disease Control and Prevention, Epi Info™) was used to calculate the minimum sample size. Considering a prevalence of 36% of individuals having food insecurity based on a recent Lebanese study done by Kharroubi et al. (21), with a 95% confidence level and an alpha error of 5%, the sample size needed was 354 participants. The final sample included 412 participants to take into account non-response or missing data. The sample size was determined before initiating the study.

## Questionnaire

The online survey tool was in Arabic language and comprised of two sections. The first part of the questionnaire consisted of sociodemographic and economic status and other descriptive characteristics of the participants. The second part included validated scales to assess food security, quality of life (QOL) measures, financial wellbeing, and fear of COVID-19.

### Sociodemographic, Economic Status and Other Descriptive Characteristics of the Study Participants

Sociodemographic status included questions on gender (male, female), age (in years), marital status (single, widowed, not married, married), educational level (primary/below 5 years of age), intermediate/below 12 years of age, secondary/below 18 years of age, and university), employment status (employed, unemployed), region of residence (governorates: Beirut, Mount Lebanon, South, North, Beqaa), area of residence (city, village), and household crowding index. The latter was calculated by dividing the number of persons living in the house by the number of rooms, excluding the bathrooms and kitchen. Economic status included questions on monthly income/financial status divided into no income, low (<1,000 USD), intermediate (1,000-2,000 USD), high (>2,000 USD), and refuse to answer. The income of 1,500,000 LBP (Lebanese Pounds) was worth 1,000 USD prior to the crises. Currently, it is worth 60 USD.

Moreover, fear of poverty was measured on a Likert scale from 0 to 10, where zero indicates no fear of poverty and ten extreme fear of poverty. Also, questions with three options of answer (yes, no, refuse to answer) were asked about the source of income at home, whether it is from work, aids from relatives, aids from governmental or non-governmental institutions, or income/aid in foreign currency. Other characteristics were also explored: taking medications for insomnia or depression or anxiety, alcohol consumption, and smoking status.

### The Food Insecurity Experience Scale

Food insecurity was assessed using the validated Arabic version of the Food Insecurity Experience Scale (FIES), an experience-based measure of food insecurity developed by the Food and Agriculture Organization, Voices of the Hungry project (24). FIES illustrates people's experiences in accessing food in the past twelve months using an 8-item scale investigating the ability to obtain enough food, households running out of food, and being forced to compromise the quality or quantity of food due to limited financial resources of respondents. For each of the eight questions of FIES, responses were coded as Yes (=1) and No/I don't know/I don't want to answer (=0). The sum of the eight responses was then calculated to obtain the raw score of FIES per household. A raw score of 0 indicated food security, while higher raw scores above 0 indicated FI, divided as follows: mild FI (1-3), moderate FI (4-6), and severe FI (7-8). In addition a binary variable (food secure vs. food insecure) was created to display those having or not FI. In this study, the Cronbach alpha value was 0.806.

**TABLE 1 |** Socio-demographic, economic, and other descriptive characteristics of the study participants ($N = 412$)[†].

| Variable | Total | Food secure $n = 236$ (57.3%) | Food insecure $n = 176$ (42.7%) | *p*-value[‡] |
|---|---|---|---|---|
| **Age** | 33.80 ± 12.02 | 33.22 ± 12.45 | 34.57 ± 11.42 | 0.262 |
| **Gender** | | | | |
| Male | 92 (22.3%) | 50 (21.2%) | 42 (23.9%) | 0.519 |
| Female | 320 (77.7%) | 186 (78.8%) | 134 (76.1%) | |
| **Marital status** | | | | |
| Single/widowed/married | 241 (58.5%) | 143 (60.6%) | 98 (55.7%) | 0.317 |
| Married | 171 (41.5%) | 93 (39.4%) | 78 (44.3%) | |
| **Education level** | | | | |
| Intermediate and below | 9 (2.1%) | 1 (0.4%) | 8 (4.5%) | 0.002 |
| Secondary | 20 (4.9%) | 7 (3.0%) | 13 (7.4%) | |
| University | 383 (93.0%) | 228 (96.6%) | 155 (88.1%) | |
| **Employment status** | | | | |
| Employed | 250 (60.7%) | 137 (58.1%) | 113 (64.2%) | 0.206 |
| Unemployed | 162 (39.3%) | 99 (41.9%) | 63 (35.8%) | |
| **Monthly income** | | | | |
| Low (<1,000$) | 61 (14.8%) | 26 (11.0%) | 35 (19.9%) | <0.001 |
| Intermediate (1,000$-2000) | 104 (25.2%) | 45 (19.1%) | 59 (33.5%) | |
| High (>2,000$) | 207 (50.2%) | 138 (58.5%) | 69 (39.2%) | |
| Refuse to answer | 40 (9.7%) | 27 (11.4%) | 13 (7.4%) | |
| **Source of income at home is from individuals work** | | | | |
| Yes | 383 (93.0%) | 223 (94.5%) | 160 (90.9%) | 0.103 |
| No | 18 (4.4%) | 6 (2.5%) | 12 (6.8%) | |
| Refuse to answer | 11 (2.7%) | 7 (3.0%) | 4 (2.3%) | |
| **Receiving financial support from relatives** | | | | |
| Yes | 60 (14.6%) | 26 (11.0%) | 34 (19.3%) | 0.050 |
| No | 342 (83.0%) | 205 (86.9%) | 137 (77.8%) | |
| Refuse to answer | 10 (2.4%) | 5 (2.1%) | 5 (2.8%) | |
| **Receiving financial assistance from governmental or non-governmental institutions?** | | | | |
| Yes | 11 (2.7%) | 9 (3.8%) | 2 (1.1%) | 0.232 |
| No | 393 (95.4%) | 223 (94.5%) | 170 (96.6%) | |
| Refuse to answer | 8 (1.9%) | 4 (1.7%) | 4 (2.3%) | |
| **Receiving any income/aid in foreign currency** | | | | |
| Yes | 99 (24.0%) | 65 (27.5%) | 34 (19.3%) | 0.153 |
| No | 297 (72.1%) | 162 (68.6%) | 135 (76.7%) | |
| Refuse to answer | 16 (3.9%) | 9 (3.8%) | 7 (4.0%) | |
| **Perceived financial status** | | | | |
| Poor | 73 (17.7%) | 19 (8.1%) | 54 (30.7%) | <0.001 |
| Average | 314 (76.2%) | 198 (83.9%) | 116 (65.9%) | |
| Rich | 6 (1.5%) | 5 (2.1%) | 1 (0.6%) | |
| Refuse to answer | 19 (4.6%) | 14 (5.9%) | 5 (2.8%) | |
| **Taking medication for insomnia** | | | | |
| Yes | 36 (8.7%) | 11 (4.7%) | 25 (14.2%) | 0.001 |
| No | 376 (91.3%) | 225 (95.3%) | 151 (85.8%) | |
| **Taking medication for depression** | | | | |
| Yes | 27 (6.6%) | 9 (3.8%) | 18 (10.2%) | 0.009 |
| No | 385 (93.4%) | 227 (96.2%) | 158 (89.8%) | |
| **Taking medication for anxiety** | | | | |
| Yes | 19 (4.6%) | 5 (2.1%) | 14 (8.0%) | 0.005 |
| No | 393 (95.4%) | 231 (97.9%) | 162 (92.0%) | |

*(Continued)*

**TABLE 1** | Continued

| Variable | Total | Food secure n = 236 (57.3%) | Food insecure n = 176 (42.7%) | p-value‡ |
|---|---|---|---|---|
| **Smoking status** | | | | |
| Yes | 127 (30.8%) | 67 (28.4%) | 60 (34.1%) | 0.215 |
| No | 285 (69.2%) | 169 (71.6%) | 116 (65.9%) | |
| **Alcohol consumption** | | | | |
| Yes | 188 (45.6%) | 116 (49.2%) | 72 (40.9%) | 0.097 |
| No | 224 (54.4%) | 120 (50.8%) | 104 (59.1%) | |
| | | **Mean ± SD** | **Mean ± SD** | |
| Fear of poverty | 6.50 ± 2.73 | 5.80 ± 2.78 | 7.44 ± 2.36 | <0.001 |
| Fear of COVID-19 score | 14.91 ± 5.98 | 13.94 ± 5.60 | 16.22 ± 6.25 | <0.001 |
| Household crowding index | 1.00 ± 0.48 | 0.94 ± 0.42 | 1.09 ± 0.55 | 0.002 |
| Financial wellbeing scale (IFDFW) | 4.31 ± 2.12 | 5.14 ± 2.09 | 3.19 ± 1.57 | <0.001 |

*†Continuous variables were presented as means ± standard deviation (SD) and categorical variables were presented as frequencies and percentages n (%). ‡ The chi-square test was used for the comparison between categorical variables whereas the independent-sample t-test was used to compare continuous variables between the food security and insecurity groups. Statistical significance was presented as $p < 0.05$.*

### The 12-Item Short-Form Health Survey (SF-12)

Health-related quality of life was assessed using the validated Arabic version of the 12-item short-form health survey (SF-12) (25). This scale was developed by the World Health Organization (WHO) and provided an overview of mental and physical functioning and overall health-related QOL. The survey derived two summary scores: physical and mental component summaries (PCS and MCS). PCS and MCS range from 0 to 100, where 0 indicates the lowest level of health measured by the scales and 100 indicates the highest level of health (26). In this study, the Cronbach alpha value of the PCS was 0.466 and 0.454 for the MCS.

### The InCharge Financial Distress/Financial Wellbeing Scale

Financial wellbeing was assessed using the validated Arabic version of the InCharge Financial Distress/Financial Wellbeing (IFDFW) scale, an 8-item self-reported measure of perceived financial distress/financial wellbeing, representing responses to one's financial state on a continuum ranging from overwhelming financial distress/lowest level of financial wellbeing to no financial distress/highest level of financial wellbeing (27). In this study, the Cronbach alpha value was 0.924.

### The Fear of COVID-19 Scale (FCV-19S)

The validated Arabic version of the Fear of COVID-19 Scale (FCV-19S) (28) is a 7-item scale designed to assess anxiety and fear related to the COVID-19 pandemic. Examples of questions included "I am most afraid of Corona," "It makes me uncomfortable to think about Corona," "My hands become clammy when I think about Corona." The items are rated on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). A total score could be calculated by summing each item score (ranged from 7 to 35) (29). A higher score indicates a greater fear of COVID-19. In this study, the Cronbach alpha value was 0.912.

## Statistical Analysis

The SPSS software version 25 was used to analyze data. Descriptive analyses were performed, where categorical variables were expressed as absolute frequencies and percentages and continuous variables as means and standard deviations. In order to describe the level of FI the ordinal categories of FI scale were used. The sample was normally distributed as verified by the visual inspection of the histogram, while the skewness and kurtosis were below |1.96|. Also, the normality of the MCS and PCS scales was verified by the normality line of the regression plot and the scatter plot of the regression residuals. The independent-sample *t*-test was used to compare continuous variables between groups, whereas the ANOVA test was used to compare between three or more means. For the comparison between categorical variables, the chi-square test was used. Pearson correlation test was used to evaluate the association between continuous variables. Cronbach's alpha values were recorded for reliability analysis for all the scales used in the present study.

A logistic regression model was conducted to explore the correlates of food insecurity, taking the binary variable of FI (food secure vs. food insecure) as the dependent variable. In addition, a three-stage linear regression analysis was performed, taking the two components of quality of life (PCS-SF12 and MCS-SF 12) as the dependent variables. In model 1, the relation between sociodemographic variables and QOL parameters (PCS-SF12 and MCS-SF12) was explored. In model 2, the binary food security variable was added to the analysis. In model 3, the relationship between food security, financial wellbeing, fear of COVID-19, alcohol consumption, and smoking status with QOL parameters was explored, adjusted for sociodemographic variables (Gender, age, household crowding index, education level, financial status, fear of poverty, monthly income and household crowding index).

Moreover, the PROCESS SPSS Macro version 3.4 model four was used to calculate three pathways in the mediation analysis. The FI variable was considered as a continuous variable and entered as a mediating variable in the model. Pathway A

**TABLE 2 |** Bivariate associations between food insecurity, sociodemographic and economic characteristics of study participants with their quality of life parameters SF-12 components (PCS-SF12 and MCS-SF12).

| | PCS-SF12[‡] Mean ± SD | *p*-value[†] | MCS-SF12[‡] Mean ± SD | *p*-value[†] |
|---|---|---|---|---|
| **Food insecurity status** | | | | |
| Food secure | 55.22 ± 6.10 | 0.024 | 36.06 ± 9.51 | 0.004 |
| Food insecure | 53.34 ± 7.38 | | 32.87 ± 8.45 | |
| **Gender** | | | | |
| Male | 54.89 ± 6.24 | 0.628 | 36.30 ± 8.68 | 0.169 |
| Female | 54.44 ± 6.76 | | 34.53 ± 9.39 | |
| **Marital status** | | | | |
| Single/widowed/married | 54.84 ± 6.59 | 0.335 | 34.51 ± 9.26 | 0.359 |
| Married | 54.09 ± 6.72 | | 35.50 ± 9.26 | |
| **Monthly income** | | | | |
| No income | 48.59 ± 0.01 | 0.100 | 35.52 ± 0.01 | 0.026 |
| Low (<1.500.000 LL) | 52.65 ± 7.68 | | 33.03 ± 8.44 | |
| Intermediate (1.500.000–3.000.000 LL) | 54.80 ± 7.19 | | 32.57 ± 9.03 | |
| High (>3.000.000 LL) | 55.24 ± 5.64 | | 35.82 ± 8.98 | |
| Refuse to answer | 52.96 ± 8.24 | | 37.92 ± 11.04 | |
| **Education level** | | | | |
| Intermediate and below | 58.13 ± 2.33 | 0.011 | 29.07 ± 9.63 | 0.279 |
| Secondary | 49.27 ± 11.71 | | 37.54 ± 14.45 | |
| University | 54.71 ± 6.32 | | 34.88 ± 8.99 | |
| **Employment status** | | | | |
| Employed | 54.70 ± 6.46 | 0.602 | 34.45 ± 9.12 | 0.296 |
| Unemployed | 54.30 ± 6.93 | | 35.59 ± 9.46 | |
| **Perceived financial status** | | | | |
| Poor | 52.91 ± 7.98 | 0.257 | 32.10 ± 9.99 | 0.011 |
| Average | 54.91 ± 6.23 | | 35.37 ± 9.08 | |
| Rich | 54.05 ± 5.23 | | 44.26 ± 5.24 | |
| Refuse to answer | 52.95 ± 9.28 | | 31.76 ± 8.34 | |
| **Smoking status** | | | | |
| Yes | 54.43 ± 6.58 | 0.854 | 33.79 ± 9.68 | 0.184 |
| No | 54.58 ± 6.68 | | 35.35 ± 9.07 | |
| **Alcohol consumption** | | | | |
| Yes | 55.44 ± 6.87 | 0.023 | 34.07 ± 9.11 | 0.126 |
| No | 53.70 ± 6.34 | | 35.69 ± 9.36 | |
| **Taking medication for insomnia** | | | | |
| Yes | 52.44 ± 6.23 | 0.145 | 32.33 ± 7.91 | 0.198 |
| No | 54.69 ± 6.66 | | 35.09 ± 9.33 | |
| **Taking medication for depression** | | | | |
| Yes | 52.58 ± 9.01 | 0.371 | 29.00 ± 9.42 | 0.052 |
| No | 54.60 ± 6.57 | | 35.09 ± 9.21 | |
| **Taking medication for anxiety** | | | | |
| Yes | 56.34 ± 7.63 | 0.469 | 24.07 ± 7.51 | 0.002 |
| No | 54.50 ± 6.63 | | 35.17 ± 9.15 | |
| | **Correlation coefficient** | ***p*-value** | **Correlation coefficient** | ***p*-value** |
| Age | −0.083 | 0.146 | 0.037 | 0.516 |
| Fear of poverty | −0.037 | 0.524 | −0.260 | <0.001 |
| Fear of COVID-19 scale | −0.079 | 0.171 | −0.213 | <0.001 |
| Household crowding index | −0.117 | 0.041 | −0.066 | 0.248 |
| Financial wellbeing scale (IFDFW) | 0.069 | 0.228 | 0.377 | <0.001 |

*[‡]MCS, mental component summary; PCS, physical component summary. PCS and MCS range from 0 (lowest level of health) to 100 (highest level of health). [†]In order to compare the categorical variable with two groups with the MCS and PCS scales, the independent-sample t-test was used, whereas the ANOVA test was used to compare between three or more means. Pearson correlation test was used to evaluate the association between continuous variables. Statistical significance was presented as $p < 0.05$.*

**TABLE 3 |** Logistic regression analysis taking the food security/food insecurity as the dependent variable.

| | Beta | *p*-value | ORa | 95% Confidence interval | |
|---|---|---|---|---|---|
| | | | | Lower bound | Upper bound |
| Fear of poverty | 0.001 | 0.978 | 1.001 | 0.901 | 1.113 |
| Financial wellbeing scale | −0.504 | <0.001 | 0.604 | 0.514 | 0.711 |
| Household crowding index | 0.412 | 0.110 | 1.510 | 0.911 | 2.504 |
| Monthly income (low vs. no income*) | 0.553 | 0.263 | 1.739 | 0.660 | 4.580 |
| Monthly income (intermediate vs. no income*) | 0.566 | 0.208 | 1.760 | 0.730 | 4.246 |
| Monthly income (high vs. no income*) | 0.290 | 0.503 | 1.337 | 0.572 | 3.124 |
| Education level (Secondary vs. primary*) | −0.990 | 0.426 | 0.371 | 0.032 | 4.258 |
| Education level (University vs. primary*) | −1.682 | 0.136 | 0.186 | 0.020 | 1.694 |
| Financial status (Average vs. poor*) | −0.132 | 0.657 | 0.876 | 0.488 | 1.571 |
| Financial status (Rich vs. poor*) | 0.357 | 0.770 | 1.429 | 0.131 | 15.540 |
| Employment status (employed vs. unemployed*) | 0.059 | 0.819 | 1.061 | 0.640 | 1.759 |

*Variables entered in the model: fear of poverty, Household crowding index, Financial wellbeing scale, monthly income, education level, employment status and financial status. The * symbol indicates the reference groups.*

determined the regression coefficient for the effect of financial wellbeing on food security. Pathway B examined the association of food security with PCS-SF12 and MCS-SF12, and pathway C estimated the total and direct effect of the financial wellbeing scale on QOL (MCS and PCS) (**Figure 1**). The macro generated bias-corrected bootstrapped 95% confidence intervals (CI) to test the significance of the indirect effect. Mediation was significant when the CI around the indirect effect did not include zero. The covariates that were included in the mediation model were those that showed significant associations with the PCS and MCS scales in the bivariate analysis. A $p$-value $< 0.05$ was considered statistically significant.

# RESULTS

## Sample Characteristics

**Table 1** shows the sociodemographic and other characteristics of the participants. Slightly less than half of the study participants (47.3%, $n = 176$) reported being food insecure with 31% ($n = 128$) experiencing mild food insecurity, 10% ($n = 41$) moderate food insecurity, and 1.5% ($n = 6$) severe food insecurity.

The mean age of the participants was 33.80 ± 12.02 years; the majority of the participants were females (77.7%) and with a university education level (93.0%). In addition, less than two-thirds of the survey respondents were employed (60.7%), 58.5% were single, and 50.2% reported a high monthly income (>2,000$). Most participants had their work as the source of income (93.0%), did not receive any aid neither from relatives (83.0%) nor from governmental or non-governmental institutions (95.4%). The majority had an average perceived financial status (76.2%), and 72.1% did not receive any aid in foreign currency. Almost all the participants did not report taking any medications for insomnia (91.3%), depression (93.4%), or anxiety (95.4%). The mean fear of poverty was 6.50 ± 2.73, the mean fear of COVID-19 was 14.91 ± 5.98, the mean household crowding index was 1.00 ± 0.48, and the mean financial status was 4.31 ± 2.12.

## Bivariate Analysis

A significantly higher proportion of food-secure participants had a high income (58.5 vs. 39.2%, $p < 0.001$), a university education level (96.6 vs. 88.1%, $p = 0.002$), and an average to rich perceived financial status (86 vs. 66.5%) as compared to those who were food insecure. Those who took medications for insomnia, depression, or anxiety were food insecure as compared to their food secure counterparts. Moreover, a significantly higher mean of fear of poverty, fear of COVID-19, and household crowding index was found in food-insecure vs. food-secure participants. However, a significantly higher financial wellbeing score was found among those who were food secure as compared to food insecure (5.14 vs. 3.19, $p < 0.001$) (**Table 1**).

**Table 2** shows the bivariate analysis taking the two components of quality of life (PCS-SF12 and MCS-SF12) as the dependent variables. The results showed a significantly higher mean of physical QOL (PCS-SF12) among those who were food secure, had a university education level, and consumed alcohol.

A significantly higher mean of mental quality of life (MCS-SF12) was found among those who were food secure, wealthy, had a high income, and did not take any medications for anxiety. In addition, a significantly higher mean of financial wellbeing was associated with higher mental QOL, whereas higher fear of poverty and higher fear of COVID-19 were significantly associated with lower mental QOL.

**TABLE 4 |** Multivariable analysis exploring associations between food insecurity, financial wellbeing sociodemographic and economic characteristics of study participants with their quality of life parameters [SF-12 components (PCS-SF12 and MCS-SF12)].

| | PCS-SF12 total scale | | | MCS-SF12 total scale | | |
|---|---|---|---|---|---|---|
| | UB (95% CI) | SB | *p*-value | UB (95% CI) | SB | *p*-value |
| **Model 1** † | | | | | | |
| Gender | −0.28 (−2.14; 1.56) | −0.01 | 0.759 | −1.25 (−3.79; 1.28) | −0.05 | 0.332 |
| Age | −0.06 (−0.13; 0.01) | −0.10 | 0.076 | 0.03 (−0.06; 0.13) | 0.04 | 0.481 |
| Household crowding index | −2.07 (−3.77;−0.37) | −0.14 | 0.017 | −0.42 (−2.75; 1.90) | −0.02 | 0.721 |
| Education level (secondary vs. primary*) | −9.76 (−17.23;−2.28) | −0.28 | 0.011 | 5.89 (−4.32; 16.11) | 0.12 | 0.258 |
| Education level (university vs. primary*) | −5.49 (−12.15; 1.16) | −0.18 | 0.106 | 1.01 (−8.09; 10.12) | 0.02 | 0.826 |
| Financial status (Average vs. poor*) | 1.20 (−0.81; 3.21) | 0.07 | 0.242 | 2.80 (0.05; 5.56) | 0.12 | 0.046 |
| Financial status (Rich vs. poor*) | −1.01 (−7.17; 5.14) | −0.02 | 0.745 | 9.34 (0.91; 17.76) | 0.12 | 0.030 |
| Fear of poverty | −0.04 (−0.32; 0.23) | −0.02 | 0.753 | −0.72 (−1.09;−0.33) | −0.22 | <0.001 |
| Monthly income (low vs. no income*) | −0.02 (−3.17; 3.13) | −0.01 | 0.989 | −2.64 (−6.96; 1.67) | −0.09 | 0.229 |
| Monthly income (intermediate vs. no income*) | 2.54 (−0.30; 5.38) | 0.16 | 0.080 | −3.51 (−7.40; 0.37) | −0.16 | 0.076 |
| Monthly income (high vs. no income*) | 2.33 (−0.18; 4.84) | 0.17 | 0.069 | −2.09 (−5.53; 1.34) | −0.11 | 0.231 |
| **Model 2** † | | | | | | |
| Food insecurity vs. food security* | −1.48 (−3.10; 0.13) | −0.10 | 0.072 | −1.46 (−3.68; 0.75) | −0.07 | 0.195 |
| Gender | −0.31 (−2.16; 1.53) | −0.02 | 0.738 | −1.27 (−3.81; 1.25) | −0.05 | 0.322 |
| Age | −0.06 (−0.13; 0.01) | −0.10 | 0.092 | 0.04 (−0.06; 0.14) | 0.05 | 0.440 |
| Household crowding index | −1.99 (−3.68;−0.29) | −0.13 | 0.022 | −0.34 (−2.67; 1.98) | −0.02 | 0.771 |
| Education level (secondary vs. primary*) | −9.78 (−17.23;−2.34) | −0.28 | 0.010 | 5.86 (−4.34; 16.06) | 0.12 | 0.259 |
| Education level (university vs. primary*) | −5.65 (−12.29; 0.97) | −0.19 | 0.094 | 0.85 (−8.25; 9.95) | 0.02 | 0.854 |
| Financial status (Average vs. poor*) | 0.97 (−1.05; 2.99) | 0.06 | 0.346 | 2.57 (−0.19; 5.35) | 0.11 | 0.069 |
| Financial status (Rich vs. poor*) | −1.54 (−7.70; 4.62) | −0.03 | 0.622 | 8.82 (0.37; 17.27) | 0.12 | 0.041 |
| Fear of poverty | 0.01 (−0.27; 0.29) | 0.01 | 0.928 | −0.66 (−1.05;−0.27) | −0.20 | 0.001 |
| Monthly income (low vs. no income*) | 0.19 (−2.96; 3.34) | 0.01 | 0.905 | −2.43 (−6.76; 1.89) | −0.09 | 0.269 |
| Monthly income (intermediate vs. no income*) | 2.67 (−0.16; 5.51) | 0.17 | 0.064 | −3.38 (−7.27; 0.50) | −0.15 | 0.088 |
| Monthly income (high vs. no income*) | 2.38 (−0.11; 4.89) | 0.18 | 0.062 | −2.04 (−5.47; 1.39) | −0.11 | 0.243 |
| **Model 3**† | | | | | | |
| Gender | 0.05 (−1.94; 2.05) | 0.003 | 0.958 | −2.79 (−5.37;−0.22) | −0.12 | 0.034 |
| Age | −0.06 (−0.13; 0.02) | −0.10 | 0.120 | 0.10 (0.01; 0.20) | 0.13 | 0.028 |
| Household crowding index | −1.80 (−3.53;−0.07) | −0.12 | 0.041 | −0.26 (−2.49; 1.97) | −0.01 | 0.819 |
| Education level (secondary vs. primary*) | −9.88 (−17.37;−2.38) | −0.28 | 0.010 | 5.03 (−4.62; 14.69) | 0.11 | 0.306 |
| Education level (university vs. primary*) | −5.79 (−12.47; 0.88) | −0.19 | 0.089 | 1.05 (−7.56; 9.66) | 0.02 | 0.810 |
| Financial status (Average vs. poor*) | 1.14 (−0.92; 3.22) | 0.07 | 0.277 | 0.90 (−1.76; 3.57) | 0.04 | 0.506 |
| Financial status (Rich vs. poor*) | −1.30 (−7.61; 5.00) | −0.02 | 0.685 | 6.51 (−1.62; 14.64) | 0.09 | 0.116 |
| Fear of poverty | −0.05 (−0.40; 0.29) | −0.02 | 0.777 | 0.05 (−0.39; 0.50) | 0.02 | 0.798 |
| Monthly income (low vs. no income*) | 0.07 (−3.12; 3.28) | 0.004 | 0.961 | −0.65 (−4.79; 3.47) | −0.02 | 0.754 |
| Monthly income (intermediate vs. no income*) | 2.50 (−0.36; 5.38) | 0.16 | 0.087 | −2.36 (−6.07; 1.34) | −0.11 | 0.210 |
| Monthly income (high vs. no income*) | 2.25 (−0.26; 4.77) | 0.17 | 0.080 | −1.72 (−4.97; 1.53) | −0.09 | 0.299 |
| Food insecurity vs. food security* | −1.52 (−3.22; 0.17) | −0.11 | 0.078 | 0.21 (−1.97; 2.39) | 0.01 | 0.851 |
| Financial wellbeing scale (IFDFW) | −0.15 (−0.68; 0.37) | −0.05 | 0.574 | 1.63 (0.94; 2.31) | 0.36 | <0.001 |
| Fear of COVID-19 | −0.03 (−0.16; 0.09) | −0.03 | 0.603 | −0.21 (−0.37;−0.04) | −0.14 | 0.012 |
| Alcohol consumption | −0.86 (−2.33; 0.60) | −0.07 | 0.247 | 0.75 (−1.14; 2.64) | 0.04 | 0.435 |
| Smoking status (smoker vs. non-smoker*) | −0.29 (−1.70; 1.11) | −0.03 | 0.682 | 2.82 (1.00; 4.64) | 0.18 | 0.002 |

*Variables entered in model 1: Gender, age, household crowding index, education level, financial status, fear of poverty, monthly income and household crowding index. Variables entered in model 2: Gender, age, household crowding index, education level, financial status, fear of poverty, monthly income and household crowding index and food insecurity. Variables entered in model 3: Gender, age, household crowding index, education level, financial status, fear of poverty, monthly income, household crowding index, food insecurity, financial wellbeing, fear of COVID-19, alcohol consumption and smoking status.*

†*Model 1 explores the relationship between sociodemographic variables and quality of life (QOL) parameters (PCS-SF12 and MCS-SF12).*

†*Model 2 explores the relationship between food security variable with QOL parameters, adjusting for sociodemographic variables, including Gender, age, household crowding index, education level, financial status, fear of poverty, monthly income and household crowding index.*

†*Model 3 explores the relationship between food security, lifestyle variables and financial wellbeing with QOL parameters adjusting for sociodemographic variables (Gender, age, household crowding index, education level, financial status, fear of poverty, monthly income and household crowding index) and fear of COVID-19. UB, Unstandardized adjusted regression coefficients; SB, Standardized adjusted regression coefficients. All results in the models were presented as adjusted beta-coefficients with 95%CI.* *Reference group.

**TABLE 5 |** Mediation analyses.

| **Model 1: taking the financial wellbeing as independent variables, food insecurity as mediators and PCS-SF12 as the dependent variable.** | | | | | | |
|---|---|---|---|---|---|---|
| | **Direct effect** | | | **Indirect effect** | | |
| | **Beta** | **SE** | ***p-value*** | **Beta** | **Boot SE** | **Boot CI** |
| Financial wellbeing scale (IFDFW) on PCS-SF12 | −0.14 | 0.26 | 0.575 | 0.19 | 0.08 | 0.02; 0.36* |
| **Model 2: taking the financial wellbeing as independent variables, food insecurity as mediators as mediators and MCS-SF12 as the dependent variable.** | | | | | | |
| | **Direct effect** | | | **Indirect effect** | | |
| | **Beta** | **SE** | ***p-value*** | **Beta** | **Boot SE** | **Boot CI** |
| Financial wellbeing scale (IFDFW) on MCS-SF12 | 1.80 | 0.34 | <0.001 | −0.02 | 0.08 | −0.20; 0.14 |

*Indicates significant mediation.

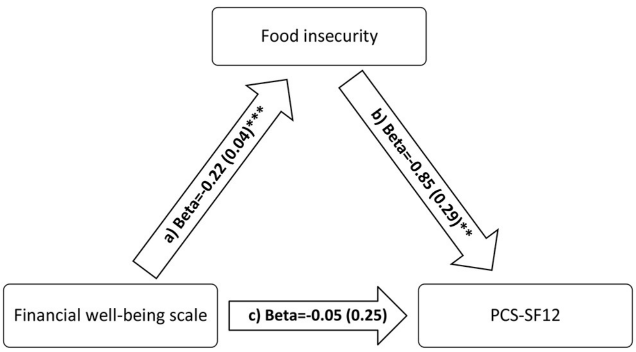


**FIGURE 2 |** a) Relation between financial wellbeing scale and food insecurity ($R^2$ = 19.16%); b) Relation between food insecurity and PCS-SF12 ($R^2$ = 5.68%); c) Relation between financial wellbeing and PCS-SF12 ($R^2$ = 3.01%). Numbers are displayed as regression coefficients (standard error). ** $p < 0.01$; *** $p < 0.001$.

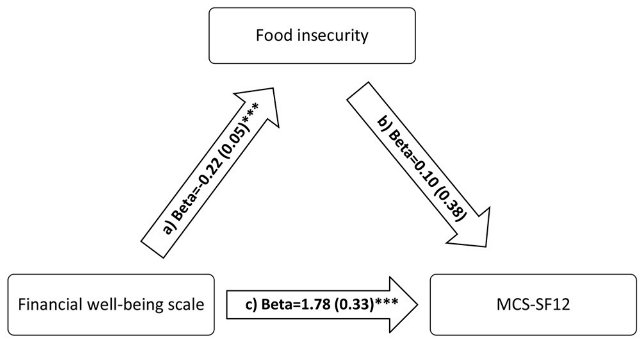


**FIGURE 3 |** a) Relation between financial wellbeing scale and food insecurity ($R^2$ = 19.16%); b) Relation between food insecurity and MCS-SF12 ($R^2$ = 16.57%); c) Relation between financial wellbeing and MCS-SF12 ($R^2$ = 16.55%). Numbers are displayed as regression coefficients (standard error). *** $p < 0.001$.

## Multivariable Analysis

The logistic regression model, taking the food security as the dependent variable, showed that participants with high financial wellbeing were less food insecure (ORa = 0.60; 95%CI: 0.51; 0.71). The fear of poverty, household crowding index, monthly income, education level, employment status and perceived financial status were not related to food security ($p > 0.05$ for all) (**Table 3**).

Two major linear regression models were performed, taking the components of QOL as the dependent variables.

When taking the physical QOL (PCS-SF12) as the dependent variable the results showed that in the first model, taking the sociodemographic characteristics as the independent variables, a higher household crowding index (Beta = −2.07, 95%CI: −3.77; −0.37) and a secondary level of education (Beta = −9.76, 95% CI: −17.23; −2.28) were significantly associated with a lower physical quality of life (lower PCS-SF12) (**Table 4**, Model 1). When adding the food security variable to the models, the results showed that food insecurity tended to significance with physical quality of life (Beta = −1.48, 95% CI: −3.10; 0.13). In the third model, the financial wellbeing and lifestyle variables were added; the results showed that higher household crowding index (Beta = −1.80, 95% CI: −3.53; −0.07) and secondary education level (Beta = -9.88, 95% CI: −17.37; −2.38) were related to a lower physical QOL. However, financial wellbeing and lifestyle variables were not significant ($p > 0.05$ for all) (**Table 4**, model 3).

When considering the mental quality of life as the dependent variable, the results in the first model showed that an average (Beta = 2.80, 95% CI: 0.05; 5.56) and rich (Beta = 9.34, 95% CI: 0.91; 17.76) financial status were associated with higher mental QOL. However, higher fear of poverty (Beta = −0.72, 95% CI: −1.09; −0.33) was associated with lower mental QOL. When adding the food security variable to the second model, the results showed no significant association between food insecurity and mental QOL (Beta = − 1.46, 95% CI: −3.68; 0.75). In the third model, by adding the financial wellbeing and lifestyle variables; the results showed that higher financial wellbeing (Beta = 1.63, 95% CI: 0.94; 2.31), higher age (Beta = 0.10, 95% CI: 0.01; 0.20) and being a smoker (Beta = 2.82, 95% CI: 1.00; 4.64) were related to a higher mental QOL. However, higher fear of COVID-19 (Beta = −0.21; 95% CI: −0.37; −0.04) was significantly associated with lower mental QOL (**Table 4**, model 3).

## Mediation Analysis

The FI variable mediated the association between financial wellbeing and physical QOL (**Table 5**; **Figure 2**) but not mental QOL (**Table 5**; **Figure 3**).

## DISCUSSION

To the best of our knowledge, this study is the first to explore the relationship between food insecurity, financial wellbeing, and quality of life parameters in Lebanon. It is known that financial constraint is related to FI (22) and is an indicator of the quality of life and wellbeing (23). In turn, FI was found in literature to be related to poor mental (13, 14) and physical health (11, 12). However, there is an absence of a similar framework, exploring the relationships between these factors (financial wellbeing, FI and QOL) in the literature.

Results showed that about 43% of study participants were experiencing FI, with 31% being mildly food insecure, 10% moderately food insecure, and 1.5% severely food insecure. The prevalence of FI in the present study was slightly lower than that in a previous study conducted in Lebanon from nationally representative samples of 1,133 Lebanese participants, where 53% of the Lebanese households had a poor food consumption score (19). In 2019, a study found that food insecurity was 49.3% among Lebanese children aged 4–18 years (30), while data from 2014 reported a prevalence of 42% among vulnerable Lebanese and Palestinian refugees in South Lebanon (31), higher than FI rates collected by the Gallup World Poll data in Lebanon between 2015 and 2017 showing that 11.7–15.3% of the Lebanese households experienced some form of FI (21). The alarming FI rates reported in our study were also in line with recently published data from humanitarian and international agencies (32–34) working closely with the Lebanese and refugee populations in the country, showcasing the catastrophic effect of the multiple crises that Lebanon has been undergoing since 2019 ranking it among the top three crises since mid-nineteenth century worldwide (3). In parallel, the country has undergone an unprecedented financial collapse with a devaluation in the currency value (plummeting from 1 USD/1500 LBP conversion rate to 1 USD/25,000 LBP rate). Moreover, banks tightened limits on foreign currency, cash withdrawals from individual accounts were stopped, and a limit was set on local currency. Consequently, the price of the basic food basket has increased to reach 483% in January 2022 (4), further exacerbating the food security status of the Lebanese households.

Consistent with the literature, study findings showed that food security was significantly associated with higher income, a university education level, a lower crowding index, and higher financial wellbeing. Previous studies conducted in Lebanon revealed that low levels of education, unemployment, low income, and higher crowding were significant correlates of household FI (30, 35). A study has found that higher education level affects food security after controlling for the household wealth index (36). Financial and economic crises have also been shown to have the highest impact on the food security status in developing countries (37), with economic status correlating directly with FI (38).

Bivariate analyses showed that food-secure individuals had significantly higher physical and mental QOL scores compared to their food insecure counterparts. FI was significantly higher among those who take medications for insomnia, depression, or anxiety, and food-insecure participants had a significantly higher mean of fear of poverty and fear of COVID-19. Those results are aligned with what has been found in the literature, and the effect of FI on mental health is elicited through deep psychological stress due to the negative psychological and behavioral experiences leading to mental health problems among youth and adults and can be associated with depressive symptoms among those struggling with FI (39–42). FI is also related to poor general physical health (11, 12), where people from food-insecure households perceived their health as poor/fair and scored lower on the physical and mental health components of the SF-12 (43). Food security was associated with better health-related quality of life in several studies conducted among children and adults (44, 45).

Multivariate analyses showed that FI was not significantly associated with lower physical and mental QOL after adjusting for demographic and socioeconomic correlates and the financial wellbeing variable. One of the challenges in isolating the influence of FI on mental health is addressing the effect of financial resources on both mental health and FI (38). For this reason, the mediation analysis was conducted, and the results showed that FI may have mediated the association between financial wellbeing and physical, but not mental QOL. Thus, financial wellness had a direct effect on the mental QOL in Lebanon (away from the path of FI), while its effect on physical QOL is indirect and mediated, at least partially, through FI. In other words, people with a low mental QOL are directly affected by financial constraints and may seem more worried about their overall situation, away from immediate food security concerns. Oppositely, people with lower physical QOL seem to be directly affected by food insecurity, related itself to financial wellness. The direct relationship between FI and physical QOL can be explained by the physiological and biological mechanisms related to feelings of hunger and deprivation that can affect the different physical health domains, including physical functioning, bodily pain, general health, and vitality (42, 46). In addition, the limited or uncertain access to adequate food due to financial limitations can affect the physical QOL by not meeting the nutritional requirements for energy (total calories) from macronutrients, including proteins, carbohydrates, and fats, along with poor intake of essential vitamins and minerals, which may, in turn, affect the general physical health.

In this study, financial wellness was shown to have a direct effect on mental QOL, independent of the FI pathway. A probable explanation could be the direct relationship between financial wellbeing and reduced stress and anxiety levels due to feelings of job security, thus leading to better general mental health and wellbeing (16). Higher financial resources and capabilities can also be associated with the increased ability to access psychosocial and mental health services (MPHSS) (47), which may further explain the positive and strong association between increased financial wellbeing and higher scores on the mental QOL measure in this study, irrespective of the food security status. Nevertheless, further studies are needed to elucidate the associations found between FI, financial wellbeing, and various measures of QOL and wellbeing, particularly in conflict-affected and crisis settings.

Worth noting that the Lebanese have been struggling with compromised mental health due to the long-term effect of exposure to wars, ongoing turmoil, added to social, political, and environmental stressors, including the most recent COVID-19 pandemic and the tragic Beirut port blast, which have taken a toll on the mental and physical health status of the Lebanese population (48–50). Other challenges that may adversely impact the overall mental health and wellbeing of the Lebanese are the persistent social stigmas and cultural taboos related to mental health problems, thus preventing individuals who are in need from seeking access to existing MHPSS services (51). In the past 2 years, the limited financial capacity of the Lebanese population, insufficient subsidies, and the shortage of essential goods and services, including medications, have rendered access to any of these services even further problematic. Moreover, the Lebanese healthcare system has been strained by years of underfunding and ever-increasing demands for serving the Lebanese residents and the high numbers of refugees in the country, including Syrian, Iraqi, and Palestinians (52). All these factors highlight the need for further studies and interventions that tackle the multiple dimensions of health and wellbeing and the gravity of the current situation.

### Strengths and Limitations

To our knowledge, this study is the first to explore the mediating effect of food insecurity on the association between financial wellbeing and QOL. Other strengths of the study include the rigorous methodology through the use of several validated tools. Nevertheless, several limitations should be considered. Causality cannot be established between financial wellbeing, FI, and QOL measures due to the cross-sectional design of the study. The online survey used for data collection might have limited the ability to reach individuals who may be the most vulnerable to FI, and thus results may not be generalizable to the entire Lebanese population. Future studies are necessary to further explore the associations between FI, financial wellbeing, and QOL parameters.

## CONCLUSION

Food insecurity was prevalent in our study sample. Food-insecure participants reported greater fear of poverty, fear of COVID-19, and FI repercussions on their health and lives.

FI also mediated the association between financial wellbeing and physical, but not mental, QOL parameters. These associations require further exploration in future studies and programs. Our study findings also call for evidence-based policies and interventions to help improve the food security, mental health and overall wellbeing of Lebanese households amidst these unprecedented circumstances.

## DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Modern University of Business and Science Ethics Committee (approval reference MU-20211005-26, Oct 2021). The patients/participants provided their written informed consent to participate in this study.

## AUTHOR CONTRIBUTIONS

JK and PS conceptualized the research design. LJ, HS, and MS provided support in designing the study. JK sought after ethics approval. PS and CH conducted data analysis. JK and CH wrote the original draft of the manuscript. PS, LJ, HS, and MS critically reviewed the manuscript. HS reviewed and edited the manuscript. All authors contributed in the spread of the survey and read and agreed to the published version of the manuscript.

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# Anthropometric indices and cut-off points for screening of metabolic syndrome among South African taxi drivers

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**Background:** Detecting the early onset of metabolic syndrome (MetS) allows for quick intervention which may slow progression to a variety of health consequences, hence, determining the best measurement to detect MetS is essential.

**Aim:** This research aimed at examining the MetS predictive power of anthropometric indices, such as body mass index (BMI), waist circumference (WC), waist-to-height ratio (WHtR), body shape index (ABSI), body roundness index (BRI), percentage body fat (%BF), conicity index (CI), and Clínica Universidad de Navarra-body adiposity estimator (CUN-BAE) to determine the cut-off points to identify male South African taxi drivers with MetS.

**Method:** A cross-sectional study was conducted among 185 male taxi drivers. Their weight, height, WC, blood lipid profile were measured. International Diabetes Federation (IDF) definition was used to define MetS. Receiver Operating Characteristic (ROC) curves were used to compare the predictive ability of Anthropometric indices to detect MetS.

**Results:** The mean age of the participants was 39.84 years. Overall, 41.6% ($N = 77$) of the participants presented with MetS. The mean values for BMI, WC, WHtR, %BF, BRI, CUN-BAE, ABSI and CI were 28.60 ± 6.20 kg/m$^2$, 99.13 ± 17.59 cm, 0.58 ± 0.10, 27.28 ± 8.28%, 5.09 ± 2.33, 27.78 ± 8.34, 0.08 ± 0.01 and 1.70 ± 0.19, respectively. The mean values for these indices were significantly ($p < 0.001$) higher in participants with MetS. The highest area under the curve (AUC) outcomes for screening MetS were for the %BF and CUN-BAE, followed by the BMI and WHtR, and lastly the BRI. All these anthropometric indices had outstanding discriminatory powers for predicting MetS with AUCs and sensitivity values above 80%. The BMI, WHtR, %BF, BRI, and CUN-BAE, had cut-off points for detection of metS in South African men at 28.25 kg/m$^2$, 0.55, 25.29%, 4.55, and 27.10, respectively. Based on the logistic regression models abnormal BMI, WHtR, %BF, BRI, CUN-BAE, TG, FBG, systolic BP, diastolic BP and WC showed increased risk of MetS.

**Conclusion:** While the %BF, CUN-BAE, BMI, WC, WHtR, BRI, CI and CUN-BAE could predict MetS among South African male taxi drivers, these indices were less effective in predicting the individual MetS risk factors such as TG, BP, and FBG.

KEYWORDS

**metabolic syndrome, anthropometric indices, a body shape index (ABSI), body roundness index (BRI), waist circumference, body mass index (BMI), waist-to-height ratio (WHtR), receiver operating characteristic curve**

## Introduction

Metabolic syndrome (MetS) is a cluster of multiple, interconnected metabolic risk factors that promote the development of non-communication diseases (NCDs) such as diabetes, abdominal obesity, high cholesterol, low high-density lipoprotein cholesterol (HDL-c), and high blood pressure (1). Several international studies report an increased prevalence of MetS among occupational drivers when compared to other professionals such as industrial and office workers (2–4). International evidence further suggests that occupational drivers are at increased risk of cardiovascular diseases (5, 6). In South Africa there is dearth of data on the prevalence of MetS among occupational drivers and more specifically minibus taxi drivers (hereafter referred to as taxi drivers). Ramukumba and Mathikhi (7) state that taxi drivers' working environment is characterized by poor eating habits, elevated stress levels caused by long hours of driving, exposure to various environmental hazards such as air pollution as well as a lack of exercise. Their poor eating habits are aggravated by regular consumption of fried foods and snacks high in sugar and salt since these foods are relatively cheap and easily accessible at taxi ranks and bus stations where they operate (8, 9). Additionally, a recent study in Cape Town reported a notable prevalence of central obesity among taxi drivers as they overconsume alcohol and smoke to overcome stress (10).

Metabolic syndrome is regarded as a public health issue that is associated with the clustering of a wide variety of risk factors that co-exist in an individual (11, 12). The World Health Organization (13), the European Group for the Study of Insulin Resistance (EGIR) (14), the National Cholesterol Education Program Adult Treatment Panel III (15), the American Association of Clinical Endocrinology (AACE) (16, 17), International Diabetes Federation (IDF) (18) and American Heart Association/National Heart, Lung, and Blood Institute (AHA/NHLBI) (19) use different algorithms to determine MetS. These algorithms are based on the risk factors considered to be clinically realistic assessment measures for MetS for the specific populations that are under study (20). In general, any MetS algorithm includes a combination of three or more risk factors, namely: body mass index (BMI), central obesity, insulin resistance, glucose intolerance and diabetes, elevated triglycerides (TG), low levels of HDL-c, and hypertension.

In rural South Africa, the MetS prevalence in men ranges from 7.9 to 17.9% of which 7.9 and 10.5% was reported by Motala et al. (21) and Motala et al. (22), respectively among individuals aged >15 years, in a rural African (black) community of Zulu descent in the Ubombo district of the province of KwaZulu-Natal. Peer et al. (23) on the other hand reported a 17.9% prevalence among black men living in Cape Town, while Sekgala et al. (24) reported it to be 8.6% in young black South African men aged 18–30 years living in Limpopo, a rural province of South Africa.

Obesity and overweight are two important risk factors for MetS (25). According to Suliga et al. (26) and Kabała and Wilczyński (27), the BMI is the most common metric for determining obesity as it is simple to calculate and has well-defined cut-off points. This index is utilized in research all around the world as it is non-invasive. This makes it the best index that allows for possible comparisons of nutritional statuses in different populations globally. However, its inability to portray sex dimorphism, including ethnic differences in adiposity, adipose tissue distribution, and age-related body composition limits the BMI for measuring MetS in different populations (28). Hence, researchers prefer to use anthropometrical measures that show adipose tissue distribution, differentiate central or abdominal obesity when classifying MetS, WC and percentage body fat (%BF), to be specific.

There is limited data on the central obesity status of South African men in the taxi driving industry. This is despite the substantiated international evidence (4, 29) suggesting that 50% of male occupational drivers display significantly higher depositions of visceral adipose tissue compared to the general male population. Visceral adipose tissue (also known as central/abdominal obesity) is a hormonally active component of total body fat, which possesses unique biochemical characteristics that influence several pathological

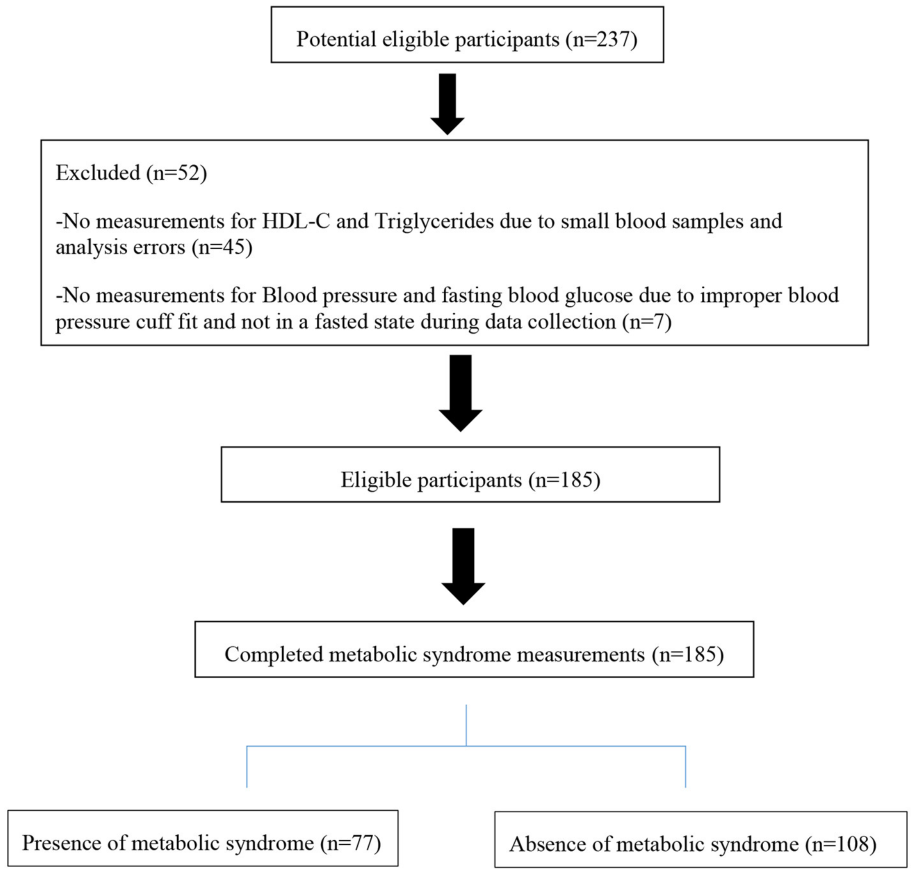


FIGURE 1
Flow diagram of participants' selection for this study.

processes in the human body (30) including the development of non-communicable diseases (NCDs) (31).

The deposition of visceral adipose tissue is measured using both invasive (32) and non-invasive anthropometrical measurements (33). Among the most common, non-invasive, and acceptable anthropometrical measurements undertaken to measure central/abdominal obesity and adipose tissue composition are the WC (34) and the %BF (35). Aside from using solely the WC to determine abdominal obesity, researchers often apply WC in the algorithms to measure its relationship with height (WHtR) (34, 36), as well as the BMI to measure the conicity index (CI) (37), body roundness index (BRI) (36) and a body shape index (ABSI) (38). International studies further suggest that the results of central obesity assessments measured by WC show the strongest connections with metabolic risk variables (39, 40).

There are four skin fold measurements (biceps, triceps, subscapular and suprailiac) that are commonly used in clinical interventions to measure %BF which, according to Rodriguez-Escudero et al. (35) is a good indicator for body composition. Aside from using solely the skinfold measurements to measure %BF, the Clínica Universidad de Navarra-Body Adiposity Estimator (CUN-BAE) is a measure that applies the outcome of %BF to an algorithm that compares it to the individual's BMI (28). The CUN-BAE is based on the BMI, but it has the added benefit of accounting for age and gender body composition differences, hence it is regarded as the best index for determining the %BF. The CUN-BAE has also been significantly associated with the actual adipose tissue composition (28) and is therefore a useful tool for identifying the risk of MetS.

Even though multiple articles on the link between adiposity and the risk of MetS have been published, it is still difficult to determine unambiguously the best measure to be applied in an algorithm to identify individuals with MetS, especially in South Africa. To our knowledge, there has never been a study conducted in South Africa to assess the ability of different anthropometric indices to detect MetS, as well as determine their cut-off point to screen for MetS among male taxi drivers. Hence, the current study was long overdue. This study aimed to examine the MetS predictive power of anthropometric indices such as the BMI, WC, WHtR, ABSI, BRI, %BF, CI, and CUN-BAE, and determine the cut-off points to identify male South African taxi drivers at risk of MetS. The outcomes of this research will inform policies directed at improving the health status of South African taxi drivers.

# Materials and methods

## Study design

This cross-sectional study was conducted among 185 conveniently sampled commercial taxi drivers aged 20 years and older who were recruited from the Bellville and Cape Town taxi ranks. These taxi ranks were chosen because they are the two busiest transport interchange areas in the Cape metropole area in the Western Cape Province of South Africa (8).

## Study participants and sample size

All taxi drivers who were available, willing to participate and those who met the inclusion criteria were included in the study. Eligible participants had to be 20 years and older, fluent in English and/or Afrikaans and/or IsiXhosa (the most spoken languages in Cape Town and surrounding areas), able to provide informed consent, and willing to donate a blood sample for metabolic assessments. Taxi drivers who have at least 1-year experience as a driver around the targeted interchange areas in the Western Cape Province and also being a members of a recognized taxi association. Only men were included in the study given that more than 99% of taxi drivers operating in these transport interchange areas were men. Participants who were on any form of chronic medication and/or with chronic diseases history were excluded.

Since no similar studies on MetS prevalence among taxi drivers in Cape Town could be located and the fact that the proposed study focused on taxi drivers (>80% black men), the sample size was based on the findings of Peer et al. (23) who indicated a 17.9% MetS prevalence among black men in Cape Town. As such, the sample size was obtained using the formula by Daniel and Cross (41) for cross-sectional studies.

$$\text{Sample Size (N)}: \; Z^{2*}\,(p)^*\,(1-p)/c^2$$

Where: $Z = Z$ value (e.g., 1.96 for 95% confidence level); $p$ = expected proportion of the population, expressed as decimal=0.179; $c$ = confidence interval, expressed as decimal = 0.05.

Therefore, the estimated sample size was $N = 226$ and after adjusting for 5% non-response the sample size increased to $N = 237$.

Of the 237 participants who agreed to participate, only 185 agreed to complete all the measurements and donate blood specimens for the metabolic parameters (see Figure 1).

## Socio-demographic data

Socio-demographic data and information on the participants' lifestyles (duration of sleep, physical activity, alcohol consumption and cigarette smoking) were collected *via* face-to-face interviews using a structured and previously validated questionnaire (30). Collected socio-demographic variables included age, socio-economic status (defined based on the household income, marital status, and education level).

## Measurements

### Anthropometric indicators

Weight, height and WC were measured to calculate the anthropometric indices using standard procedures (42). All measurements were conducted by a qualified dietitian, with the help of qualified and trained field nurses.

Skinfold thickness was measured on both sides of the body using a Lange Skinfold Caliper at four locations: biceps, triceps, subscapular, and suprailiac. The biceps skinfold thickness was measured at the midpoint of the arm while the individual sat in a supine position with arms relaxed and resting on the thighs. Triceps skinfold thickness was measured in the sitting position with arms crossed at a 90° bend and resting on thighs at the midpoint between the acromion and the olecranon process. The subscapular skinfold was measured while standing with arms to the side. The shoulder blade was located and followed down to the point where it began to curve. The skin was pinched and the calipers were used to measure the skinfold. Still in the standing position the suprailiac skinfold was also measured. The skin above the right hipbone was measured along the midaxillary line (43).

Waist circumference was measured in cm above the iliac crest and below the lowest rib margin at minimum respiration by the use of a non-stretch tape measure (44). Height was measured in meters to the nearest cm using a SECA stadiometer with a right-angle headboard wide enough to rest across the top of the head. The participants were measured without shoes and standing up-right, feet together, knees straight, and heels, buttocks, and shoulder blades in contact with the stadiometer (45). Weight was measured to the closest hundredth of a gram using an electronic scale that was calibrated before use with a total calibration weight of 200 kg. Weight was measured while the participants were standing in the center of the scale and looking straight ahead with minimal clothing (46).

Based on the afore-mentioned measurements, the following indicators were calculated:

a. BMI = weight (kg) / height$^2$ (m$^2$): <18 kg/m$^2$, 18–24.9 kg/m$^2$, 25–29.9 kg/m$^2$, and $\geq$ 30 kg/m$^2$ considered as underweight, normal weight, overweight and obese, respectively (38).

TABLE 1 Sociodemographic and anthropometric characteristics by the presence/absence of MetS among the taxi drivers in Western Cape, South Africa.

| | Total $N = 185$ mean ± SD | MetS present $n = 77$ mean ± SD | MetS absent $n = 108$ mean ± SD | *P*-value |
|---|---|---|---|---|
| Age (years) | 39.84 ± 10.46 | 43.73 ± 10.34 | 37.27 ± 10.21 | <0.001 |
| Race *n* (%) | | | | 0.932 |
| Black | 146 (78.9) | 33 (42.9) | 85 (78.7) | |
| Non-black | 39 (21.1) | 44 (57.1) | 23 (21.3) | |
| Merital status *n* (%) | | | | 0.279 |
| Single, divorced, separated or widowed | 88 (47.3) | 33 (42.9) | 55 (50.9) | |
| Married, or living as married | 97 (52.7) | 44 (57.1) | 53 (49.1) | |
| Driving experience (years) *n* (%) | | | | <0.001 |
| 1–7 | 103 (55.7) | 31 (40.3) | 72 (66.7) | |
| 8> | 82 (44.3) | 46 (59.7) | 36 (33.3) | |
| Educational level *n* (%) | | | | 0.714 |
| No schooling or primary | 58 (31.4) | 23 (29.9) | 35 (32.4) | |
| Some high school and higher education | 127 (68.6) | 54 (70.1) | 73 (67.6) | |
| BMI (kg/m$^2$) | 28.60 ± 6.20 | 32.71 ± 5.88 | 25.65 ± 5.21 | <0.001 |
| WC (cm) | 99.13 ± 17.59 | 110.83 ± 16.72 | 90.72 ± 14.50 | <0.001 |
| WHtR | 0.58 ± 0.10 | 0.64 ± 0.09 | 0.53 ± 0.09 | <0.001 |
| Weight (kg) | 84.74 ± 19.67 | 97.35 ± 18.66 | 75.52 ± 16.41 | <0.001 |
| Height (cm) | 172.03 ± 7.93 | 172.59 ± 9.33 | 171.44 ± 7.23 | 0.387 |
| %BF | 27.28 ± 8.28 | 33.11 ± 7.63 | 23.16 ± 6.85 | <0.001 |
| ABSI | 0.0812 ± 0.0840 | 0.0829 ± 0.0901 | 0.0800 ± 0.00775 | <0.001 |
| BRI | 5.09 ± 2.33 | 6.68 ± 2.50 | 4.06 ± 1.81 | <0.001 |
| CUN-BAE | 27.78 ± 8.34 | 33.55 ± 6.61 | 23.53 ± 7.52 | <0.001 |
| CI | 1.70 ± 0.19 | 1.78 ± 0.21 | 1.65 ± 0.17 | <0.001 |
| Biceps | 10.66 ± 6.73 | 12.84 ± 6.06 | 8.53 ± 3.31 | <0.001 |
| Triceps | 17.41 ± 8.75 | 20.56 ± 9.53 | 14.95 ± 7.40 | <0.001 |
| Subscapular | 26.16 ± 13.58 | 32.14 ± 13.76 | 21.21 ± 10.87 | <0.001 |
| Suprailiac | 24.20 ± 13.08 | 29.40 ± 11.07 | 19.40 ± 10.90 | <0.001 |

BMI, Body Mass index; WC, Waist circumference; WHtR, waist-to-height Ratio; %B, percentage body fat; ABSI, a body shape index; BRI, body roundness index; CUN-BAE, Clínica Universidad de Navarra-Body Adiposity Estimator; CI, Conicity index; MetS, metabolic syndrome. The numerical values are presented as mean ± standard deviation and intergroup compared using the Mann-Whitney U test.

b. WHtR = WC (cm)/height (cm), The WHtR of > 0.5 was considered abnormal (47).
c. ABSI = WC (m)/[BMI$^{2/3}$(kg/m$^2$) * height$^{1/2}$ (m)] (38). The ABSI of >0.07 was considered abnormal.
d. CI = 0.109$^{-1}$ WC (m) [weight (kg)/height (m)]$^{-1/2}$. The CI of >1.25 was considered abnormal (37).
e. $BRI = 364.2 - 365.5\,x\sqrt{(1 - \frac{(\frac{WC}{2\pi})2}{(0.5Xheight\ )2})}$

BRI of >3.5 was considered abnormal (35).

f. %BF= (495/Body Density) - 450 (35). The %BF of >25.00 is considered abnormal (48). %BF was calculated based on the average skinfold thickness measurement from each of the four sites.
g. CUN-BAE was calculated using the equation %BF = -44.988 + (0.503 x age) + (10.689 x sex) + (3.172 x BMI) - (0.026 x BMI$^2$) + (0.181 x BMI x sex) - (0.02 x BMI x age) - (0.005 x BMI$^2$ x sex) + (0.00021 x BMI$^2$ x age), where age is measured in years, and sex was codified as 0 for men. A CUN-BAE of >20.00 is considered abnormal (28).

## Blood pressure and blood biochemical parameters

Blood pressure was measured using an Omron BP monitor (Model M3 Intellisense, Mannheim, Germany). Blood pressure was measured on the artery of the right upper limb when the individual was seated and rested at ground level. Following

TABLE 2 Mean non-communicable disease risk factors by the presence/absence of MetS.

| Risk factors of MetS | Total<br>mean ± SD | MetS present $n = 77$<br>mean ± SD | MetS absent $n = 108$<br>mean ± SD | Intergroup comparison $p$-value |
|---|---|---|---|---|
| Triglycerides (mmol/L) | 1.35 ± 1.12 | 1.88 ± 1.49 | 0.96 ± 0.45 | <0.001 |
| HDL-c (mmol/L) | 1.11 ± 0.34 | 1.00 ± 0.28 | 1.20 ± 0.36 | <0.001 |
| FBG (mmol/L) | 6.50 ± 3.44 | 7.87 ± 4.82 | 5.33 ± 1.13 | <0.001 |
| SBP (mmHg) | 133.44 ± 17.17 | 141.47 ± 18.79 | 127.40 ± 13.33 | <0.001 |
| DBP (mmHg) | 84.71 ± 13.08 | 92.73 ± 13.94 | 79.07 ± 9.12 | <0.001 |
| WC (cm) | 99.13 ± 17.59 | 110.83 ± 16.72 | 90.72 ± 14.50 | <0.001 |

HDL-c, high-density lipoprotein cholesterol; FBG, fasting blood glucose; SBP, systolic blood pressure; DBP, diastolic blood pressure; WC, waist circumference; MetS, metabolic syndrome. Values are reported as the mean ± standard deviation.

TABLE 3 Risk factors of MetS grouped by the presence and absence of MetS.

| Components of MetS | | Total<br>N (%) | MetS present $n = 77$<br>N (%) | MetS absent $n = 108$<br>N (%) | Intergroup comparison $p$-value |
|---|---|---|---|---|---|
| Triglycerides (mmol/L) | Normal | 152 (79.2) | 46 (59.7) | 101 (93.5) | <0.001 |
| | Abnormal | 40 (20.8) | 31 (40.3) | 7 (6.5) | |
| HDL-c (mmol/L) | Normal | 93 (48.4) | 19 (24.7) | 71 (65.7) | <0.001 |
| | Abnormal | 99 (51.6) | 58 (75.3) | 37 (34.3) | |
| FBG (mmol/L) | Normal | 111 (48.3) | 18 (23.4) | 75 (69.4) | <0.001 |
| | Abnormal | 119 (51.7) | 59 (76.6) | 33 (30.6) | |
| SBP (mmHg) | Normal | 93 (40.3) | 22 (28.6) | 55 (50.9) | 0.003 |
| | Abnormal | 138 (59.7) | 55 (71.4) | 53 (49.1) | |
| DBP (mmHg) | Normal | 131 (56.7) | 23 (29.9) | 82 (75.9) | <0.001 |
| | Abnormal | 100 (43.3) | 54 (70.1) | 24.1 (26.0) | |
| Hypertension | Normal | 149 (64.5) | 28 (29.9) | 92 (85.2) | <0.001 |
| | Abnormal | 82 (35.5) | 54 (70.1) | 16 (14.8) | |
| WC (cm) | Normal | 95 (40.1) | 6 (7.8) | 69 (63.9) | <0.001 |
| | Abnormal | 142 (59.9) | 71 (92.2) | 39 (36.1) | |

HDL-c, high-density lipoprotein cholesterol; FBG, fasting blood glucose; SBP, systolic blood pressure; DBP, diastolic blood pressure; WC, waist circumference; MetS, metabolic syndrome. Values are reported as the mean ± standard deviation.

a 5-min rest period in a sitting position BP was measured twice with at least a 5-min interval apart. The average of the 2 measurements was considered for data analysis. Hypertension was defined as systolic blood pressure (SBP) > 130 mm Hg or diastolic blood pressure (DBP) > 85 mmHg (49).

## Metabolic parameters

Blood was sampled from participants by qualified field nurses in the morning after a 12-h overnight fast and was kept on dry ice and transported to the laboratory for processing. On arrival at the lab, the blood specimens were centrifuged for 5 min at 2,500 rpm at room temperature to separate the plasma and red blood cells. The concentration of TGs was assessed using the phosphoglycerides oxidase peroxidase method while HDC-C was obtained using the colorimetric non-precipitation method. Plasma was used for analysis. The glucose concentration was estimated by the capillary method using a glucometer (One Touch®).

## Definition of metabolic syndrome

Following the criteria established by the International Diabetes Federation (IDF) Task Force on Epidemiology and Prevention (joint interim statement in 2009) (49), MetS was defined as the presence of three or more of the following five NCDs: abdominal obesity (WC > 94 cm) in males; FBG ≥ 5.5 mmol/L; TGs ≥1.7 mmol/L; HDL-c <1.0 mmol/L in males and SBP ≥130 mmHg or DBP ≥85 mmHg.

TABLE 4 Area under the curves (AUC) and cut-off points for the anthropometric indices for the prediction of MetS and its risk factors.

| Anthropometric indices | MetS and risk factors | AUC | 95% CI | *P*-value | Cut-off point | Sensitivity | Specificity |
|---|---|---|---|---|---|---|---|
| BMI (kg/m$^2$) | MetS (IDF criterion) | 83.8% | 0.782–0.895 | <0.001 | 28.25 | 80.5% | 25.0% |
| WHtR | | 83.2% | 0.775–0.889 | <0.001 | 0.55 | 87.0% | 36.1% |
| %BF | | 84.8% | 0.794–0.902 | <0.001 | 25.29 | 85.7% | 29.6% |
| ABSI | | 67.7% | 0.599–0.756 | <0.001 | 0.08 | 70.1% | 38.9% |
| BRI | | 83.2% | 0.775–0.889 | <0.001 | 4.55 | 80.5% | 36.1% |
| CUN-BAE | | 84.6% | 0.791–0.901 | <0.001 | 27.10 | 84.4% | 27.8% |
| CI | | 76.2% | 0.694–0.831 | <0.001 | 1.70 | 74.0% | 36.1% |
| BMI (kg/m$^2$) | Triglycerides (mmol/L) | 67.8% | 0.588–0.768 | 0.001 | 28.69 | 63.2% | 39.5% |
| WHtR | | 69.3% | 0.606–0.780 | <0.001 | 0.57 | 71.1% | 44.2% |
| %BF | | 60.5% | 0.577–0.761 | 0.001 | 25.57 | 71.1% | 46.2% |
| ABSI | | 69.3% | 0.506–0.705 | 0.046 | 0.08 | 60.5% | 40.8% |
| BRI | | 69.3% | 0.606–0.780 | <0.001 | 5.25 | 60.5% | 34.0% |
| CUN-BAE | | 67.6% | 0.586–0.767 | 0.001 | 29.19 | 60.5% | 36.7% |
| CI | | 63.4% | 0.535–0.732 | 0.011 | 1.71 | 60.5% | 38.8% |
| BMI (kg/m$^2$) | HDL-C (mmol/L) | 70.9% | 0.634–0.784 | <0.001 | 27.74 | 70.5% | 34.4% |
| WHtR | | 65.0% | 0.582–0.738 | <0.001 | 0.57 | 60.0% | 37.8% |
| %BF | | 69.0% | 0.614–0.766 | <0.001 | 25.35 | 67.4% | 36.7% |
| ABSI | | 53.7% | 0.453–0.621 | 0.384 | 0.081 | 50.5% | 43.3% |
| BRI | | 66.0% | 0.582–0.738 | <0.001 | 4.77 | 60.0% | 37.8% |
| CUN-BAE | | 70.2% | 0.627–0.777 | <0.001 | 26.85 | 70.5% | 35.6% |
| CI | | 60.3% | 0.521–0.685 | 0.015 | 1.71 | 60.0% | 36.7% |
| BMI (kg/m$^2$) | Fasting glucose (mmol/L) | 62.5% | 0.544–0.706 | 0.003 | 27.74 | 60.9% | 46.2% |
| WHtR | | 61.3% | 0.532–0.694 | 0.008 | 0.57 | 57.6% | 44.1% |
| %BF | | 64.5% | 0.566–0.725 | 0.001 | 25.68 | 60.9% | 40.9% |
| ABSI | | 55.3% | 0.470–0.636 | 0.214 | 0.081 | 52.2% | 45.2% |
| BRI | | 61.3% | 0.532–0.694 | 0.008 | 4.88 | 54.3% | 39.8% |
| CUN-BAE | | 63.5% | 0.555–0.716 | 0.001 | 27.25 | 60.9% | 40.9% |
| CI | | 57.3% | 0.491–0.656 | 0.085 | 1.72 | 42.4% | 37.6% |
| BMI (kg/m$^2$) | BP (mmHg) | 64.0% | 0.558–0.722 | 0.002 | 27.44 | 64.6% | 49.2% |
| WHtR | | 63.3% | 0.551–0.716 | 0.003 | 0.58 | 60.0% | 36.7% |
| %BF | | 66.0% | 0.578–0.741 | <0.001 | 26.23 | 64.6% | 39.2% |
| ABSI | | 59.6% | 0.511–0.682 | 0.031 | 0.08 | 61.5% | 39.2% |
| BRI | | 63.4% | 0.551–0.716 | 0.003 | 4.92 | 60.0% | 36.7% |
| CUN-BAE | | 64.8% | 0.565–0.731 | 0.001 | 28.31 | 60.0% | 37.5% |
| CI | | 63.4% | 0.550–0.719 | 0.003 | 1.70 | 60.0% | 43.3% |
| BMI (kg/m$^2$) | WC (cm) | 91.8% | 0.876–0.961 | <0.001 | 25.52 | 91.8% | 25.3% |
| WHtR | | 96.2% | 0.933–0.991 | <0.001 | 0.52 | 99.1% | 29.3% |
| %BF | | 92.9% | 0.887–0.970 | <0.001 | 23.84 | 92.7% | 17.3% |
| ABSI | | 78.3% | 0.714–0.852 | <0.001 | 0.08 | 77.3% | 29.3% |
| BRI | | 96.2% | 0.933–0.991 | <0.001 | 4.14 | 94.5% | 12.0% |
| CUN-BAE | | 92.8% | 0.887–0.970 | <0.001 | 25.12 | 92.7% | 16.0% |
| CI | | 93.5% | 0.899–0.971 | <0.001 | 1.66 | 90.9% | 14.7% |

BMI, Body Mass index; WC, Waist circumference; WHtR, waist-to-height Ratio; %B, percentage body fat; ABSI, a body shape index; BRI, body roundness index; CUN-BAE, Clínica Universidad de Navarra-Body Adiposity Estimator; CI, Conicity index; MetS, metabolic syndrome; HDL-C, high-density lipoprotein cholesterol; FBG, fasting blood glucose; SBP, systolic blood pressure; DBP, diastolic blood pressure; WC, waist circumference.

TABLE 5 Optimal cut-off point for components of MetS.

| Variable | The area under the curve ROC | (95% CI) | *P*-value | Optimal cut-off point | Sensitivity | Specificity |
|---|---|---|---|---|---|---|
| Triglycerides (mmol/L) | 76.7% | 0.697–0.837 | <0.000 | 1.11 | 70.1% | 29.6% |
| HDL-c (mmol/L) | 71.2% | 0.635–0.789 | <0.000 | 1.03 | 70.4% | 32.5% |
| Fasting blood glucose (mmol/L) | 77.0% | 0.703–0.838 | <0.000 | 5.35 | 79.2% | 37.0% |
| SBP (mmHg) | 72.5% | 0.650–0.800 | <0.000 | 130.50 | 70.1% | 44.4% |
| DBP (mmHg) | 80.5% | 0.739–0.870 | <0.000 | 85.5 | 70.1% | 23.1% |
| Waist circumference (cm) | 83.6% | 0.780–0.837 | <0.000 | 99.00 | 81.8% | 29.6% |

SBP, systolic blood pressure; DBP, diastolic blood pressure; HDL-C, high density lipo-protein- cholesterol.

## Ethical approval

This study was approved by the Biomedical Science Research Ethics Committee of the University of the Western Cape (Reference number: BM18/9/25), the City of Cape Town (CCT), and the Western Cape Department of Health. Permission to collect data from the participants was granted by the taxi rank coordinators affiliated with the Western Cape Taxi Drivers' associations. Taxi drivers were informed about the details of the study, what would be expected of them, and that they could withdraw from the study at any time and no punitive measures will be taken against them if they chose to do so. Those who were willing to participate were provided information sheets with details of the research and the contacts they could use in case of further information or to lodge disputes. They were then invited to provided written consent before the commencement of this study. Their rights for data confidentiality and anonymity were ensured throughout the study.

## Statistical analysis

All data were analyzed using the Statistical Package for Social Science (IBM-SPSS, version 24.0 for Windows; SPSS Inc., Chicago, IL, USA). All continuous variables were expressed as means and standard deviations (Mean±SD) while categorical variables were reported as frequencies and percentages (N and %). To measure the relationship between dependent and independent variables the *t-test* was used for continuous variables and the chi-square test for categor-ical variables.

The Receiver Operating Characteristic (ROC) curve analyses were used to compare the MetS predictive abilities of different anthropometric indices and to determine the optimal cut-off values. Using the same method, the area under the curve (AUC) with 95% Confidence Intervals (CIs) were also estimated. The AUC was used to measure the accuracy for each anthropometric index to discriminate between individuals who presented with MetS and those who did not. The AUC values between ≥0.5 and <0.6 (50 and 60%), ≥0.6 and <0.7 (60 and 70%), ≥0.7 and <0.8 (70–80%), and ≥0.8 and ≥0.9 (80–90%) were regarded to have poor, acceptable, excellent and outstanding abilities to predict MetS, respectively (50). The best cut-off points were determined as those closest to the upper left angle of the ROC curve (51). In this approach, the lowest cut-off value corresponds to a Sensitivity = 1 and Specificity = 0. Until a cut-off value corresponding to a test Sensitivity = 0 and Specificity = 1 is reached, the test Sensitivity declines, and the test Specificity increases as the cut-off value rises. There is a cutoff value over this interval at which the test's sensitivity and specificity are equal. As a result, the criterion for determining the test cut-off value that corresponds to this specific point where Sensitivity = Specificity is the one that is used. This point is analytically the intersection of the line connecting the left-upper corner and the right-lower corner of the unit square (the line Sensitivity = Specificity) of the ROC curve. Logistic regression analysis was applied to calculate the association between each of the anthropometric indices (BMI, WC, WHtR, %BF, BRI, CUN-BAE, ABSI and CI), MetS and its risk factors. Combinations of several indices were investigated to comprehensively predict the risk of MetS among taxi drivers The associations were presented as odds ratios (ORs) with CI that did not overlap and $p < 0.05$ showing significant differences between the OR outcomes. The OR outcomes were also adjusted by age group, race, employment, province, locality, education, smoking, alcohol intake and physical activity. Three logistic regression models were applied: *model 1*, adjusted for age; *model 2*, adjusted for age, race, marital status, driving experience in years, and education; and *model 3*, further adjusted for age, race, marital status, driving experience in years, education, smoking, alcohol intake and physical activity. $P < 0.05$ and CIs that did not overlap were assumed statistically significant for all other calculations.

## Result

Table 1 presents the sociodemographic and anthropometric characteristics of 185 male participants who completed the study.

TABLE 6 The risk for metabolic syndrome among South African males aged 20 years and older by anthropometric indices.

| | Unadjusted | | | Adjusted OR model 1 | | | Adjusted OR model 2 | | | Adjusted OR model 3 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Anthropometric indices** | **Crude OR** | **95% CI** | ***p*-Value** | **Crude OR** | **95% CI** | ***p*-Value** | **Crude OR** | **95% CI** | ***p*-Value** | **Crude OR** | **95% CI** | ***p*-Value** |
| BMI (kg/m$^2$) | 1.277 | 1.182–1.379 | <0.001 | 1.261 | 1.166–1.363 | <0.001 | 1.271 | 1.170–1.382 | <0.001 | 1.269 | 1.165–1.382 | <0.001 |
| WHtR (cat) | 0.023 | 0.003–0.174 | <0.001 | 0.026 | 0.003–0.196 | <0.001 | 0.028 | 0.004–0.215 | 0.001 | 0.030 | 0.004–0.232 | 0.001 |
| %BF | 1.214 | 1.145–1.288 | <0.001 | 1.213 | 1.137–1.294 | <0.001 | 1.221 | 1.140–1.308 | <0.001 | 1.220 | 1.136–1.309 | <0.001 |
| ABSI (cat) | 2.853 | 0.254–32.041 | 0.395 | 1.663 | 0.145–19.041 | 0.683 | 2.228 | 0.170–29.270 | 0.540 | 1.754 | 0.123–25.036 | 0.679 |
| BRI | 1.922 | 1.549–2.386 | <0.001 | 1.817 | 1.466–2.250 | <0.001 | 1.860 | 1.478–2.342 | <0.001 | 1.819 | 1.442–2.294 | <0.001 |
| CUN-BAE | 1.215 | 1.146–1.288 | <0.001 | 1.202 | 1.132–1.276 | <0.001 | 1.210 | 1.136–1.289 | <0.001 | 1.210 | 1.134–1.292 | <0.001 |
| CI cat | 2.853 | 0.254–32.041 | 0.395 | 1.663 | 0.145–19.041 | 0.683 | 2.228 | 0.170–29.270 | 0.540 | 1.754 | 0.123–25.036 | 0.679 |
| **MetS risk factors** | | | | | | | | | | | | |
| Triglycerides (mmol/L) | 5.468 | 2.879–10.387 | <0.001 | 5.883 | 2.957–11.703 | <0.001 | 6.205 | 2.986–12.892 | <0.001 | 7.370 | 3.337–16.279 | <0.001 |
| HDL-c (mmol/L) | 0.089 | 0.026–0.308 | <0.001 | 0.085 | 0.023–0.320 | <0.001 | 0.079 | 0.020–0.308 | <0.001 | 0.067 | 0.016–0.288 | <0.001 |
| FBG (mmol/L) | 1.869 | 1.402–2.492 | <0.001 | 1.765 | 1.317–2.366 | <0.001 | 1.693 | 1.254–2.286 | 0.001 | 1.770 | 1.295–2.419 | 0.001 |
| SBP (mmHg) | 1.063 | 1.037–1.089 | <0.001 | 1.064 | 1.037–1.092 | <0.001 | 1.070 | 1.041–1.101 | <0.001 | 1.067 | 1.037–1.098 | <0.001 |
| DBP (mmHg) | 1.121 | 1.080–1.163 | <0.001 | 1.117 | 1.075–1.161 | <0.001 | 1.121 | 1.077–1.167 | <0.001 | 1.119 | 1.073–1.168 | <0.001 |
| Hypertension (cat) | 0.099 | 0.049–0.201 | <0.001 | 0.108 | 0.052–0.223 | <0.001 | 0.092 | 0.042–0.203 | <0.001 | −0.102 | 0.046–0.226 | <0.001 |
| WC (cm) | 1.097 | 1.065–1.129 | <0.001 | 1.090 | 1.059–1.122 | <0.001 | 1.092 | 1.059–1.126 | <0.001 | 1.090 | 1.056–1.124 | <0.001 |

Three logistic regression models were applied: model 1, adjusted for age; model 2, adjusted for age, race, marital status, driving experience in years, and education; and model 3, further adjusted for age, race, marital status, driving experience in years, education, smoking, alcohol and physical activity. BMI, Body Mass index; WC, Waist circumference; WHtR, waist-to-height Ratio; %BF, percentage body fat; ABSI, a body shape index; BRI, body roundness index; CUN-BAE, Clínica Universidad de Navarra-Body Adiposity Estimator; CI, Conicity index; MetS, metabolic syndrome; HDL-C, high-density lipoprotein cholesterol; FBG, fasting blood glucose; SBP, systolic blood pressure; DBP, diastolic blood pressure; WC, waist circumference. Cat: categorical variable, Hypertension: systolic blood pressure ≥ 130 mmHg and/or diastolic blood pressure ≥ 85 mmHg, WHtR: (> 0.5), CI: (>1.25), ABSI: > 0.086.



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TABLE 7 The unadjusted and adjusted odds ratios (ORs) of the combination BMI and BRI, BMI and WHtR, and BRI and WHtR for prediction of MetS and its risk factors.

| | BMI and BRI | | | BMI and WHtR | | | BRI and WHtR | | |
|---|---|---|---|---|---|---|---|---|---|
| | OR | 95% CI | *P*-value | OR | 95% CI | *P*-value | OR | 95% CI | *P*-value |
| **Unadjusted** | | | | | | | | | |
| MetS | 1.211 | 1.141–1.286 | <0.001 | 1.274 | 1.180–1.375 | <0.001 | 1.871 | 1.522–2.302 | <0.001 |
| Triglycerides | 1.072 | 1.029–1.117 | <0.001 | 1.095 | 1.038–1.156 | <0.001 | 1.222 | 1.069–1.397 | 0.003 |
| HDL-c | 1.088 | 1.045–1.133 | <0.001 | 1.121 | 1.062–1.182 | <0.001 | 1.256 | 1.097–1.439 | <0.001 |
| FBG | 1.051 | 1.015–1.087 | 0.005 | 1.065 | 1.019–1.114 | 0.005 | 1.173 | 1.041–1.321 | 0.009 |
| Hypertension | 1.056 | 1.021–1.093 | 0.002 | 1.073 | 1.026–1.123 | 0.002 | 1.184 | 1.053–1.332 | 0.005 |
| WC | 1.564 | 1.388–1.761 | <0.001 | 1.601 | 1.419–1.806 | <0.001 | 9.955 | 5.234–19.010 | <0.001 |
| **Adjusted OR model 1** | | | | | | | | | |
| MetS | 1.197 | 1.128–1.277 | <0.001 | 1.258 | 1.165–1.358 | <0.001 | 1.773 | 1.444–2.177 | <0.001 |
| Triglycerides | 1.072 | 1.028–1.118 | 0.001 | 1.094 | 1.036–1.156 | 0.001 | 1.219 | 1.063–1.397 | 0.005 |
| HDL-c | 1.092 | 1.047–1.138 | <0.001 | 1.125 | 1.064–1.187 | <0.001 | 1.267 | 1.101–1.458 | <0.001 |
| FBG | 1.039 | 1.004–1.076 | 0.030 | 1.051 | 1.005–1.100 | 0.030 | 1.124 | 0.995–1.269 | 0.060 |
| Hypertension | 1.048 | 1.012–1.086 | 0.009 | 1.063 | 1.016–1.113 | 0.008 | 1.150 | 1.020–1.297 | 0.023 |
| WC | 1.584 | 1.396–1.797 | <0.001 | 1.629 | 1.429–1.857 | <0.001 | 9.783 | 5.091–18.800 | <0.001 |
| **Adjusted OR model 2** | | | | | | | | | |
| MetS | 1.203 | 1.130–1.280 | <0.001 | 1.264 | 1.167–1.370 | <0.001 | 1.777 | 1.436–2.199 | <0.001 |
| Triglycerides | 1.072 | 1.027–1.120 | 0.002 | 1.094 | 1.034–1.158 | 0.002 | 1.225 | 1.065–1.408 | 0.004 |
| HDL-c | 1.094 | 1.047–1.142 | <0.001 | 1.127 | 1.065–1.193 | <0.001 | 1.266 | 1.097–1.460 | 0.001 |
| FBG | 1.039 | 1.003–1.076 | 0.035 | 1.050 | 1.004–1.100 | 0.035 | 1.122 | 0.993–1.267 | 0.065 |
| Hypertension | 1.049 | 1.011–1.088 | 0.010 | 1.064 | 1.015–1.115 | 0.010 | 1.151 | 1.018–1.301 | 0.025 |
| WC | 1.581 | 1.394–1.795 | <0.001 | 1.625 | 1.425–1.853 | <0.001 | 9.979 | 5.158–19.307 | <0.001 |
| **Adjusted OR model 3** | | | | | | | | | |
| MetS | 1.191 | 1.118–1.269 | <0.001 | 1.250 | 1.153–1.356 | <0.001 | 1.710 | 1.384–2.113 | <0.001 |
| Triglycerides | 1.072 | 1.026–1.121 | 0.002 | 1.094 | 1.033–1.160 | 0.002 | 1.274 | 1.059–1.415 | 0.006 |
| HDL-c | 1.097 | 1.047–1.148 | <0.001 | 1.131 | 1.066–1.201 | <0.001 | 1.260 | 1.088–1.460 | 0.002 |
| FBG | 1.036 | 0.999–1.074 | 0.054 | 1.047 | 0.999–1.097 | 0.055 | 1.114 | 0.983–1.262 | 0.092 |
| Hypertension | 1.040 | 1.002–1.080 | 0.039 | 1.053 | 1.003–1.106 | 0.036 | 1.115 | 0.981–1.266 | 0.096 |
| WC | 1.610 | 1.404–1.846 | <0.001 | 1.639 | 1.427–1.883 | <0.001 | 10.798 | 5.362–21.744 | <0.001 |

Three logistic regression models were applied: model 1, adjusted for age; model 2, adjusted for age, race, marital status, driving experience in years, and education; and model 3, further adjusted for age, race, marital status, driving experience in years, education, smoking, alcohol and physical activity. BMI, Body Mass index; WC, Waist circumference; WHtR, waist-to-height Ratio; BRI, body roundness index; MetS, metabolic syndrome. HDL-C, high-density lipoprotein cholesterol; FBG, fasting blood glucose; WC, waist circumference.

The Mean ± SD age of the participants was 39.84 ± 10.45 years. The mean values for BMI, WC, WHtR, %BF, BRI, CUN-BAE, ABSI and CI were 28.60 ± 6.20 kg/m$^2$, 99.13 ± 17.59 cm, 0.58 ± 0.10, 27.28 ± 8.28%, 5.09 ± 2.33, 27.78 ± 8.34, 0.08 ± 0.01 and 1.70 ± 0.19, respectively. Overall, 41.6% participants presented with MetS, while those with MetS were significantly older ($p < 0.001$) than those without MetS (mean age of 43.73 ± 10.34 vs. 37.27 ± 10.21 years).

The mean values for BMI, WC, WHtR, %BF, BRI, CUN-BAE, ABSI and CI were significantly ($p < 0.001$) higher in participants with MetS compared to those without MetS. The mean values for all 4 skinfolds were significantly (p<0.001) higher among participants with MetS than those without MetS.

Table 2 presents mean NCD risk factors by the presence/absence of metabolic syndrome. Participants who presented with MetS displayed significantly ($p < 0.001$) higher mean values for TG (1.88 ± 1.49 vs. 0.96 ± 0.45), FBG (7.87 ± 4.82 vs. 5.33 ± 1.13), SBP (141.47 ± 18.79 vs. 127.40 ± 13.33) and WC (110.83 ± 16.72 vs. 90.72 ± 14.50) compared to those without MetS. Participants who presented with MetS displayed significantly lower mean values for HDL-c compared to those without MetS (1.00 ± 0.28 vs. 1.20 ± 0.36, $p < 0.001$).

Table 3 shows the distribution of normal/abnormal proportions of different risk factors for MetS. Abnormal values were recorded for TGs (20.8%), HDL-c (51.6%), FBG (51.7%), SBP (59.7%), DBP (43.3%), BP (35.5%) and WC (59.9%) Based on the participants who had abnormal risk factor outcomes significantly more of them also presented with clustering of these risk factors (presented with MetS) when compared to those who had normal risk factor outcomes [TG (40.3 vs. 6.5%), HDL-c (75.3 vs. 34.3%), FBG (76.6 vs. 30.6%,) SBP (71.4 vs. 49.1%), DBP (70.1 vs. 26.0%), BP (70.1 vs. 14.8%) and WC (92.2 vs. 36.1%)].

Based on Table 4, the most sensitive AUC outcomes for screening MetS were for the %BF (84.8%) and CUN-BAE (84.6%) followed by the BMI (83.8%) and WHtR (83.2%), and lastly the BRI (83.2%). All these indices displayed outstanding discriminatory power for predicting MetS since their AUCs and sensitivity values were all above 80%. The BMI, WHtR, %BF, BRI, and CUN-BAE, cut-off points for detection of MetS in this group were 28.25 kg/m$^2$, 0.55, 25.29%, 4.55, and 27.10, respectively. While the CI showed the excellent AUC (76.2%) for predicting the MetS with the cut-off point

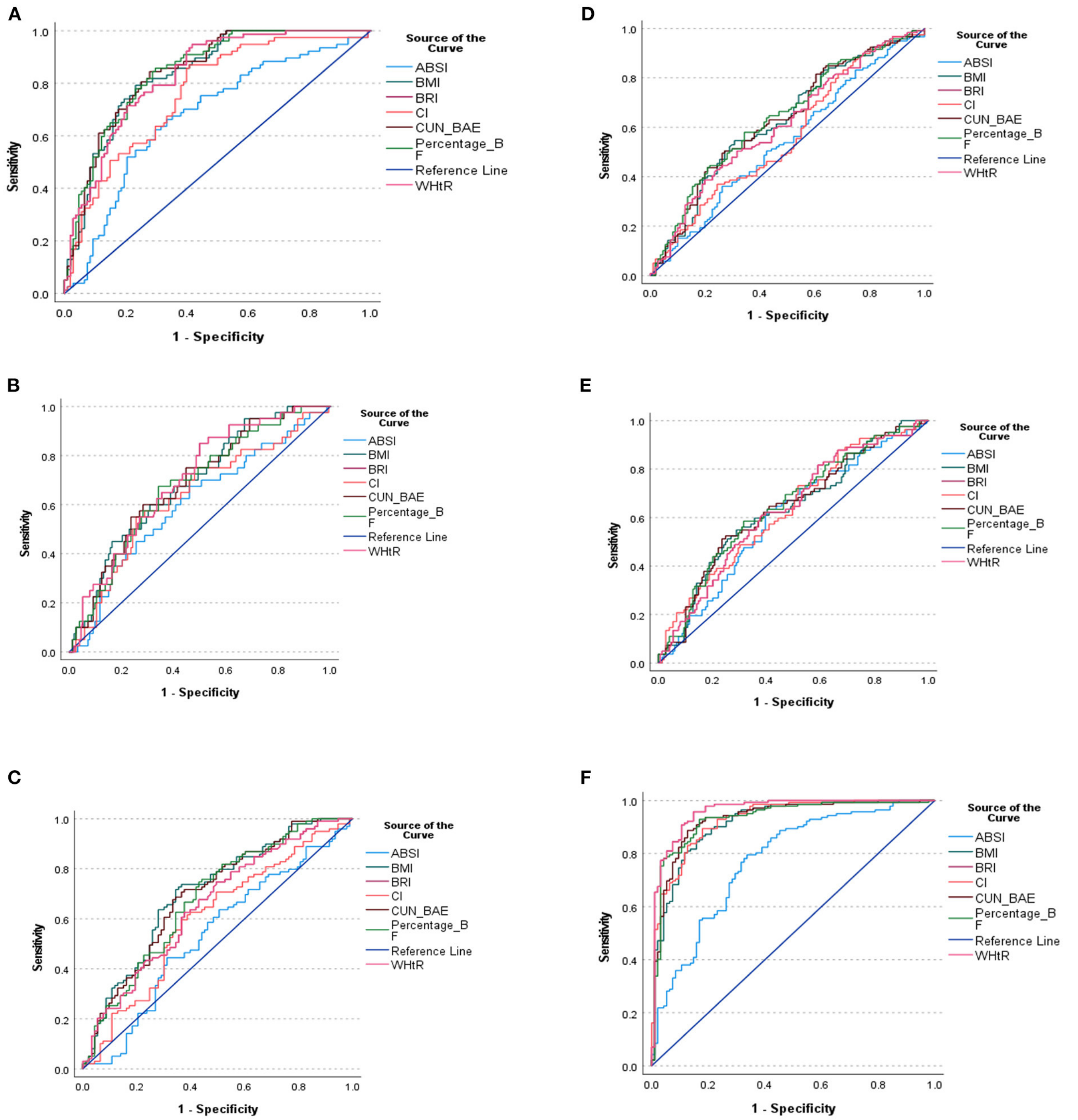


FIGURE 2
**(A)** ROC curve of the anthropometric indices for the prediction of MetS. **(B)** ROC curve of the anthropometric indices for the prediction of triglyceride. **(C)** ROC curve of the anthropometric indices for the prediction of HDL-C. **(D)** ROC curve of the anthropometric indices for the prediction of FBG. **(E)** ROC curve of the anthropometric indices for the prediction of Hypertension. **(F)** ROC curve of the anthropometric indices for the prediction of WC. **(A–F)** shows the ROC curve of the anthropometric indices cut off points for the prediction of MetS and its components.

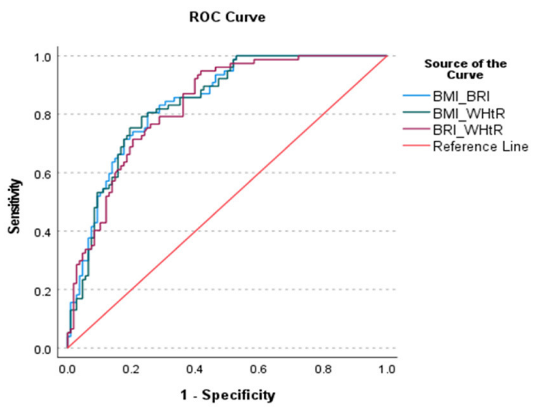


FIGURE 3
ROC curve of the various combination of two anthropometric indices fir identifying the MetS.

of 1.70 and the sensitivity of 74% the ABSI only showed acceptable discriminatory power for predicting MetS, with an AUC of 67.7%, and the cut-off point of 0.8, while its sensitivity was 70.1%. The virtualization of the anthropometric indices cut off points for the prediction of MetS and its components is shown in Figures 2A–F.

Of note is that, based on the CIs that overlapped, there were no significant differences between AUC outcomes for %BF, CUN-BAE, BMI, WHtR, BRI and CI. Moreover, the CIs for the ABSI overlapped with those of the CI, but did not overlap with the rest of the other indices. This showed that, while there was no significant difference between the AUC outcomes for ABSI and CI, there were significant difference between the AUC outcomes for ABSI and those of the other anthropometrical indices. This showed that the ABSI predicted MetS to a significantly lesser degree than the BMI, WHtR, %BF, BRI, and CUN-BAE.

It is further shown that some of these anthropometric indices could not predict the individual risk factors for MetS (predict TG, HDL-c, TG, FBG and BP) since none of these risk factors produced AUCs above 70% in this group of participants, satisfactorily. The only AUCs ≥70% observed was with BMI's and CUN-BAE's ability to predict low HDL-c with the cut-off points at 27.74 kg/m$^2$ and 26.85, respectively. The rest of the indices only produced AUC outcomes (>60%) with ABSI still performing more poorly than the other indices (AUC < 60%). It is further imperative to note the outstanding predictive powers of BMI, %BF, CUN-BAE and CI to predict WC as an important risk factor for MetS with the respective, cut-off points at 25.52 kg/m$^2$, 23.84, 25.12 and 1.66. The highest AUC outcomes for screening WC were for the CI and %BF, followed by CUN-BAE then BMI (93.5 and 92.9%, followed by 92.8% then 91.8%), respectively.

According to Table 5, only the DBP and WC could outstandingly predict MetS, with cut-off points of 85.5 mmHg and 99 cm and Sensitivity levels of 70.1 and 81.8%, respectively. The rest of the risk factors managed to predict MetS excellently.

The outcomes of the logistic regression analyses are shown in Table 6. The unadjusted odds ratios (OR) and adjusted odd ratio (AOR) with 95% confidence intervals (95% CIs) are also presented. While the BMI, WHtR, %BF, BRI and CUN-BAE yielded OR and AOR outcomes (for all the 3 models) that showed significant probability for MetS risk, the OR outcomes for ABSI and CI were not significant. The highest positive (increased) likelihood for MetS risk was with the BRI (almost 2 times more likelihood), than the BMI (almost 1.3 times more likelihood), followed by %BF and CUN-BAE (1.214 and 1.215 more likelihood, respectively). All the $p < 0.001$ and the positive likelihoods remained after removing the confounding effects of age, race, marital status, driving experience in years, education, smoking, alcohol intake and physical activity. The WHtR on the other hand yielded a negative (0.977 less likelihood) for MetS risk (where the $p$-value for OR was <0.001). This less likelihood persisted after removing the confounding effects of age, race, marital status, driving experience in years, education, smoking, alcohol intake and physical activity.

Moreover, the TG, FBG, SBP, DBP and WC yielded positive outcomes (increased likelihood of 5.5, 1.9, 1.1, 1.2 and 1.1 times) for MetS risk, respectively. All the $p < 0.01$ and these remained after adjusting for age, race, marital status, driving experience in years, education, smoking, alcohol intake and physical activity. The HDL-c and hypertension on the other hand yielded negative outcomes (reduced likelihood of 0.911 and 0.901) for MetS risk, respectively. All the $p < 0.001$ and these remained after adjusting for age, race, marital status, driving experience in years, education, smoking, alcohol intake and physical activity.

We further investigated how the combinations of two indices behaved in predicting MetS among study participants in Table 7. It was shown that all combination of two indices had significantly better performances in predicting MetS. e.g., One unit increase in the combination of BRI and WHtR increased two times chances of MetS (OR: 1.871 95% CI 1.522–2.302, $p <$ 0.001) for unadjusted. While in the adjusted model 1, increased 1.7 times chances of MetS incident (OR 1.773 95CI 1.444–2.177, $p < 0.001$).

Since we had the evidence that the anthropometric indices would predict the risk of MetS, we now investigated how much it could be improved with combinations of indices using AUC. Figure 3 and Table 8 show the AUC's of various combinations of two indices for predicting MetS. It was obvious that the predictive capacity for MetS with two indices was much better than that with a single index. For example, the AUC of BMI and BRI, BMI and WHtR and BRI and WHtR for predicting MetS were 0.843, 0.839 and 0.832, respectively.

## Discussion

The current study aimed to examine the power of anthropometric indices such as the BMI, WC, WHtR, ABSI, BRI, %BF, CI, and CUN-BAE to predict MetS, and determine

TABLE 8 Area under the curves (AUC) for the various combinations of two anthropometric indices for identifying MetS.

| | The area under the curve ROC | *P*-value | 95% CI | |
|---|---|---|---|---|
| BMI and BRI | 0.843 | <0.001 | 0.788 | 0.898 |
| BMI and WHtR | 0.839 | <0.001 | 0.783 | 0.895 |
| BRI and WHtR | 0.832 | <0.001 | 0.775 | 0.889 |

BMI, Body Mass index; WC, Waist circumference; WHtR, waist-to-height Ratio; BRI, body roundness index; MetS, metabolic syndrome. HDL-C, high-density lipoprotein cholesterol; FBG, fasting blood glucose; WC, waist circumference.

the cut-off points to identify male South African taxi drivers at risk of MetS. The mean age of the participants was 39.84 years. Overall, more than 41% of the participants had MetS. Participants presenting with MetS were significantly older than those without MetS. The highest AUC outcomes for screening MetS were for the %BF and CUN-BAE, followed by the WC, WHtR and BMI, and lastly by the BRI. All these anthropometric indices had outstanding discriminatory powers for predicting MetS since their AUC outcomes were above 80%. While all the indices had outstanding capabilities to predict MetS, ABSI was considered a poor indicator of MetS when compared to the rest of the indices. In terms of the abilities of the indices to predict the risk of elevated TGs, FBG and BP, as well as reduced HDL-c, only the BMI and CUN-BAE produced AUC outcomes that were above 70%. Finally, based on the logistic regression models shown in the current paper, the taxi drivers that presented with abnormal levels of BMI, WHtR, %BF, BRI, CUN-BAE, TG, HDL-c, FBG, SBP, DBP and WC displayed an increased risk of MetS.

The prevalence for MetS in our study appears to be high (41.6%) when compared to other documented South African studies. In fact, Motala et al. (21); Motala et al. (22) and Sekgala et al. (24) found MetS to be 7.9, 10.5 and 8.6% in rural South African men, respectively. Peer et al. (23), on the other hand, reported a 17.9% prevalence of MetS in black men living in urban townships in Cape Town, South Africa. Our results are also higher than the prevalence of 17.1% observed by Mabetwa et al. (52) among taxi drivers operating in the City of Tshwane and the prevalence of other international studies among occupational drivers for example Chen et al. (2) (6.23%), Montazerifar et al. (3) (20.0%) and Saberi et al. (4) (35.9%). However, we need to mention that the prevalence of MetS might be different according to the definition used to determine MetS. Several international studies define MetS using the Adult Treatment Panel III for Asians which considers any three of MetS clusters while for Sub-Saharan Africa (SSA) the IDF European definition is used which considers WC and any two clusters of cardiometabolic disorders.

The increased prevalence might also be attributed to the fact that almost 60% of the taxi drivers participating in the current research presented with central obesity while the majority the taxi drivers with central obesity also presented with MetS. Though comparable to the 50% of international male long distance and long duration drivers observed by Hirata, et al. (29) and Saberi et al. (4), the current abnormal WC prevalence outcome is still the highest when compared to all other outcomes we could review from literature. In the current study it has also been shown that WC correlates well with other anthropometric indices including the BMI, WHtR, %BF, BRI, CUN-BAE (AUC >90%).

Because central obesity explains fat mass that lines internal organs, if in excess, it is likely to disturb the natural functioning of these organs, hence it is detrimental to human health. According to available South African (21–24, 52, 53) and international (4, 54) studies, central obesity is more prevalent in middle age to older men, and it positively correlates with other body composition outcomes including abnormal BMI, WC, waist to hip ratio (WHpR), %BF and all sorts of CVD risk factors and MetS.

Other notable outcomes of the current study indicated that indices which determine body fat distribution, %BF, CUN-BAE, WHtR and BRI, specifically showed outstanding discriminatory power for predicting the risk of MetS. These findings are corroborated by other cross-sectional South African (53) and international (34, 55) studies conducted among different ethnic groups of men operating in the driving industry. Moreover, in line with our current findings, Głuszek et al. (34) showed that the ABSI index showed the lowest discriminatory powers to predict MetS when compared to other anthropometrical indices with an AUC of 60%. Zhang et al. (56), also showed the weakness of CI in predicting MetS in Chinese male adults with the AUC of 66%. These outcomes can be attributed to the fact that the algorithms for ABSI and CI consider BMI and body weight, respectively. Evidence suggests that the BMI and body weight do not consider the distribution of adipose tissue. Earlier presented evidence indicate that MetS is sensitive to central obesity (57, 58). Moreover, Głuszek et al. (34), Mongraw-Chaffin et al. (59), and Heymsfield et al. (60) have eloquently argued that the cut-off points for the BMI and weight do not consider the individual's ethnicity, gender and age-group, hence they appear to be less sensitive in predicting MetS, especially in a group of participants in the current study, who were males of whom the majority were of black decent.

There is growing evidence (53, 61) that highly recommend WC and WHtR as the best anthropometric indices to be used in the diagnosis of MetS and its risk factors. Both these indices have been shown to produce AUC outcomes that are >80% when detecting MetS and its risk factors including diabetes mellitus. Moreover, Rajput et al. (62) previously argued that the WHtR can be used independently as a universal screening tool to identify individuals at high risk of developing metabolic complications, regardless of the individuals' gender or geographical location. Other researchers have also advocated the importance of using the WC, WHtR, BRI and CUN-BAE in the diagnosis of cardiometabolic disorders and MetS (36, 45, 63, 64). According to Thomas et al. (36), the BRI was created to measure body fat and the percentage of visceral adipose tissue by using WC and height in the algorithm. Pairing WC and height in the same algorithm elevates the discriminatory power of the index to predict the risk of MetS. It should also be noted that, according to Maessen et al. (65), the BRI has a relatively strong correlation ($r = 0.999$) with WHtR among the Dutch population. Several other studies have confirmed the BRI's ability to identify the risk of MetS in both men and women (56, 66, 67).

Prospective studies (68–70) have highlighted the usefulness of anthropometric indices to identify individuals at risk of cardiometabolic disorders such as hypertension, elevated blood glucose and blood lipids. However, none of the anthropometrical indices produced AUCs above 70% in the calculations undertaken to predict FBG, TGs, hypertension, DBP, and SBP, with the exceptions being the BMI's and CUN-BAE's ability to predict low HDL-c (where both AUC outcomes were 70%), with the cut-off points at 27.74 kg/m$^2$ and 26.85, respectively.

Similar results were reported by Głuszek et al. (34) where CUN-BAE, BMI, and WC in men (AUC = 0.734, 0.728, and 0.728, respectively) had the highest discriminatory power for the identification of at least one MetS component. Contrary to our outcomes, none of the anthropometric indices were shown to predict the incidence of low HDL-c in the study by Latifi et al. (71). It is unclear why such contrasting outcomes were observed. However, it needs to be acknowledged that these studies were undertaken, to a large extent, in different ethnic groups, genders, age groups and geographic location.

The current research outcomes also established new anthropometric indices' cut-off points to predict MetS among South African taxi drivers. For instance, the cut-off point established for BMI (28.25 kg/m$^2$) in the current study seems lower than 30 kg/m$^2$ recommended by the IDF (49). Al-Odat et al. (72) found lower cut-off points of 28.4 kg/m$^2$ in their research conducted in the male Jordan population while Ofer et al. (73) reported cut-off points of 27 kg/m$^2$ in the retrospective, observational, cohort-based study. Even though several papers, including the current manuscript highlight the limitations of using BMI independently (28, 74, 75) to predict MetS, BMI can still be a very user friendly, non-invasive and affordable tool to measure adiposity and predict other of chronic metabolic diseases.

In terms of WC cut-off points to predict MetS, ours were within the range recommended by the IDF and WHO. In fact, 99 vs. 94 cm and 102 cm, respectively, were observed in the current study. Moreover, the cut-off point of 0.55 for WHtR reported falls within the range of 0.51 to 0.58 as recommended by the IDF and Głuszek et al. (34). Moreover, several studies (56, 76–78) recommend a WHtR cut-off value of >0.5 as a simple and reliable outcome to identifying those individuals (male and female) who are at an increased risk of metabolic complications.

According to the IDF (2005), the European cut-off point for abdominal obesity should be 94 cm for men (49), whereas the WHO cut-off point is 102 cm for men (47). These figures have been found to be highly correlated with a BMI of around 30 kg/m$^2$.

In the current study, we also observed that the %BF and the CUN-BAE were better predictors of MetS (79), compared to BMI, WHtR, CI and BRI. We could attribute these outcomes to the fact that the total body fat predicts metabolic disorders more precisely than other anthropometric indices derived from WC (80). In fact, according to Lear et al. (81) % BF highly correlates with visceral adipose tissue (VAT) hence the excess body fat is primarily responsible for the health consequences associated with obesity (55, 82, 83).

Similar to Macek et al. (84) findings (25.8%), the optimal cut-off point for %BF in the current study was 25.29%. These outcomes were expected given that in the afore-mentioned two studies, men of a similar age group were studied. Similarly, Joseph et al. (85) indicated that 25.5 %BF was sufficient to predict cardiovascular risk in Asian Indian men. Our cut-off point was also similar to the cut-off point recommended by the WHO (25%). However, 25.29% is lower than the outcomes observed in the improving interMediAte RisK management (MARK) study (cut-off point of 31.22%) by Gomez-Marcos et al. (55). The differences could probably be ascribed to the different age groups studied. Gomez-Marcos et al. (55) studied 35–74-year old participants, while in the current research taxi drivers 20 years and older were included.

Finally, based on the logistic regression models shown in the current paper, abnormal BMI, WHtR, %BF, BRI, CUN-BAE, TG, FBG, SBP, DBP and WC outcomes showed increased likelihood for MetS while abnormal HDL-c outcomes showed less likelihood for MetS. There is South African (52, 53) evidence on men and taxi drivers including long distance and long duration drivers, respectively to corroborate these outcomes. However, the outcome in the current study that suggested that hypertensive taxi drivers had decreased likelihood of MetS was surprising. Nonetheless, blood pressure results further showed that elevated DBP and SBP were significantly positively associated with the likelihood of developing MetS among participants. This outcome seems similar to the study of Mabetwa et al. (52). Even though not significant ($p = 0.117$), taxi drivers with hypertension in Mabetwa et al. (52) study were 45% less likely to present with MetS (CI: 0.261–1.161). The take-home messages from the current study are summarized in Box 1.

## Limitations

While several strengths of the current study are outlined above, there are limitations that should be considered when interpreting the current outcomes. Firstly, this study was the cross-sectional design which cannot infer causality. Secondly,

BOX 1
Take-home messages from the current research.

- Based on the current study, Overall, 41.6% of the South African men taxi drivers had MetS.
- The mean values for BMI, WC, WHtR, %BF, BRI, CUN-BAE, ABSI and CI were significantly higher in older participants and those that presented with MetS compared to younger participants without MetS.
- Participants who presented with MetS had higher mean values for triglycerides (1.88 vs 0.96), FBG (7.87 vs. 5.33), SBP (141.47 vs. 127.40) and WC (110.83 vs. 90.72) as compared to those without MetS.
- Overall, 20.8, 51.6, 51.7, 59.7, 43.3, 35.5 and 59.9% of the participants had abnormal Triglyceride, HDL-c, FBG, SBP, DBP, Hypertension and WC, respectively.
- The highest AUC outcomes for screening MetS were for the %BF and CUN-BAE and then followed by the WC, BMI and WHtR, and lastly the BRI (84.8 and 84.6%, and then followed by 83.8 and 83.2%, and lastly the 83.2%, respectively).
  - ➢ This means that all these anthropometrical indices had outstanding discriminatory power for predicting MetS since their AUC and sensitivity levels were above 80%.
- The BMI, WHtR, %BF, BRI, and CUN-BAE, had cut-off points for detection of MetS in South African men at 28.25 kg/m$^2$, 0.55, 25.29%, 4.55, and 27.10, respectively.
- While the CI only showed the excellent AUC (76.2%) for predicting the MetS with the cut-off point of 1.70 and the sensitivity of 74%.
- Some of these anthropometric indices could not satisfactorily predict the individual risk factors for MetS (i.e., predict TG, HDL-c, TG, FBG and BP).

➢ This means that none produced the AUCs that were above 70% in this group of participants.
➢ The only acceptable outcome (AUCs ≥70%) observed was with BMI's and CUN-BAE's ability to predict HDL-c with the cut-off points at 27.74 kg/m$^2$ and 26.85, respectively.
➢ There was outstanding predictive powers of BMI, %BF, CUN-BAE and CI to predict WC with the cut-off point at 25.52 kg/m$^2$, 23.84, 25.12 and 1.66, respectively.
➢ This means that all these anthropometrical indices had outstanding discriminatory power for predicting WC since their AUCs and sensitivity values were all above 90%.
➢ DBP and WC showed outstanding predictive powers to diagnose MetS with cut-off points of 85.5 mmHg and 99 cm, respectively.

- We observed the highest positive likelihood for BRI and BMI to increase the incidence of MetS in the unadjusted and all the adjusted models.
- Increased in CUN-BAE and %BF were positively associated with likelihood of MetS incidence.
- High triglycerides had a greater risk of increasing MetS in both adjusted and unadjusted models.

the sample size because of the specific nature of the chosen participants (male and taxi drivers), therefore, as only male taxi drivers that were recruited conveniently are included, the outcomes obtained can only be generalizable in populations with similar characteristics as the current participants. Possible reasons for the high prevalence of MetS in our analysis might be influenced by genetic variation and epigenetic factors (86), adipose-related hormonal and immunological reactions can exacerbate metabolic disorders, such as dyslipidemia and high blood pressure (87). The main environmental factors influencing the expression of genes involved in the occurrence of MetS are eating habits and physical activity (88). Diets high in fat, particularly saturated fat, with a high glycemic index and low fiber content can increase the risk of MetS. Therefore, not all MetS cases can be characterized by high anthropometric indices as MetS can be linked not only to excess adipose tissue but also to its location.

## Conclusion

The results of our study confirmed the usefulness of BMI, WHtR, %BF, BRI, and CUN-BAE for identifying MetS in male drivers, whereas ABSI was found to be the weakest predictor of the syndrome.

Therefore, the cut-off points proposed in this study provide an earlier diagnosis of MetS than the commonly accepted obesity criterion (BMI ≥30 kg/m$^2$). In our analysis, we included the MetS definition (three of five components according to the IDF) and anthropometric indices excluding WC. To avoid a late diagnosis of MetS, consideration should be given to setting cut-off points for the indicators in question that would allow people with only one MetS component to be diagnosed. This data might be clinically significant, as anthropometric index reference thresholds can be used to identify those adults who are at high metabolic risk. Additionally, these results highlight the usefulness of BMI, WHtR, %BF, BRI, and CUN-BAE for public health purposes given their higher accuracy and low cost for measurement.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by Ms. Patricia Josias Research Ethics

Committee Officer University of the Western Cape. The patients/participants provided their written informed consent to participate in this study.

## Author contributions

MDS and ZJ-RM: conceptualization and funding acquisition. MDS: formal data analysis, methodology, and writing-original draft. ZJ-RM and MO: supervision and writing-review and editing. BM: biochemical analysis. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2022.974749/full#supplementary-material

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# Determinants of dietary patterns in school going adolescents in Urban Zambia

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**Background:** Understanding dietary patterns in a population is critical for decision making. This study aimed to identify the prevailing dietary patterns and their associated individual and school environment factors among school going adolescents in Lusaka, Zambia.

**Method:** A cross-sectional study involving 404 Grade 10 pupils from 10 secondary schools in Lusaka district was conducted. A 108-item unquantified Food Frequency Questionnaire (FFQ) was used to assess the learner's food intake practices. Principal component analysis (PCA) was used to derive dietary patterns from the 108 food items. In addition, a mapping of food vendors and types of food sold was conducted in the same 10 schools using a semi-structured observation checklist. Bivariate and multivariate multilevel regression was used to analyse the individual and school level determinants of the adolescent dietary patterns.

**Results:** The average age of learners was 16.1 years (SD 1.4 years); 234 (58%) were female while 170 (42%) male. "Snacking," "vegetarian," "health conscious," and "traditional" dietary patterns accounting for 54.5% of variability in learner's diets were identified using PCA. At individual level, having weekly pocket money was significantly associated with snacking ($p \leq 0.0001$). Self-identified poverty was associated with snacking ($p \leq 0.0001$), vegetarian ($p = 0.009$) and traditional ($p = 0.009$) dietary patterns. School level factors like a school tuckshop (similar to canteen) that sells fast foods or a *kantemba (semi-permanent makeshift store)* within the school vicinity ($p = 0.023$) were significantly associated with a snacking dietary pattern. School tuckshop selling *nshima (a thick maize based porridge)* was significantly associated with vegetarian ($p = 0.007$), health conscious ($p = 0.02$) and traditional dietary patterns (p=0.01) while a tuckshop with fruit significantly predicted traditional ($p \leq 0.0001$), vegetarian ($p = 0.041$), and snacking ($p = 0.002$), dietary patterns. Having a supermarket or fast food restaurants in the school vicinity did not significantly influence any dietary pattern.

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**Conclusion:** Both individual behavioral and school environment level factors were found to be significant determinants of the four dietary patterns identified in this study.

KEYWORDS

**food environment, Zambia, school nutrition, nutrition policy, adolescents**

## Introduction

Dietary practices have drastically shifted in Low- and Middle-Income Countries (LMICs) in recent years (1, 2). Most countries are experiencing the nutrition transition and dealing with the double burden of malnutrition (3). Understanding prevailing dietary practices in a population is critical for decision making as it provides insights into short term and long-term diseases outcomes in the population (4). Consequently, there is a growing interest in understanding the dietary practices of adolescents as it represents one of the key intervention points in the lifecycle of a person (5). The adolescence period provides an opportunity for cost effective policy action and investments that can help establish healthy dietary patterns that reduce the risk of nutrition related health outcomes like obesity, diabetes and hypertension later in adulthood (6, 7).

Dietary pattern analysis is one of the methods used to profile the nutrition status of a population (8). The term dietary pattern refers to the quantities, proportions, variety, or combination of different foods, drinks, and nutrients in diets, and the frequency with which they are habitually consumed (9). The dietary pattern analysis approach has gained popularity over more traditional methods like single food or nutrient analysis because of the recognition that no single nutrients are consumed in isolation but are part of a larger diet (10). Studying the whole diet therefore provides a better way to explore correlations between different dietary components and the interactions between diet and health.

Adolescents are generally associated with the snacking dietary pattern, characterized by consumption of snacks, sugar sweetened drinks, and fast foods (11). Demographic factors like age and gender as well as social economic status (SES) factors like income (12) are among the well-known individual level influencers of dietary patterns in adolescents. The school food environment is another important factor that influences adolescents' dietary patterns as adolescents spend a significant amount of time in school. The school structure provides an opportunity for adolescents to express their autonomy through independent food choices (13). Healthy dietary patterns characterized by frequent consumption of fruit and vegetables has been associated with availability of these food options in school tuck-shops (14). Conversely, availability of fast food outlets within school vicinities has been associated with unhealthy dietary patterns (15, 16).

While there is a growing body of knowledge on adolescent dietary patterns and their determinants from LMICs (17–20), this area remains understudied in Zambia. Adolescent nutrition assessments have largely focused on micronutrient deficiencies in girls of child bearing age (21, 22). Moreover, other assessments with a nutrition component like the WHO STEPS survey only include people above 18 years (23), under-representing adolescents who make up a quarter of Zambia's population (24). The Global School Health Survey which generates nutrition related data on school going children was last conducted in 2004 (25). This study therefore aims to identify the prevailing dietary patterns and the individual and school environment factors associated with dietary patterns among school going adolescents. The study will generate evidence that can guide decisions on nutrition policy reforms that might be required to support healthier dietary patterns among school going adolescents in urban settings.

## Materials and methods

### Study design

A cross sectional survey of school going adolescents in selected secondary schools in Lusaka District was conducted in order to establish their dietary patterns and to map the food environment surrounding the schools. The survey involved administration of a food frequency questionnaire (FFQ) to school going adolescents in 10 sampled schools.

### Study sites

The study was conducted in ten purposively sampled secondary schools in in Lusaka District of Lusaka, the capital city of Zambia. At the time of the research, Lusaka District had fifty-four secondary schools (seven private-owned and forty-one government) registered with the Ministry of General Education.

## Study population

The survey was administered to randomly selected, consenting Grade 10 pupils in the sampled schools. Only Grade 10 learners (both male and female) in the selected schools participated in the study, because this class is a non-exam class and participation would hence cause minimum disruption of the adolescent's school activity. In addition, it is expected that Grade 10 pupils (on average aged between 14 and 16 years) would have well developed food preferences to accurately complete the questionnaire (26).

## Study tools

We administered a three-part questionnaire to collect data used to determine the dietary patterns of the adolescents. The first part of the questionnaire collected socio-demographic data including age, sex, residence, and self-assessed poverty. The second part was adapted from the nutritional behavior module of the global school health survey (27) and included questions assessing nutrition related practices such as consumption of fruit and vegetables or snacks and exposure to fast food advertisements in the previous 30 days. The third part was the unquantified food frequency questionnaire (FFQ) which was developed based on the Food and Agriculture Organization (FAO)'s dietary assessment guide for low resource settings (8). The 108 food items included in the FFQ in this study were adapted from the Zambian food guidelines produced by the National Food and Nutrition Commission (NFNC) (28). The questions in the FFQ asked learners to rate how often they consumed a food item in the previous month on an ordinal scale of never; seldom (less than once a month); 1–3 times per month; 1–2 times per week; 3–4 times per week; or daily.

A semi-structured observation checklist was developed and used to map typology of vendors and food sold around the school environment. The food types were categorized into seven main groups: (1) fruits; (2) snacks (such as biscuits, potato crisps, fritters, doughnuts, roasted groundnuts, roasted maize); (3) fast foods (including fried chicken, sausage, pizza, pies, chips, samosas); (4) soft drinks (including carbonated sugar sweetened drinks and energy drinks); (5) water; (6) milk and (7) *nshima* (a thick maize based porridge eaten with relish). Food vendors were categorized as either school tuckshops, street vendors, *kantemba* (a semi-permanent makeshift store), supermarket, grocery or convenience store.

Construct validity of the FFQ, including face and content validity was assessed by a nutrition expert from the NFNC. Both tools were pilot tested among 40 learners in two schools with similar characteristics to the schools included in the study sample before data collection. The purpose of the pilot testing was to assess the readability, logic of questions and length of interviews. Based on feedback from the pilot test, the FFQ was revised to include local names of some food items. The data collection tools were not translated into the local languages, but administered in English, Bemba or Nyanja by trained research assistants.

## Sampling

Ten secondary schools, representing 20% of the total population of secondary schools in Lusaka District were purposively selected for the research. The 10 schools (nine government owned and one private owned) were purposively selected to ensure a representation of various demographics and socio-economic status of adolescents in Lusaka. Purposive sampling based on the residential area where a school was located was used as proxy for socio-economic status of adolescents. This is based on studies that have shown an inverse relationship between population density of a residential area and economic status (29). Data was collected from a total of 404 adolescents in the ten sampled secondary schools based on calculation of the minimum sample size for infinite populations (with a 95% confidence level and +/−5% precision) (30).

## Recruitment and data collection

The lead author sought and obtained permission first from the Ministry of General Education and then from individual school administrators before the study was conducted. Data was collected over a period of 2 days for each school. On the first day, the trained research assistant obtained the sampling frame, consisting of the names of all grade 10 learners (available on that day[1]), from the teacher assigned by the school administrator to oversee the study once the school granted permission to proceed with the research. The lead author then entered the sampling frame into Stata and assigned each learner a unique random number. The random numbers were then sorted in ascending order and the first 40 learners on the list were invited to participate in the study. Where a learner declined to participate, a replacement was made with the next learner on the list. The selected learners were given information sheets and parent permission forms for their guardian to consent to their participation. On the second day, all learners with parental permission where further asked to provide assent to participate in the research by completing an assent form. Learners were informed that they still had the right to choose not to participate in the research with no negative consequences for them. The FFQ was only administered to learners who assented and had parental permission.

Data was collected in November 2020. The FFQ and school food environment checklist were programmed into electronic

1 Because of the COVID-19 prevention measures, we found that schools had randomly split classes to report on different days in order to maintain social distancing.

versions using Open Data Kit for ease of data collection. Data was collected by five research assistants who were trained and supervised by the lead author. All research assistants had a minimum of a bachelor's degree, at least 1-year experience collecting quantitative data and native speakers of Bemba or Nyanja, the main local languages used in Lusaka. The research assistants were trained on ethical conduct of research where justice, beneficence and right of person was emphasized. Research assistant were also trained on dietary assessment in adolescents using a FFQ and how to administer the questions in both English, Bemba and Nyanja. All interviews were conducted within the school premises after class.

## Data analysis

Data analysis was done in three steps for each type of data from the different sections of the tool as described below. All data analyses were conducted in Stata version 15 (31).

### Step 1: Analysis of demographic, nutritional behavior, and school environment

Descriptive statistics were used to summarize the categorical demographic and nutritional behavior data (see Table 1) as well as school environment data on food and vendors types (Table 2) into proportions or frequencies. In addition, food intake variables were summarized into three categories of frequency of consumption (Supplementary Table 1).

### Step 2: Analysis of dietary patterns

Principal component analysis (PCA) was used to obtain a dietary pattern for each adolescent in the study based on data from the food intake variables. Principal component analysis is an exploratory data driven approach that uses a correlation matrix of food intake variables to identify common patterns of food consumption within the data to account for the largest amount of variation in diet [i.e., statistical technique to determine dietary patterns based on shared variance across dietary variables].

The reduction of food intake variables into food groups was done in three steps. In the first step, the food intake variables, which were measured on an ordinal scale, were recoded and converted to frequency of consumption per week. The conversion of variables was done as follows: "never" = 0; "seldom (less than once a month)" = 0; "1–3 times per month" = 0.5; "1–2 times per week" = 1.5; "3–4 times per week" = 3.5; and "daily" = 7. In the second step, all the food intake variables were allocated to one of the 15 broad food groups based on the FAO/WHO Global Individual Food consumption data Tool (GIFT) nutrition-sensitive food grouping (see Supplementary Table 2) (32). In the last step, a compound score for the food group was obtained by summing the individual scores of the food intake variables in each food group. A higher compound score for a food group indicated a higher frequency of consumption of the food items under that food group.

Principal component analysis was then performed on the 15 food groups to identify correlations that point to particular dietary patterns. The Kaiser–Meyer–Olkin (KMO) test, a measure of sampling adequacy used to assess the suitability of the data for PCA retained an overall value of 0.84 warranting a factor analysis. Varimax (orthogonal) rotation was performed following PCA to improve the interpretability of results. Orthogonal rotation following PCA is useful as it maximizes loadings of variables on extracted factors while minimizing loading on other factors. Four components were retained using the scree plot (Supplementary Figure 1) and Kaiser's stopping rule (33) of an eigenvalue of $\geq$1, which has been applied in other studies (12, 20). The four components accounted for 54.6% of total variance in food intake among the school going adolescents (see Supplementary Table 3). A cut off point of $>$0.30 on the factor loading was used to identify significant food groups in each component and to determine which dietary pattern best described the component.

### Step 3: Analysis of determinants of identified dietary patterns

Multilevel regression analysis was conducted to determine the statistically significant determinants of the dietary patterns identified in the PCA of food groups. This analysis method addressed the possible non-independence in the sample which might result in clustering of learner behaviors at school level. An intra-cluster correlation (ICC) analysis was conducted using a cut off level of 0.05 to confirm the presence of clustering and the need for a multilevel model.

The dependent variables in the multilevel model were the four dietary patterns represented by the components retained from the PCA. Predictor variables were classified into two groups. The first group contained demographic characteristics such as age, gender, and household size. The second group included variables related to the food environment, such as presence of a tuck shop at school, exposure to food marketing and types of food vendors around a school. An investigator led step wise approach was used to fit the model. In the first step, a bivariate regression between each identified dietary pattern and predictor variables was conducted to identify significant predictors with a 95% confidence interval (Table 4). This was followed by fitting of the full model containing both the individual level and food environment predictors. The model with the least ICC and without any multicollinearity was retained and reported in Table 5.

TABLE 1 Survey participant characteristics ($n = 404$).

| Characteristic | Frequency | Percentage (%) |
|---|---|---|
| **Gender** | | |
| Female | 234 | 58 |
| Male | 170 | 42 |
| **Age** | | |
| 14–16 | 268 | 67 |
| 17 and above | 136 | 33 |
| **Self-assessed poverty** | | |
| Poor | 83 | 21 |
| Non-poor | 321 | 79 |
| **Guardian employed** | | |
| Employed | 321 | 79 |
| Unemployed | 83 | 21 |
| **Had weekly pocket money** | | |
| Yes | 303 | 75 |
| No | 101 | 25 |
| **Household size** | | |
| Up to 5 | 158 | 39 |
| 6–10 | 234 | 58 |
| More than 10 | 12 | 3 |
| **Residence** | | |
| High density | 220 | 54 |
| Medium density | 109 | 27 |
| Low density | 75 | 19 |
| **Eat breakfast at home** | | |
| Always | 170 | 42 |
| Regularly | 164 | 41 |
| Rarely | 55 | 13 |
| Never | 15 | 4 |
| **Eat breakfast at school** | | |
| Always | 11 | 3 |
| Regularly | 16 | 4 |
| Rarely | 6 | 1 |
| Never | 371 | 92 |
| **Eat lunch at school** | | |
| Always | 12 | 3 |
| Regularly | 18 | 4 |
| Rarely | 8 | 2 |
| Never | 366 | 91 |
| **Saw TV advertisement for fast foods ($n = 389$)** | | |
| Always | 104 | 27 |
| Regularly | 247 | 63 |
| Rarely | 34 | 9 |
| Never | 4 | 1 |
| **Bought sugar sweetened beverage at school** | | |
| Yes | 247 | 39 |
| No | 157 | 61 |
| **Bought fast food at school** | | |
| Yes | 233 | 58 |
| No | 171 | 42 |
| **Healthy eating taught at school ($n = 374$)** | | |
| Yes | 235 | 63 |
| No | 139 | 37 |
| **Benefits of fruit and vegetables taught at school ($n = 379$)** | | |
| Yes | 248 | 65 |
| No | 131 | 35 |

## Ethics considerations

Ethics clearance for the study was obtained from the University of the Western Cape's Humanities and Social Sciences Research Ethics Committee (HSSREC) in South Africa (reference number HS20/6/19) and Eres Converge ethic review board in Zambia [reference number 2020-Aug-012). Parental consent was sought for learners to participate in the study and individual assent obtained from learners.

# Results

## Participant characteristics

Table 1 summarizes the demographic characteristics of the learners who completed the food frequency questionnaire. A total of 404 students were interviewed of whom 234 (58%) were female and 170 (42%) male. The average age of learners was 16.1 years (SD 1.4 years).

Analysis of SES characteristics showed that most students identified as being non-poor (79%); had a guardian who was employed (79%) and had weekly pocket money (75%) averaging K38 (US$2). A little over half of the students (54%) were from high-density neighborhoods and the most common household size was 6–10 people (58%).

In terms of dietary patterns, most students reported that they always or regularly ate breakfast (80%); were not on a diet (80%); and did not eat breakfast (91%) or lunch (92%) at school. More students said they bought fast foods (58%) than sugar sweetened beverages (39%) at school.

A similar proportion of students reported learning about healthy eating (63%) and benefits of eating fruit and vegetables (65%) at school.

TABLE 2 Food environment characteristics of the schools ($n = 10$).

| Characteristic | Frequency | Percentage |
|---|---|---|
| **Tuck shop present** | | |
| Yes | 10 | 100 |
| **Types of food sold in the school tuck shop** | | |
| **Snacks** | | |
| Yes | 10 | 100 |
| No | | |
| **Fruit** | | |
| Yes | 1 | 10 |
| No | 9 | 90 |
| **Fast foods** | | |
| Yes | 3 | 30 |
| No | 7 | 70 |
| ***Nshima*** | | |
| Yes | 2 | 20 |
| No | 8 | 80 |
| **Sugar sweetened beverages** | | |
| Yes | 10 | 100 |
| No | | |
| **Milk** | | |
| Yes | 1 | 10 |
| No | 9 | 90 |
| **Water** | | |
| Yes | 10 | 100 |
| No | | |
| **Food sold by vendors around school ($n = 10$)** | | |
| **Snacks** | | |
| Yes | 100 | 100 |
| No | | |
| **Fruit** | | |
| Yes | 9 | 90 |
| No | 1 | 10 |
| **Fast food** | | |
| Yes | 7 | 70 |
| No | 3 | 30 |
| ***Nshima*** | | |
| Yes | 6 | 60 |
| No | 4 | 40 |
| **Sugar sweetened beverages** | | |
| Yes | 10 | 100 |
| No | | |
| **Milk** | | |
| Yes | 8 | 80 |
| No | 2 | 20 |
| **Water** | | |
| Yes | 10 | 100 |
| No | | |

*(Continued)*

TABLE 2 (Continued)

| Characteristic | Frequency | Percentage |
|---|---|---|
| **Types of vendors around school ($n = 10$)** | | |
| **Supermarket** | | |
| Yes | 2 | 20 |
| No | 8 | 80 |
| ***Kantemba*** | | |
| Yes | 5 | 50 |
| No | 5 | 50 |
| **Street vendors** | | |
| Yes | 10 | 100 |
| No | | |
| **Grocery** | | |
| Yes | 6 | 60 |
| No | 4 | 40 |
| **Fast food restaurant** | | |
| Yes | 5 | 50 |
| No | 5 | 50 |

## Description of the school food environment

Table 2 summarizes the characteristics of the school environment for the 10 secondary schools. All schools had a tuckshop within the school premises. While snacks, SSBs and water were sold in 100% of the tuckshops, only a few schools had tuckshops selling fruit (10%), milk (10%), and *nshima* (20%). The most common type of food vendors outside the school premises was street vendors who were present around all of the schools. Groceries were found around 60% of the schools while fast food restaurants and *kantemba* were present outside 50% of the schools. Only 20% of the schools had a supermarket within walking distance of the school premises.

## Description of the identified dietary patterns

The factor loading of the 15 food groups for the four retained components from the PCA are presented in Table 3. Based on these factor loadings, we identified 4 main dietary patterns as prevalent among the students and these are described below. The name for each dietary pattern was chosen to represent the food groups with high factor loadings accounting for the most significant variation in that dietary pattern. The first component explained 29.9 % variance; the three remaining components explained 8.8, 8.5, and 7.3% of the variance in food intake, respectively.

TABLE 3 Factor loadings of the 15 food groups in the four principal components extracted from the PCA.

| Variable | Comp1: Snacking (29.9%) | Comp2: Vegetarian (8.8%) | Comp3: Health conscious (8.5%) | Comp4: Traditional (7.3%) |
|---|---|---|---|---|
| Cereal | −0.0547 | 0.0947 | 0.1100 | **0.6172** |
| Roots | 0.0264 | **0.3530** | −0.0830 | 0.2755 |
| Pulses | 0.0187 | **0.4591** | 0.0923 | −0.0124 |
| Milk | **0.3671** | −0.1337 | 0.1892 | 0.1604 |
| Fish | −0.0545 | **0.5662** | −0.1786 | 0.1389 |
| Meat | 0.2609 | −0.0714 | −0.0032 | **0.4658** |
| Insect | 0.2643 | 0.0276 | −0.0536 | **−0.3309** |
| Vegetables | 0.0061 | **0.4570** | 0.2257 | −0.2035 |
| Fruit | 0.1536 | 0.1745 | **0.4144** | −0.2615 |
| Fats | **0.3452** | −0.0179 | −0.0335 | 0.1723 |
| Sweets | **0.4611** | −0.1464 | −0.0131 | 0.0008 |
| Soft drink | **0.3584** | 0.1913 | −0.2254 | −0.0233 |
| Beverage | 0.2119 | 0.0478 | **0.3284** | 0.0050 |
| Savory snacks | **0.4322** | 0.0936 | −0.1027 | −0.1452 |
| Egg products | −0.0695 | −0.0514 | **0.7133** | 0.1019 |

The bold values indicate the food groups with factor loading above the cut off point of >0.30, which significantly contribute to the dietary pattern identified.

### "Snacking" dietary pattern

Component 1 was named "snacking" dietary pattern because it had high positive factor loadings for snacks, sweets, soft drinks, fats and milk. The most commonly consumed food items in the snacks group were *jiggies (processed corn-based snacks)* (59%), potato chips (20%), and potato crisps (15%). Fritters and sweets were the most consumed food items in the sweets group with over a quarter of adolescents saying they eat them at least three times a week. Ice-cream, chocolate and cake were relatively less frequently consumed. In the soft drinks group, locally produced products like *freezits (sugary beverage sold frozen)* (64%) and various brands of carbonated SSBs (22%) were frequently consumed compared to international brands like Coca-Cola (14%).

### "Vegetarian" dietary pattern

Component 2 was named "vegetarian" pattern as it had high positive factor loadings for roots, pulses, fish and vegetables. In the pulses food group, dried beans (14%) was the most commonly consumed legume followed by soya (11%). Modern vegetables like rape (64%), cabbage (15%), and cucumber (17%) and more traditional vegetables like pumpkin leaves (21%), sweet potato leaves (19%), and okra (15%) were most frequently consumed in the vegetable group. Dried *kapenta (small sardine like fish)* (17%) followed by fresh fish was the most frequently consumed food in the fish and shellfish group.

### "Healthy conscious" dietary pattern

Component 3 was named "health conscious" because of the high positive factor loading on fruits and eggs, and negative factor loadings on snacks, soft drinks, sweets, and fats. Bananas (41%), oranges (19%) and apples (16%) compared to local or home-grown fruits like watermelon (14%), guava (8%), and pineapples (5%) were frequently consumed in the fruits group. Nearly almost half of the adolescents reported they consume eggs three times a week or more and as many as 80% consume them at least once a week.

### Traditional dietary pattern

Component 4 was named "traditional" based on high factor loadings for cereals and meat and negative factor loadings on fruit, vegetables and snacks. The majority of adolescents (80%) said they eat breakfast meal *nshima* three times a week or more compared to roller meal *nshima* (23%). Chicken was the most common meat protein consumed with two-thirds of the adolescents reporting they ate it at least once a week. Small livestock like rabbit and goal were rarely consumed.

## Determinants/drivers of dietary patterns

Table 4 shows the results of the bivariate analysis of the dependent variables and the individual and school environment level predictors while Table 5 shows the results of multilevel analysis of the fitted model.

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TABLE 4 Bivariate analysis of the individual and food environment predictors of dietary patterns of adolescents.

| Predictor | Snacking | | | Vegetarian | | | Healthy | | | Traditional | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean pattern score | *P*-value | 95% CI | Mean pattern score | *P*-value | 95% CI | Mean pattern score | *P*-value | 95% CI | Mean pattern score | *P*-value | 95% CI |
| **Individual level predictors** | | | | | | | | | | | | |
| Gender | | | | | | | | | | | | |
| Female | 1 | | | 1 | | | 1 | | | 1 | | |
| Male | −0.526 | **0.002** | −0.860, −0.192 | −0.103 | 0.423 | −0.357, 0.150 | −0.112 | 0.366 | −0.356, 0.131 | 0.059 | 0.580 | −0.150, 0.268 |
| Age | | | | | | | | | | | | |
| 14–16 | 1 | | | 1 | | | 1 | | | 1 | | |
| 17 and above | −0.412 | **0.020** | −0.765, −0.060 | 0.082 | 0.544 | −0.184, 0.345 | −0.024 | 0.857 | −0.279, 0.232 | −0.078 | 0.489 | −0.297, 0.142 |
| Guardian employed | −0.014 | 0.944 | −0.421, 0.392 | −0.317 | **0.040** | −0.620, −0.014 | 0.194 | 0.194 | −0.099, 0.488 | 0.222 | 0.082 | −0.028, 0.473 |
| Poor | −1.053 | **0.0001** | −1.449, −0.657 | −0.360 | **0.020** | −0.664, −0.056 | −0.375 | **0.012** | −0.668, −0.083 | −0.434 | **0.001** | −0.684, −0.185 |
| Had weekly income | 0.006 | **0.0001** | 0.003, 0.009 | 0.001 | 0.645 | −0.002, 0.003 | 0.002 | 0.174 | −0.001, 0.004 | −0.001 | 0.506 | −0.003, 0.001 |
| Eating breakfast at home | | | | | | | | | | | | |
| Always | 1 | | | 1 | | | 1 | | | 1 | | |
| Regularly | −0.274 | 0.140 | −0.637, 0.090 | 0.679 | 0.628 | −0.206, 0.342 | −0.123 | 0.356 | −0.385, 0.138 | −0.364 | **0.001** | −0.586, −0.142 |
| Rarely | −0.417 | 0.129 | −0.956, 0.121 | −0.053 | 0.798 | −0.461, 0.354 | −0.055 | 0.780 | −0.440, 0.330 | −0.372 | **0.027** | −0.702, −0.042 |
| Never | −0.744 | 0.099 | −1.628, 0.139 | −0.243 | 0.473 | −0.908, 0.421 | −0.835 | **0.010** | −1.470, −0.196 | −0.936 | **0.001** | −1.474, −0.397 |
| Saw fast food adverts on TV | | | | | | | | | | | | |
| Always | 1 | | | 1 | | | 1 | | | 1 | | |
| Regularly | −0.183 | 0.342 | −0.560, 0.194 | −0.209 | 0.142 | −0.487, 0.070 | −0.088 | 0.527 | −0.361, 0.185 | −0.098 | 0.407 | −0.329, 0.133 |
| Rarely | −0.536 | 0.103 | −1.182, 0.109 | −0.428 | 0.079 | −0.906, 0.050 | 0.113 | 0.635 | −0.353, 0.578 | −0.150 | 0.458 | −0.547, 0.247 |
| Never | −0.841 | 0.316 | −2.486, 0.803 | −0.054 | 0.931 | −1.271, 1.163 | 1.011 | 0.095 | −0.177, 2.201 | 0.450 | 0.382 | −0.560, 1.459 |
| Benefits of fruit and vegetables taught | 0.063 | 0.731 | −0.298, 0.425 | −0.006 | 0.966 | −0.277, 0.265 | −0.017 | 0.896 | −0.278, 0.243 | 0.158 | 0.164 | −0.065, 0.381 |
| **School food environment predictors** | | | | | | | | | | | | |
| School tuck shop sells *nshima* | 0.060 | 0.917 | −1.063, 1.183 | −0.857 | 0.142 | −2.005, 0.288 | −0.364 | 0.250 | −0.984, 0.257 | 0.065 | 0.905 | −1.000, 1.130 |
| School tuck shop sells fruit | 1.039 | 0.119 | −0.266, 2.345 | 1.194 | 0.112 | −0.277, 2.668 | 0.624 | 0.102 | −0.125, 1.372 | 0.436 | 0.535 | −0.943, 1.816 |
| School tuckshop sells milk | −0.541 | 0.451 | −0.866, 1.949 | −0.377 | 0.651 | −2.001, 1.255 | −0.550 | 0.150 | −1.299, 0.198 | 1.606 | **0.001** | 0.640, 2.573 |
| Vendor sells snacks | −0.816 | 0.114 | −1.828, 0.196 | −0.400 | 0.535 | −1.665, 0.864 | 0.014 | 0.965 | −0.630, 0.658 | −0.873 | **0.042** | −1.717, −0.030 |
| Vendor sells fruit | −0.816 | 0.114 | −1.828, 0.196 | −0.400 | 0.535 | −1.665, 0.864 | 0.014 | 0.965 | −0.630, 0.658 | −0.873 | **0.042** | −1.717, −0.030 |
| Vendor sells *nshima* | −0.007 | 0.987 | −0.892, 0.877 | 0.866 | 0.051 | −0.004, 1.737 | −0.001 | 0.996 | −0.512, 0.510 | 0.318 | 0.407 | −0.434, 1.071 |
| Vendor sells SSB | −0.816 | 0.114 | −1.828, 0.196 | −0.400 | 0.535 | −1.665, 0.864 | 0.014 | 0.965 | −0.630, 0.658 | −0.873 | **0.042** | −1.717, −0.030 |
| Vendor sells fast foods | −0.481 | 0.278 | −1.351, 0.389 | −0.166 | 0.754 | −1.201, 0.869 | −0.297 | 0.244 | −0.796, 0.202 | 0.568 | 0.129 | −0.166, 1.301 |
| Vendor sells milk | −0.685 | 0.131 | −1.573, 0.203 | −0.024 | 0.967 | −1.140–1.092 | 0.185 | 0.508 | −0.362, 0.731 | −0.932 | **0.005** | −1.589, −0.277 |
| Vendor sells water | −0.816 | 0.114 | −1.828, 0.196 | −0.400 | 0.535 | −1.665, 0.864 | 0.014 | 0.965 | −0.630, 0.658 | −0.873 | **0.042** | −1.717, −0.030 |
| Fast food restaurant | 0.133 | 0.768 | −0.748, 1.013 | 0.479 | 0.328 | −0.480, 1.438 | 0.189 | 0.458 | −0.309, 0.687 | −0.125 | 0.751 | −0.894, 0.645 |
| Grocery | 0.308 | 0.486 | −0.559, 1.176 | −0.364 | 0.466 | −1.344, 0.615 | 0.339 | 0.161 | −0.136, 0.815 | −0.331 | 0.386 | −1.079, 0.417 |
| *Kantemba* | −0.474 | 0.273 | −1.322, 0.373 | −0.498 | 0.310 | −1.460, 0.464 | 0.059 | 0.822 | −0.453, 0.570 | −0.673 | **0.048** | −1.341, −0.005 |
| Street vendor | −1.035 | 0.138 | −2.403, 0.333 | −1.215 | 0.127 | −2.778, 0.347 | −0.573 | 0.154 | −1.361, 0.215 | 0.025 | 0.970 | −1.302, 1.352 |
| Supermarket | −0.192 | 0.736 | −1.314, 0.929 | 0.946 | 0.110 | −0.214, 2.105 | 0.170 | 0.604 | −0.472, 0.812 | 0.152 | 0.762 | −0.837, 1.142 |

Predictors with a $p < 0.05$ were considered significant. The bold values represent the significant predictors of the diaetary patterns at 95% confidence level.

TABLE 5 Multivariate analysis of the individual and food environment predictors of dietary patterns of adolescents.

| Predictor | Snacking | | | Vegetarian | | | Healthy | | | Traditional | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean pattern score | *P*-value | 95% CI | Mean pattern score | *P*-value | 95% CI | Mean pattern score | *P*-value | 95% CI | Mean pattern score | *P*-value | 95% CI |
| **Individual level predictors** | | | | | | | | | | | | |
| Gender | | | | | | | | | | | | |
| Female | 1 | | | 1 | | | 1 | | | 1 | | |
| Male | −0.285 | 0.157 | −0.678, 0.109 | −0.017 | 0.913 | −0.325, 0.291 | −0.036 | 0.812 | −0.336, 0.263 | 0.112 | 0.366 | −0.131, 0.354 |
| Age | | | | | | | | | | | | |
| 14–16 | 1 | | | 1 | | | 1 | | | 1 | | |
| 17 and above | −0.225 | 0.279 | −0.634, 0.183 | 0.229 | 0.161 | −0.091, 0.549 | 0.047 | 0.768 | −0.264, 0.357 | 0.036 | 0.777 | −0.215, 0.287 |
| Guardian employed | −0.639 | **0.006** | −1.097, −0.182 | −0.617 | **0.001** | −0.977, −0.256 | 0.055 | 0.757 | −0.293, 0.403 | 0.011 | 0.938 | −0.270, 0.292 |
| Poor | −0.679 | **0.009** | −1.186, −0.172 | −0.511 | **0.012** | −0.911, −0.112 | −0.101 | 0.609 | −0.486, 0.285 | −0.412 | **0.010** | −0.724, −0.100 |
| Had weekly income | 0.004 | **0.01** | 0.001, 0.008 | 0.0001 | 0.889 | −0.003, 0.002 | 0.001 | 0.291 | −0.001, 0.004 | −0.002 | **0.029** | −0.004, 0.0001 |
| Eating breakfast at home | | | | | | | | | | | | |
| Always | 1 | | | 1 | | | 1 | | | 1 | | |
| Regularly | −0.575 | **0.005** | −0.981, −0.169 | −0.037 | 0.822 | −0.358, 0.284 | −0.256 | 0.103 | −0.565, 0.052 | −0.428 | **0.001** | −0.677, −0.179 |
| Rarely | −0.628 | **0.035** | −1.213, −0.043 | −0.226 | 0.344 | −0.696, 0.243 | −0.145 | 0.523 | −0.589, 0.300 | −0.312 | 0.088 | −0.671, 0.046 |
| Never | −0.526 | 0.279 | −1.479, 0.426 | −0.052 | 0.891 | −0.801, 0.697 | −0.899 | **0.015** | −1.624, −0.175 | −0.860 | **0.004** | −1.446, −0.275 |
| Saw fast food adverts on TV | | | | | | | | | | | | |
| Always | 1 | | | 1 | | | 1 | | | 1 | | |
| Regularly | −0.285 | 0.169 | −0.690, 0.121 | −0.288 | 0.075 | −0.605, 0.029 | −0.079 | 0.616 | −0.388, 0.230 | −0.175 | 0.171 | −0.425, 0.075 |
| Rarely | −0.646 | 0.059 | −1.318, 0.025 | −0.554 | **0.039** | −1.081, −0.027 | 0.192 | 0.462 | −0.319, 0.702 | −0.291 | 0.167 | −0.704, 0.122 |
| Never | −1.113 | 0.18 | −2.740, 0.514 | −0.148 | 0.82 | −1.420, 1.125 | 1.008 | 0.110 | −0.230, 2.245 | 0.724 | 0.157 | −0.278, 1.726 |
| Benefits of fruit and vegetables taught | 0.245 | 0.228 | −0.153, 0.643 | 0.084 | 0.598 | −0.228, 0.396 | 0.055 | 0.722 | −0.248, 0.358 | 0.163 | 0.193 | −0.082, 0.408 |
| **School food environment predictors** | | | | | | | | | | | | |
| School tuck shop sells fruit | 1.747 | **0.002** | 0.637, 2.857 | 1.332 | **0.041** | 0.053, 2.610 | 0.443 | 0.296 | −0.389, 1.276 | 1.333 | **<0.0001** | 0.689, 1.976 |
| School tuck shop sells *nshima* | 0.003 | 0.992 | −0.561, 0.566 | −0.884 | **0.007** | −1.524, −0.244 | −0.502 | **0.020** | −0.924, −0.079 | 0.431 | **0.010** | 0.103, 0.759 |
| School tuckshop sells SSB | −0.449 | 0.262 | −1.233, 0.335 | 0.616 | 0.201 | −0.327, 1.559 | 0.650 | **0.030** | 0.063, 1.236 | −1.398 | **<0.0001** | −1.848, −0.948 |
| School tuckshop sells fast food | −0.656 | **0.025** | −1.232, −0.080 | −0.492 | 0.162 | −1.182, 0.198 | −0.278 | 0.206 | −0.708, 0.152 | 0.064 | 0.702 | −0.265, 0.394 |
| Supermarket | −0.687 | 0.107 | −1.521, 0.148 | 0.191 | 0.700 | −0.780, 1.162 | −0.248 | 0.437 | −0.873, 0.377 | −0.372 | 0.131 | −0.854, 0.111 |
| *Kantemba* | −0.719 | **0.023** | −1.338, −0.101 | −0.902 | **0.012** | −1.605, −0.198 | 0.051 | 0.831 | −0.414, 0.515 | −0.578 | **0.002** | −0.938, −0.218 |
| Fast food restaurant | 0.095 | 0.779 | −0.567, 0.756 | −0.027 | 0.944 | −0.783, 0.729 | 0.046 | 0.856 | −0.450, 0.542 | 0.052 | 0.79 | −0.332, 0.436 |

Predictors with a $p < 0.05$ were considered significant. The bold values represent the significant predictors of the diaetary patterns at 95% confidence level.



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### Individual-Level predictors of dietary patterns

From the bivariate analysis, being male ($p = 0.002$) and being above 17 years were significant predictors of snacking dietary pattern. Being poor significantly predicted all the dietary patterns while having a guardian who is employed ($p = 0.040$) and having pocket money ($p \leq 0.0001$) predicted vegetarian and snacking dietary patterns, respectively. Eating breakfast at home also predicted traditional dietary pattern.

From the multivariate model, SES and dietary habit variables were found to be significant predictors of dietary patterns. Pocket money was a significant predictor of the snacking dietary pattern: a higher amount of weekly pocket money was associated with a higher factor score and a high likelihood for the snacking dietary pattern ($p = 0.01$). Paradoxically, students who self-identified as poor were also likely to have a snacking dietary pattern ($p \leq 0.0001$) as well as vegetarian ($p = 0.009$) and traditional ($p = 0.009$) dietary pattern. In addition, vegetarian dietary pattern was significantly predicted by exposure to food advertisements: adolescents who rarely saw adverts for fast food and drinks on TV were more like to have a vegetarian dietary pattern compared to those who saw such adverts frequently. Neither age, gender nor being taught about benefits of eating fruit and vegetables significantly predicted any dietary pattern.

### School-Level predictors of dietary patterns

From the bivariate analysis, we found that none of the school level predictors significantly influenced the snacking, vegetarian and healthy dietary patterns. However, having a school tuckshop sells milk (0.001), vendor that sells milk (0.005), and *kantemba* ($P = 0.045$) predicted the traditional dietary pattern.

Results from the multivariate analysis showed the snacking dietary pattern was significantly predicted by having a tuckshop that sells fast foods within the school and the presence of a *Kantemba* ($p = 0.023$) within the school vicinity. A school tuckshop selling *nshima* significantly predicted vegetarian ($p = 0.007$), health conscious ($p = 0.02$) and traditional dietary patterns ($p = 0.01$) while a tuckshop with fruit significantly predicted traditional ($p \leq 0.0001$), vegetarian ($p = 0.041$), and snacking ($p = 0.002$), dietary patterns. Having a supermarket or fast food restaurants in the school vicinity did not significantly influence any dietary pattern.

## Discussion

This study assessed the dietary patterns of school going adolescents in urban Zambia as well as the individual and school-level determinants of these patterns. Four main dietary patterns were identified as most prevalent among the adolescents: (1) snacking pattern characterized by consumption of snacks and sweets; (2) vegetarian characterized by consumption of pulses, fish and vegetables; (3) health conscious characterized by fruits and eggs; and (4) traditional characterized by consumption of cereals and meat. Individual level SES factors like having weekly pocket money, a guardian who is employed and self-assessed poverty as well as school environment factors like having a tuckshop that sells fruits or *nshima* and having street vendors outside the school were significant predictors of the identified dietary pattern.

The snacking dietary pattern identified in this study is common and has been demonstrated in school going adolescents in developing countries (34). The predominance of the snacking dietary pattern is evidence of the ongoing nutrition transition toward more westernized diets which features fast foods, snacks and sweets, and is associated with development of cardiometabolic conditions (35). Interestingly, while the focus of nutrition advocates has largely been on the role of "big food" in the dual burden of malnutrition (36, 37), the snacking dietary pattern observed in our study was characterized by consumption of locally manufactured brands of biscuits, carbonated drinks and sweets and less of international brands. This observed difference could be because locally produced snacks are relatively cheaper than international brands. These findings highlight the need for a contextualized approach that account for country specific nuances like locally manufactured unhealthy foods in finding solutions for addressing the dual burden of malnutrition. For instance, the Zambia government has prioritized the food and beverage subsector which currently makes up 65% of the local manufacturing industry as a key driver of economic growth through job creation (38). It would be worthwhile for the government to also incentivize healthy food production so that the economic needs are balanced with promoting population health.

This study found that the relatively healthier and less common vegetarian and healthy conscious dietary patterns were also present among adolescents. The vegetarian dietary pattern in our study was characterized by high factor loadings on roots, pulses, fish, and vegetables. Consumption of similar food groups by vegetarian adolescents has been demonstrated in other contexts (39, 40). Vegetarian dietary patterns are associated with better long-term health outcomes like lower cardiovascular risk scores (41) and better bone structure (42), and should thus be promoted among adolescents. However, vegetarian dietary pattern has also been associated with negative behaviors such as eating and weight disorders among adolescents in high income countries (43). As the vegetarian dietary pattern is relatively uncommon in Zambia, additional qualitative research using phenomenological designs might be required to understand the factors associated with this dietary pattern to better inform interventions aimed at promoting uptake of such diets among adolescents.

Dietary patterns termed "traditional" are usually country specific, consisting of indigenous foods and country specific staples (19, 20, 44–46). Similarly, the traditional dietary pattern identified in this study was characterized by high factor

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loadings on cereals and meat, exemplifying the typical Zambian meal that consists of *nshima* and protein and/or relish. The persistence of consumption of traditional foods like *nshima* and vegetables associated with the vegetarian and traditional dietary patterns presents an opportunity to promote preservation of indigenous foods that has potential to contribute to slowing the nutrition transition.

Socio-economic factors like income have consistently been shown to influence dietary patterns (47). Studies from high- and middle-income countries suggest that unhealthy food consumption is relatively higher in low income populations compared to those with higher incomes (48, 49). In developing countries, evidence shows an inverse relationship between SES and unhealthy food consumption (12). Similarly, this study found a significant association between SES and dietary patterns, but the effects were observed across all dietary patterns. On one hand, adolescents who had weekly pocket money were more likely to exhibit a snacking and traditional dietary pattern while those who had an employed guardian likely had a snacking and vegetarian dietary pattern. On the other hand, self-assessed poverty significantly predicted snacking, vegetarian and traditional dietary patterns.

Unhealthy dietary patterns have been linked to lack of nutrition-related knowledge (50). For instance, a study in rural Italy found an association between nutrition knowledge scores and the number of snacks a student consumed in a day (51). Generally, adolescents in our study had a good nutrition knowledge with 75% reporting having "been taught" about the benefits of fruits and vegetables. However, having knowledge on the benefits of fruit and vegetable consumption did not significantly influence any dietary pattern in our study population. While we did not assess the accuracy of the self-reported nutrition-related knowledge, there might be need to evaluate the method used to educate adolescents on nutrition to identify how knowledge can translate to better dietary habits. This finding also supports the need for additional non-informational policy measures to promote healthier dietary patterns. Information-based interventions have been widely used for addressing nutrition related problems owing to their ease of implementation and relative lack of resistance from stakeholders (52). Despite their popularity, evidence of the impact of information-based interventions on nutrition behavior change is mixed (53). However, information-based interventions like mass campaigns remain valuable for raising public awareness in support of more effective, more contentious policy options like taxations and restrictions (54, 55).

The school food environment is an important influencer of dietary patterns as it determines the proximity, availability and cost of different food options (56). School tuckshops and semi-permanent food vendors were significantly associated with adolescents' dietary patterns in our study population compared to supermarkets and fast food restaurants, which have been identified in other studies (14–16). One reason for this finding might be that supermarkets are cost prohibitive for adolescents who our findings showed only have on average $2 dollar per week of pocket money. Our findings suggest that more informal semi-permanent vendors are key stakeholders in promoting healthy dietary patterns in urban school environments as they had a higher food variety and healthier food options compared to school tuckshops and were likely to be more affordable than supermarkets. Similar findings linking informal food vendors to increased fruit and vegetable consumption have been shown in Tanzania (57) and the US (58).

This study found that school environment level factors in addition to individual factors were significant determinants of dietary patterns in adolescents. Currently, school nutrition interventions as outlined in the school health and nutrition policy largely focus on behavior change of adolescents through educational measures (59). However, our findings imply that there is an urgent need for policy measures that will promote healthier school environments. The government in Zambia should consider implementing policies that have been shown to be effective for the school going adolescents such as healthy food provisioning policies, school food meals and school food standards (60). These policy measures should be adapted to make them relevant for the Zambian context.

This study used PCA to determine dietary patterns of school going adolescents in urban Zambia from data collected using a FFQ. Data from FFQs have been associated with recall bias because it is dependent on a respondent's memory to report what they ate over a long period of time (10). The self-reported measures of poverty and income that were used as measures of SES are also associated with social desirability bias (61). In addition, PCA does not provide information about the actual quantities consumed for each food group in each pattern (62). Therefore, these findings should be interpreted with these limitations in mind. Despite this, the large sample size and high response rate contribute to the strength of the findings. Moreover, the approach of using PCA with FFQ data has been shown to be reliable and widely used to study dietary patterns of a specific population (63, 64). Our findings therefore remain useful as they have provided insight into existing dietary patterns of school going adolescents in Zambia, a very under-researched population, and are essential for developing public health interventions. Because dietary patterns are highly context specific, the generalizability of our findings is limited to other urban settings similar to Lusaka. Future research is required to: (1) determine the dietary patterns and food environments in rural settings and (2) analyse how the different dietary patterns correlated with nutritional outcomes like body mass index which can be used to estimate risk for adverse health outcomes like diabetes and hypertension.

## Conclusion

Dietary behavior among school going adolescents in Urban Lusaka was found to be characterized by four dominant dietary patterns in this study: snacking, vegetarian, health-conscious and traditional. Individual level predictors of these dietary patterns included socio-economic characteristics such as having a guardian who was employed and an adolescent having pocket money or self-assessed poverty. School environment characteristics such as having a tuckshop that sold fruits or *nshima* and having street vendors and *kantemba* outside the school vicinity were also associated with the four identified dietary patterns. The significance of both individual behavioral and school environment level factors in influencing dietary patterns in this context points to the need for solutions that go beyond behavior change based educational interventions if Zambia is to promote healthy food consumption patterns among its school-going adolescents.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by ERES Converge (2020-Aug-012) in Zambia and the University of the Western Cape's Humanities and Social Sciences Research Ethics Committee (HSSREC) in South Africa (Reference Number: HS20/6/19). Participation in the study was voluntary. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin. All the participants below 18 years provided written assent before the could be enrolled in the study.

## Author contributions

MM: conceptualization, formal analysis, investigation, and writing—original draft preparation. MM, AT, PD, and ZM methodology and writing—review and editing. AT, PD, and ZM validation. All authors contributed to the article and approved the submitted version.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2022.956109/full#supplementary-material

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# The impact of the COVID-19 pandemic on lifestyle patterns: Does gender matter?

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**Background:** The COVID-19 pandemic has significantly impacted individuals to deviate from normal lifestyle behaviors. But, there is a paucity of studies conducted in Bangladesh assessing how lifestyle patterns (i.e., smoking, drug use, physical exercise) have changed after the pandemic, which was investigated in this study.

**Methods:** An online-based cross-sectional survey was conducted among a total of 756 Bangladeshi young adults between April 1 and 13, 2020. Lifestyle patterns data were collected based on two periods from the COVID-19 pandemic inception point in the country, (i) '1 year before', and (ii) '1 year after'. Basic descriptive statistics (i.e., frequency and percentages) and Chi-square tests were performed to examine the associations of the independent variables in relation to lifestyle patterns.

**Results:** A 0.2 and 4.7% reduction in smoking and physical exercise, respectively, was observed after the pandemic. But the prevalence of drug use was 1.5% before the COVID-19 pandemic, which rose to 1.9% during the pandemic; representing a 0.4% increment. The changes in lifestyle patterns before and during the COVID-19 pandemic was statistically significant only for physical exercise. Of the gender, male participants were more prevalent in smoking, drug use, and performing physical exercise in both periods.

**Conclusion:** It is suggested to increase awareness concerning adverse effects of drug use and not performing physical exercise, where the gender-based focus is highly appreciated.

KEYWORDS
**COVID-19, lifestyle patterns, physical activity, substance use, prevalence, behavioral factors**

## Introduction

The virus, 2019-nCoV pneumonia, emerged from a Chinese fish market in Wuhan at the beginning of December 2019. Subsequently, the outbreak became a Public Health Emergency of International Concern, and later as a pandemic. The pandemic has soon become a global health issue affecting all aspects of human life. Due to the changes

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imposed by the pandemic, there is a massive impact on lifestyle (1, 2). For instance, Akter et al. found that there was a 4.4% increment in overweight after the pandemic inception in Bangladesh (30.5% 'before' the COVID-19 pandemic, to 34.9% 'during' the pandemic) (3). Such changes further impact mental health status, including suicidality (4). However, a Ugandan study based on a hospital registry found that 5.90% of adolescents had substance use disorders before the pandemic, which raise to 9.80% during the pandemic; but such change was not statistically significant (5). However, the impact of the pandemic on behavioral aspects is still an issue of consideration.

Behavioral health can be defined as an accumulation of physical and mental wellbeing where individuals play a crucial role in maintaining health and preventing disease and dysfunction (6). Healthy lifestyle behavior such as being free from substance use, performing regular physical exercise, etc., can often affect mental health. It can affect several factors such as emotional wellbeing, healthy behavioral adjustment, relative relief from anxiety and disabling symptoms, and the ability to build a meaningful relationship along with difficulties and challenges (7). However, lifestyle is viewed as a multidimensional construct encompassing a broader range of behaviors, including smoking, alcohol or substance abuse, stress management, social support, screen time, and digital technology usage (8–10). During the COVID-19 (Coronavirus disease) pandemic, people's lifestyles changed due to the implementation of different non-pharmaceutical measures such as social distancing, lockdowns, quarantine for suspected cases, and shutting down of educational institutions, and restricted all types of movement except emergency cases (11, 12). Consequently, sedentary behavior, abnormal sleeping patterns, smoking habits, physical inactivity, and consuming alcohol have been increased (13–15), which are the common risk factors for several non-communicable diseases, including mental health problems (16–19).

In the prior pandemic, such as SARS (Severe acute respiratory syndrome), evidence suggests an increment in drinking and smoking frequency compared to the period before the pandemic (20). Evidently, during the COVID-19 pandemic, several studies had reported changes in daily lifestyle behaviors (i.e., physical inactivity, smoking, and drug/substance use) (21, 22). For instance, consumption of recreational drugs has increased since the pandemic in the USA and Canada; that is, an increment of 23 and 16% for alcohol abuse and drug abuse among the prior pandemic consumers (23). On the other hand, more than 17 and 30% of Italian people reported increasing their alcohol and cigarette consumption, respectively, whereas many former consumers started reusing (21). Such increment is because stressed people during the lockdown time preferred to cope with emotional distress by unhealthy stress coping behaviors such as smoking and drug use; cross-national studies also support that (24). In addition, the pandemic was also responsible for changes in physical activity as well as eating behaviors due to the resulting confinement that ensured. For instance, a study conducted amongst Italians indicated that 56% had reduced the time devoted to physical activity during the pandemic, whereas inappropriate eating behavior such as increasing unhealthy food without increasing healthy ones had increased to 29.9% (21). Other studies also confirmed that both physically active or inactive people before the pandemic are less likely to perform physical activities; for example, 40.5 and 22.4% reduction among Canadian physically inactive and active people are reported after the pandemic inception (25).

In line with the situation, Bangladeshi people are anticipated to be at higher risk of performing unhealthy lifestyles, although there is a lack of evidence. For example, a study conducted during the early phase of the pandemic reported a prevalence of 37.9% physical inactivity (<600 MET–min/week), whereas a high level of sedentary behaviors (≥8 h/day) was also reported (20.9%) (26). Nevertheless, another study reported a reduction in physical activity at about 6.5% (4). Furthermore, a 15.9% increment in elderly's tobacco use after the inception of the pandemic was also found (27). Evidently, there is a need for further studies investigating the impact of the pandemic on unhealthy lifestyles for adopting appropriate policy and practice. Therefore, this study aimed to explore – (i) the prevalence of lifestyle patterns (smoking, drug use, and physical exercise) based on two time periods, 1 year before and 1 year after the pandemic inception in Bangladesh, (ii) the changes in these lifestyle patterns after the pandemic inception, and (iii) the factors influencing these lifestyle patterns.

## Methods

### Study procedure, participants, and ethics

A cross-sectional online survey was carried out among Bangladeshi young adults from April 1 to 13, 2020. Popular social media platforms (i.e., Facebook, WhatsApp) in Bangladesh were used to circulate the survey link. The criteria for participating in this study included being a Bangladeshi young adult resident. The data was collected using the snowball sampling technique to ensure maximum participation in the study. Approximately 782 data were collected, where a total of 756 data was used for final analysis after removing incomplete responses. The Helsinki Declaration 2013 was also considered in the study to ensure ethical aspects of the participants. Before conducting the study, an IRB approval was granted by the ethics committee at the Institute of Allergy and Clinical Immunology of Bangladesh (Reference: IRBIACIB/CEC/03202032). An online consent form was required for participating in the study.

Abbreviations: COVID-19, Coronavirus disease 2019; SARS, severe acute respiratory syndrome; MET, Min per week; SPSS, Statistical Software for Social Science.

## Sample size calculation

The sample size was calculated using the following formula

$$n = z^2pq/d^2$$

Where, $n$ = sample size, $z$ = 1.96 for 95% of confidence interval, $p$ = prevalence, 50%; $q$ = (1-p); $d$ = 5% margin of error. In this way, the estimated sample size is 384. Considering a 10% non-response rate, the final estimated sample size was 424.

## Measures

### Independent variables

A number of sociodemographic information such as age, gender, marital status, religion, educational qualification, socio-economic status (categorized based on 15,000 BDT intervals for higher, middle, and lower class), occupation, current residence status, etc. were collected. Participants were asked if they were suffering from any kind of comorbidities such as asthma, hypertension, heart disease, cardiovascular disease, cancer, diabetes, and others, based on a binary response. In addition, perceived self-rated health condition was assessed using a five-point Likert item (very good to very bad). Of the COVID-19 related issues, three questions with binary responses were asked. This included if (i) the participant themselves were infected with COVID-19, (ii) their family members/friends were infected with COVID-19, and (iii) any deaths occurred within family/friends due to COVID-19 infection.

### Dependent variables

Unhealthy lifestyle patterns such as smoking, drug use, and physical exercise were considered in this study as the dependent variables. A total of three items with binary responses (yes/no) were included to assess the participants' lifestyle patterns based on two time periods (that is, 1 year before and 1 year after the COVID-19 pandemic inception in Bangladesh). Firstly, questions were asked about whether they were smokers and drug users (i) before the pandemic and (ii) during the pandemic (28). Again, if the participants performed physical exercise at least 30 min daily (i) before the pandemic and (ii) during the pandemic – they were asked (29–31).

## Statistical analysis

Before conducting the analysis, data were cleaned by Microsoft Excel 2019. Then data were analyzed using the Statistical Package for Social Science (SPSS) version 25. Descriptive statistics (i.e., percentage, frequency, mean & standard deviation) and inferential statistics (i.e., Chi-square test) were performed. A Chi-square test was performed to examine the associations between dependent and independent variables. Smoking, drug use, and physical inactivity were considered as the dependent variables for the 'before' and 'during' the COVID-19 pandemic, whereas sociodemographic variables and COVID-19 related factors were the predictors. Additionally, the overall changes in the lifestyle patterns (i.e., smoking, drug use, and physical exercise) considering the pre and post pandemic have been observed by the McNemar's test. A $p$-value of $<0.05$ was set as statistically significant.

# Results

## Characteristics of the participants

Table 1 presents the characteristics of the participants. Most of them were male (59%), aged between 21 and 23 years (47.9%), unmarried (90.6%), and Muslim (89.4%). About 80% of the participants had more than secondary education, 35.7% were from a higher-class family, and 82.7% were students. Furthermore, higher participants were recorded from the urban region (64.8%), about 56.2% reported good health status, 15.5% reported very good health status, and 27.2% were suffering from comorbidities. Moreover, only 6% were infected with COVID-19, 42.9 and 12.8% of the participants reported that their family or friends were COVID-19 infected and died being infected with the virus, respectively (Table 1).

## Prevalence rate of lifestyle patterns and its changes

The prevalence rates of smoking, drug use, and physical exercise are reported in Tables 2, 3. About 12.4 and 12.2% of the participants reported smoking before and during the pandemic, respectively, which means that there is a 0.2% reduction in smoking behavior (Table 2). In addition, there was a 0.4% increment in drug use after the pandemic inception (from 1.5 before to 1.9% during the pandemic) (Table 3), whereas physical exercise decreased by 4.7% (from 49.3 before to 54.0% during the pandemic) (Table 4). The changes were significant only in terms of physical exercise ($p < 0.05$); whereas non-significant results were found for both smoking and drug use ($p > 0.05$).

## Association between the explanatory variables and smoking

Table 2 presents the associations between the explanatory variables and smoking status. Participants aged ≥24 years reported a higher rate of smoking than participants aged ≤20 years and 21 to 23 years before the pandemic ($p$ = 0.063);

TABLE 1 Distribution of the sociodemographic variables of the respondents.

| Variables | Frequency (*n*) | Percentage (%) |
|---|---|---|
| **Age** | | |
| ≤20 years | 228 | 30.2 |
| 21 to 23 years | 362 | 47.9 |
| ≥24 years | 166 | 22 |
| **Gender** | | |
| Female | 310 | 41 |
| Male | 446 | 59 |
| **Marital status** | | |
| Unmarried | 685 | 90.6 |
| Married | 71 | 9.4 |
| **Religion** | | |
| Muslim | 676 | 89.4 |
| Hindu | 80 | 10.6 |
| **Education level** | | |
| Secondary | 151 | 20 |
| More than secondary | 605 | 80 |
| **Socio-economic status** | | |
| Lower class | 189 | 25 |
| Middle class | 237 | 31.3 |
| Higher class | 270 | 35.7 |
| **Occupation** | | |
| Students | 625 | 82.7 |
| Non-students | 131 | 17.3 |
| **Residence** | | |
| Rural | 266 | 35.2 |
| Urban | 490 | 64.8 |
| **Perceived health status** | | |
| Very good | 117 | 15.5 |
| Good | 425 | 56.2 |
| Neither good nor bad | 184 | 24.3 |
| Bad | 27 | 3.6 |
| Very bad | 3 | 0.4 |
| **Comorbidity status** | | |
| Yes | 206 | 27.2 |
| No | 550 | 72.8 |
| **Personal COVID-19 infection** | | |
| No | 711 | 94 |
| Yes | 45 | 6 |
| **Friends or family COVID-19 infection** | | |
| No | 432 | 57.1 |
| Yes | 324 | 42.9 |
| **Friends or family COVID-19 death** | | |
| No | 659 | 87.2 |
| Yes | 97 | 12.8 |

whereas participants aged between 21 and 23 years reported a higher rate of smoking during the pandemic than ≤20 years and ≥24 years ($p = 0.017$). Male participants reported a significantly higher tendency to smoke than their counterparts in both periods ($p < 0.001$). Despite these, no other variables were significantly associated with the smoking status (Table 2).

## Association between the explanatory variables and drug use

Table 3 presents the associations between the explanatory variables and drug use. The age group was not statistically significant with drug use at both times, but the gender was. More specifically, male participants were predominantly higher among the drug users both before ($p = 0.005$) and during ($p = 0.009$) the pandemic. Also, it is observed that 5% of the participants, Hindu in religious status during the pandemic, were more likely to be drug users than Muslims (1.5%; $p = 0.027$). In addition, drug use was more prevalent among the COVID-19 infected participants ($p = 0.183$) (Table 3).

## Association between the explanatory variables and physical exercise

Table 4 presents the associations between the explanatory variables and physical exercise. Gender showed a significant difference in terms of physical exercise. That is, female participants were less physically active than their male counterpart (42.9 vs. 56.1%, $p < 0.001$ for before pandemic; and 39 vs. 50.9%, $p = 0.001$ for during pandemic). Also, lower-class people were physically more active than others, showing a significant relationship before and during the pandemic. Participants who perceived their health status as very good reported more physical exercise than others in both periods ($p < 0.05$). In addition, these participants' friends and family who were infected with COVID-19 were less likely to be active in performing physical exercise during the pandemic ($p < 0.05$) (Table 4).

# Discussion

The COVID-19 pandemic-related movement restriction and confinement are essential to suppress the infection rate of the virus. Such a situation can be stressful and may affect the way of normal living, leading to prolonged stays at home. As a result, is it not surprising to observe changes in common lifestyle patterns such as eating habits, physical activity, substance use, etc. However, for the first time in Bangladesh, this study investigated

TABLE 2 Associations between the independent variables and smoking.

| Variables | Before COVID-19 pandemic | | | During COVID-19 pandemic | | |
|---|---|---|---|---|---|---|
| | Yes (94, 12.4%) | No (662, 87.6%) | $\chi^2$ (*p*-value) | Yes (92, 12.2%) | No (664, 87.8%) | $\chi^2$ (*p*-value) |
| **Sociodemographic information** | | | | | | |
| **Age** | | | | | | |
| ≤20 years | 19, 8.3 | 209, 91.7 | 5.514 (0.063) | 16, 7 | 212, 93 | 8.172 (**0.017**) |
| 21 to 23 years | 49, 13.5 | 313, 86.5 | | 53, 14.6 | 309, 85.4 | |
| ≥24 years | 26, 15.7 | 140, 84.3 | | 23, 13.9 | 143, 86.1 | |
| **Gender** | | | | | | |
| Female | 4, 1.3 | 306, 98.7 | 59.931 (**<0.001**) | 3, 1 | 307, 99 | 61.687 (**<0.001**) |
| Male | 90, 20.2 | 356, 79.8 | | 89, 20 | 357, 80 | |
| **Marital status** | | | | | | |
| Unmarried | 87, 12.7 | 598, 87.3 | 0.477 (0.490) | 84, 12.3 | 601, 87.7 | 0.06 (0.807) |
| Married | 7, 9.9 | 64, 90.1 | | 8, 11.3 | 63, 88.7 | |
| **Religion** | | | | | | |
| Muslim | 84, 12.4 | 592, 87.6 | <0.001 (0.985) | 82, 12.1 | 594, 87.9 | 0.009 (0.924) |
| Hindu | 10, 12.5 | 70, 87.5 | | 10, 12.5 | 70, 87.5 | |
| **Education level** | | | | | | |
| Secondary | 21, 13.9 | 130, 86.1 | 0.376 (0.540) | 20, 13.2 | 131, 86.8 | 0.204 (0.651) |
| More than secondary | 73, 12.1 | 532, 87.9 | | 72, 11.9 | 533, 88.1 | |
| **Socio-economic status** | | | | | | |
| Lower class | 19, 10.1 | 170, 89.9 | 2.140 (0.343) | 21, 11.1 | 168, 88.9 | 1.067 (0.587) |
| Middle class | 35, 14.8 | 202, 85.2 | | 34, 14.3 | 203, 85.7 | |
| Higher class | 36, 13.3 | 234, 86.7 | | 33, 12.2 | 237, 87.8 | |
| **Occupation** | | | | | | |
| Students | 72, 11.5 | 553, 88.5 | 2.767 (0.096) | 70, 11.2 | 555, 88.8 | 3.171 (0.075) |
| Non-students | 22, 16.8 | 109, 83.2 | | 22, 16.8 | 109, 83.2 | |
| **Residence** | | | | | | |
| Rural | 30, 11.3 | 236, 88.7 | 0.503 (0.478) | 31, 11.7 | 235, 88.3 | 0.102 (0.750) |
| Urban | 64, 13.1 | 426, 86.9 | | 61, 12.4 | 429, 87.6 | |
| **Perceived health status** | | | | | | |
| Very good | 21, 17.9 | 96, 82.1 | 7.724 (0.102) | 20, 17.1 | 97, 82.9 | 7.322 (0.120) |
| Good | 43, 10.1 | 382, 89.9 | | 42, 9.9 | 383, 90.1 | |
| Neither good nor bad | 28, 15.2 | 156, 84.8 | | 28, 15.2 | 156, 84.8 | |
| Bad | 2, 7.4 | 25, 92.6 | | 2, 7.4 | 25, 92.6 | |
| Very bad | – | 3, 100.0 | | – | 3, 100 | |
| **Comorbidity status** | | | | | | |
| Yes | 23, 11.2 | 183, 88.8 | 0.518 (0.419) | 24, 11.7 | 182, 88.3 | 0.071 (0.789) |
| No | 71, 12.9 | 479, 87.1 | | 68, 12.4 | 482, 87.6 | |
| **COVID-19 related information** | | | | | | |
| **Personal COVID-19 infection** | | | | | | |
| No | – | – | – | 87, 12.2 | 624, 87.8 | 0.050 (0.823) |
| Yes | – | – | | 5, 11.1 | 40, 88.9 | |
| **Friends or family COVID-19 infection** | | | | | | |
| No | – | – | – | 52, 12.0 | 380, 88.0 | 0.017 (0.898) |
| Yes | – | – | | 40, 12.3 | 284, 87.7 | |
| **Friends or family COVID-19 death** | | | | | | |
| No | – | – | – | 85, 12.9 | 574, 87.1 | 2.554 (0.110) |
| Yes | – | – | | 7, 7.2 | 90, 92.8 | |

The bold values indicated that the results are significant in the test.

TABLE 3 Association between the independent variables and drug use.

| Variables | Before COVID-19 pandemic | | | During COVID-19 pandemic | | |
|---|---|---|---|---|---|---|
| | Yes (11, 1.5%) | No (745, 98.5%) | $\chi^2$ (*p*-value) | Yes (14, 1.9%) | No (742, 98.1%) | $\chi^2$ (*p*-value) |
| **Sociodemographic information** | | | | | | |
| **Age** | | | | | | |
| ≤20 years | 2, 0.9 | 226, 99.1 | 0.778 (0.678) | 4, 1.8 | 224, 98.2 | 0.371 (0.831) |
| 21 to 23 years | 6, 1.7 | 356, 98.3 | | 6, 1.7 | 356, 98.3 | |
| ≥24 years | 3, 1.8 | 163, 98.2 | | 4, 2.4 | 162, 97.6 | |
| **Gender** | | | | | | |
| Female | 0, 0 | 310, 100 | 7.759 **(0.005)** | 1, 0.3 | 309, 99.7 | 6.761 **(0.009)** |
| Male | 11, 2.5 | 435, 97.5 | | 13, 2.9 | 433, 97.1 | |
| **Marital status** | | | | | | |
| Unmarried | 11, 1.6 | 674, 98.4 | 1.157 (0.282) | 13, 1.9 | 672, 98.1 | 0.085 (0.771) |
| Married | 0, 0 | 71, 100 | | 1, 1.4 | 70, 98.6 | |
| **Religion** | | | | | | |
| Muslim | 8, 1.2 | 668, 98.8 | 3.286 (0.070) | 10, 1.5 | 666, 98.5 | 4.879 **(0.027)** |
| Hindu | 3, 3.8 | 77, 96.3 | | 4, 5.0 | 76, 95.0 | |
| **Education level** | | | | | | |
| Secondary | 3, 2.0 | 148, 98.0 | 0.372 (0.542) | 4, 2.6 | 147, 97.4 | 0.660 (0.417) |
| More than secondary | 8, 1.3 | 597, 98.7 | | 10, 1.7 | 595, 98.3 | |
| **Socio-economic status** | | | | | | |
| Lower class | 4, 2.1 | 185, 97.9 | 0.749 (0.688) | 6, 3.2 | 183, 96.8 | 2.419 (0.298) |
| Middle class | 4, 1.7 | 233, 98.3 | | 5, 2.1 | 232, 97.9 | |
| Higher class | 3, 1.1 | 267, 98.9 | | 3, 1.1 | 267, 98.9 | |
| **Occupation** | | | | | | |
| Students | 7, 1.1 | 618, 98.9 | 2.823 (0.093) | 9, 1.4 | 616, 98.6 | 3.366 (0.067) |
| Non-students | 4, 3.1 | 127, 96.9 | | 5, 3.8 | 126, 96.2 | |
| **Residence** | | | | | | |
| Urban | 4, 1.5 | 262, 98.5 | 0.007 (0.934) | 6, 2.3 | 260, 97.7 | 0.368 (0.544) |
| Rural | 7, 1.4 | 483, 98.6 | | 8, 1.6 | 482, 98.4 | |
| **Perceived health status** | | | | | | |
| Very good | 3, 2.6 | 114, 97.4 | 1.716 (0.788) | 4, 3.4 | 113, 96.6 | 3.972 (0.410) |
| Good | 5, 1.2 | 420, 98.8 | | 5, 1.2 | 420, 98.8 | |
| Neither good nor bad | 3, 1.6 | 181, 98.4 | | 5, 2.7 | 179, 97.3 | |
| Bad | – | 27, 100 | | – | 27, 100.0 | |
| Very bad | – | 3, 100 | | – | 3, 100 | |
| **Comorbidity status** | | | | | | |
| Yes | 1, 0.5 | 205, 99.5 | 1.857 (0.173) | 3, 1.5 | 203, 98.5 | 0.244 (0.622) |
| No | 10, 1.8 | 540, 98.2 | | 11, 2.0 | 539, 98.0 | |
| **COVID-19 related information** | | | | | | |
| **Personal COVID-19 infection** | | | | | | |
| No | – | – | – | 12, 1.7 | 699, 98.3 | 1.769 (0.183) |
| Yes | – | – | | 2, 4.4 | 43, 95.6 | |
| **Friends or family COVID-19 infection** | | | | | | |
| No | – | – | – | 8, 1.9 | 424, 98.1 | <0.001 (1.00) |
| Yes | – | – | | 6, 1.9 | 318, 98.1 | |
| **Friends or family COVID-19 death** | | | | | | |
| No | – | – | – | 13, 2.0 | 646, 98.0 | 0.413 (0.521) |
| Yes | – | – | | 1, 1.0 | 96, 99.0 | |

The bold values indicated that the results are significant in the test.

TABLE 4 Association between the independent variables and physical exercise.

| Variables | Before COVID-19 pandemic | | | During COVID-19 pandemic | | |
|---|---|---|---|---|---|---|
| | Yes (383, 50.7%) | No (373, 49.3%) | $\chi^2$ (*p*-value) | Yes (348, 46%) | No (408, 54%) | $\chi^2$ (*p*-value) |
| **Sociodemographic information** | | | | | | |
| **Age** | | | | | | |
| ≤20 years | 112, 49.1 | 116, 50.9 | 1.491 (0.474) | 104, 45.6 | 124, 54.4 | 1.901 (0.386) |
| 21 to 23 years | 180, 49.7 | 182, 50.3 | | 160, 44.2 | 202, 55.8 | |
| ≥24 years | 91, 54.8 | 75, 45.2 | | 84, 50.6 | 82, 49.4 | |
| **Gender** | | | | | | |
| Female | 133, 42.9 | 177, 57.1 | 12.653 (**<0.001**) | 121, 39.0 | 189, 61.0 | 10.363 (**0.001**) |
| Male | 250, 56.1 | 196, 43.9 | | 227, 50.9 | 219, 49.1 | |
| **Marital status** | | | | | | |
| Unmarried | 343, 50.1 | 342, 49.9 | 1.010 (0.315) | 311, 45.4 | 374, 54.6 | 1.166 (0.280) |
| Married | 40, 56.3 | 31, 43.7 | | 37, 52.1 | 34, 47.9 | |
| **Religion** | | | | | | |
| Muslim | 344, 50.9 | 332, 49.1 | 0.131 (0.718) | 313, 46.3 | 363, 53.7 | 0.188 (0.665) |
| Hindu | 39, 48.8 | 41, 51.2 | | 35, 43.8 | 45, 56.3 | |
| **Education level** | | | | | | |
| Secondary | 77, 51.0 | 74, 49.0 | 0.008 (0.927) | 66, 43.7 | 85, 56.3 | 0.410 (0.522) |
| More than secondary | 306, 50.6 | 299, 49.4 | | 282, 46.6 | 323, 53.4 | |
| **Socio-economic status** | | | | | | |
| Lower class | 120, 63.5 | 69, 36.5 | 13.352 (**0.001**) | 114, 60.3 | 75, 39.7 | 19.249 (**<0.001**) |
| Middle class | 110, 46.4 | 127, 53.6 | | 106, 44.7 | 131, 55.3 | |
| Higher class | 135, 50.0 | 135, 50.0 | | 108, 40.0 | 162, 60.0 | |
| **Occupation** | | | | | | |
| Student | 306, 49.0 | 319, 51.0 | 4.177 (**0.041**) | 282, 45.1 | 343, 54.9 | 1.207 (0.272) |
| Non-student | 77, 58.8 | 54, 41.2 | | 66, 50.4 | 65, 49.6 | |
| **Residence** | | | | | | |
| Urban | 139, 52.3 | 127, 47.7 | 0.417 (0.518) | 138, 51.9 | 128, 48.1 | 5.650 (0.017) |
| Rural | 244, 49.8 | 246, 50.2 | | 210, 42.9 | 280, 57.1 | |
| **Perceived health status** | | | | | | |
| Very good | 66, 56.4 | 51, 43.6 | 10.235 (**0.037**) | 62, 53.0 | 55, 47.0 | 24.560 (**<0.001**) |
| Good | 227, 53.4 | 198, 46.6 | | 218, 51.3 | 207, 48.7 | |
| Neither good nor bad | 80, 43.5 | 104, 56.5 | | 58, 31.5 | 126, 68.5 | |
| Bad | 9, 33.3 | 18, 66.7 | | 9, 33.3 | 18, 66.7 | |
| Very bad | 1, 33.3 | 2, 66.7 | | 1, 33.3 | 2, 66.7 | |
| **Comorbidity status** | | | | | | |
| Yes | 105, 51.0 | 101, 49.0 | 0.011 (0.917) | 94, 45.6 | 112, 54.4 | 0.018 (0.892) |
| No | 278, 50.5 | 272, 49.5 | | 254, 46.2 | 296, 53.8 | |
| **COVID-19 related information** | | | | | | |
| **Personal COVID-19 infection** | | | | | | |
| No | – | – | – | 326, 45.9 | 385, 54.1 | 0.157 (0.692) |
| Yes | – | – | | 22, 48.9 | 23, 51.1 | |
| **Friends or family COVID-19 infection** | | | | | | |
| No | – | – | – | 216, 50.0 | 216, 50.0 | 6.389 (**0.011**) |
| Yes | – | – | | 132, 40.7 | 192, 59.3 | |
| **Friends or family COVID-19 death** | | | | | | |
| No | – | – | – | 303, 46.0 | 356, 54.0 | 0.006 (0.939) |
| Yes | – | – | | 45, 46.4 | 52, 53.6 | |

The bold values indicated that the results are significant in the test.

the prevalence rates of smoking, drug use, and physical exercise 'before' and 'during' the pandemic and the factors associated with these lifestyle patterns in both periods. In addition, how the prevalence rate of these patterns has changed after the pandemic is also observed.

It was found that there was a 0.2% reduction in smoking status after the pandemic's inception, although the prevalence of drug use was reported to be increased by 0.4%. However, the changes were not significant based on pre and post-pandemic COVID-19 status. This finding is contradictory to the only prior Bangladeshi study that observed a 15.9% increment in tobacco use among the elderly (27); this may be due to the difference between the study population of the two studies (i.e., young adults are considered in the present study) as well as other factors such as study time for considering the change from the pandemic inception point. Similar to this study, some studies reported decreasing the use of tobacco products after the inception of the pandemic (e.g., 3.3% in Italy (13), 58.8% (32), despite most of the studies suggesting there is an increment in smoking and drug use (21, 23, 24, 27). However, an increasing trend of drug use after the pandemic was found (i.e., by 0.4 from 1.5 to 1.9%). Similarly, in the Netherlands, about 41.3% of the respondents reported using more cannabis, whereas 49.4% used it more often than before (33). Another study in the USA and Canada reported that about 16% of the respondents were using recreational drugs (23), whereas the increment rate was 17% in Italy (21).

As demonstrated in previous studies, physical inactivity can be influenced by lack of motivation, time availability, and restricted access to parks, dance, and fitness centers (22). The present study reported that physical activity was significantly reduced by 4.7%, which is consistent with the prior study conducted in Bangladesh, suggesting a 6.5% reduction in physical activity (i.e., 40.7% before the pandemic vs. 47.2% during the pandemic) (4). Similarly, a study from neighboring countries such as India found a 12.5% reduction (i.e., 38.5 and 50.5% before and during the pandemic) in not routinely 30 min moderate-intensity aerobic exercises or sports (22). Other studies confirmed the present findings, for example, 56% reduction in Italy (21), 40.5, and 22.4% reduction for these physically active and inactive people, respectively, before the pandemic in Canada (25).

All forms of drug abuse, including initiation, escalation of use, addiction, and relapse following abstinence, present in gender differences (34). Regarding gender and lifestyle patterns, the male gender was highly prone to tobacco and drug use at both times. Consistent with the prior Bangladeshi findings, 0.5 and 20.7% substance use, including smoking, drug, and alcohol use for females and males, was reported (28). A review of studies reported that males are at a 2–3 times higher risk of drug dependency, where such difference can be because of sociodemographic factors and biological factors. Sex chromosomes alone or by associating with gonadal hormones influence gender-based risk (34). During the COVID-19 pandemic, similar findings to this study were reported. For example, a higher prevalence of substance use behavior is reported among Chinese males compared with females (i.e., 32.7, 11.6, and 7.2% of hazardous, harmful, and dependent alcohol use vs. 24.9, 1.9, and 1.2%) (35). Similarly, drugs like cannabis use increased among the Netherlands population during the early period of the COVID-19 pandemic compared to before the lockdown period, where females were reportedly using more cannabis (i.e., 50.4% for females and 36.5% for males) (33).

Although males were found at a higher risk of substance use behaviors in this study, females reported performing less physical exercise. Such gender differences in performing physical activities can be determined by social determinants related to gender norms, social acceptability of exercise, cultural acceptance of females to go outside for exercise, etc. (36, 37). During the COVID-19 pandemic, the Bangladeshi males are reported to be 1.3 times more at risk of physically inactive than females (38.9 vs. 36.4%) (26), which is consistent with this study in both periods before and during the pandemic. According to a Spanish study, male participants had remarkably decreased vigorous physical activity than female participants (21% for females and 9% for males), whereas it was 8.2 and 11% for moderate physical activities (38).

With respect to other sociodemographic factors of this study, young participants were found to be at more risk of being smokers after the pandemic's inception. But the other study reported opposite findings; for example, a 3.3 times higher risk of smoking during the pandemic was found among the Bangladeshi elderlies aged 60–69 years compared to 70 and above (27). Another study reported that physical inactivity was higher in upper-class people (47.5%) in comparison to lower and middle classes (23 and 35.9%) (26), which was the same in this study. People of the higher class are at more risk of performing less physical exercise; this may be due to avoiding social interaction in fear of COVID-19 infection and being confined as they have more financial support from other groups. In addition, the participants with poor self-rated health status were less likely to perform physical exercise. As well as having a history of COVID-19 infection in the participants' family or friend circles, they were at a higher likelihood of physical inactivity, which can be because of psychological distress turned by their COVID-19 suffering hindering performing physical exercise.

The study, for the first time, assesses (i) the prevalence rates of lifestyle patterns based on before and during the COIVD-19 pandemic, (ii) the factors associated with such rate, and (iii) the changes in lifestyle patterns prevalence rate after the pandemic. As an exploratory study, the findings reported in this study could add value to implicate further study and direct policymaking. However, it is worth mentioning that this study's findings can be limited because its study nature is cross-sectional, where causality can be inferred. Secondly, an online survey may involve selection bias, information bias, and also memory recall bias. Thirdly, the study involved the country's young adults, which can be limited because of not involve the general population. Fourthly, this study strength would be better if it was longitudinal in nature to assess such data types and avoid memory recall bias and collected data by repeatedly over a longer period of time. Finally, diet modification related factors were not considered for this study, which is one of the major factor of lifestyle related issues.

## Conclusions

Overall, this study demonstrates how the COVID-19 pandemic affects the lifestyle patterns of Bangladeshi young adults. Some of the baseline data with respect to the pandemic effect is provided, showing that the rate of smoking and physical activity was reduced during the COVID-19 pandemic compared to the before pandemic, although an inverse finding was reported for drug use and such changes were significant only for physical exercise. Male participants were more prevalent than females to be involved in unhealthy lifestyles like smoking and drug use, although females performed less physical exercise. Therefore, increasing awareness concerning the adverse effects of drug use and not performing physical exercise is suggested, where the gender-based focus is highly appreciated. Because it would be more effective to pay more attention to males while implementing any programs related to the adverse effect of drug use, whereas females can be motivated and provided familial and social support that includes ensuring available time and place for exercise to increase their participation in physical activities, which might prevent cardiovascular disease related complications as suggested by pervious literatures (39–41).

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by Institute of Allergy and Clinical Immunology of Bangladesh. The patients/participants provided their written informed consent to participate in this study.

## Author contributions

MMa planned the study. NS and FA-M analyzed the data and contributed to data interpretation. NS, MA, FA-M, and MMa wrote the first draft. Critical review and edits were done by all authors, especially MMu and MMa. All authors partook in project implementation and management. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The reviewer SD declared a shared affiliation with the authors MMu, IH, FA-M, and MMa to the handling editor at the time of the review.

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# Life history trade-offs associated with exposure to low maternal capital are different in sons compared to daughters: Evidence from a prospective Brazilian birth cohort

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**Background:** Environmental exposures in early life explain variability in many physiological and behavioural traits in adulthood. Recently, we showed that exposure to a composite marker of low maternal capital explained the clustering of adverse behavioural and physical traits in adult daughters in a Brazilian birth cohort. These associations were strongly mediated by whether or not the daughter had reproduced by the age of 18 years. Using evolutionary life history theory, we attributed these associations to trade-offs between competing outcomes, whereby daughters exposed to low maternal capital prioritised investment in reproduction and defence over maintenance and growth. However, little is known about such trade-offs in sons.

**Methods:** We investigated 2,024 mother–son dyads from the same birth cohort. We combined data on maternal height, body mass index, income, and education into a composite "maternal capital" index. Son outcomes included reproductive status at the age of 18 years, growth trajectory, adult anthropometry, body composition, cardio-metabolic risk, educational attainment, work status, and risky behaviour (smoking, violent crime). We tested whether sons' early reproduction and exposure to low maternal capital were associated with adverse outcomes and whether this accounted for the clustering of adverse outcomes within individuals.

**Results:** Sons reproducing early were shorter, less educated, and more likely to be earning a salary and showing risky behaviour compared to those not reproducing, but did not differ in foetal growth. Low maternal capital was associated with a greater likelihood of sons' reproducing early, leaving school, and smoking. High maternal capital was positively associated with sons' birth weight, adult size, and staying in school. However, the greater adiposity of high-capital sons was associated with an unhealthier cardio-metabolic profile.

**Conclusion:** Exposure to low maternal investment is associated with trade-offs between life history functions, helping to explain the clustering of adverse outcomes in sons. The patterns indicated future discounting, with reduced maternal investment associated with early reproduction but less investment in growth, education, or healthy behaviour. However, we also found differences compared to our analyses of daughters, with fewer physical costs associated with early reproduction. Exposure to intergenerational "cycles of disadvantage" has different effects on sons vs. daughters, hence interventions may have sex-specific consequences.

KEYWORDS

**maternal investment, life history theory, trade-offs, reproduction, growth, education, inter-generational effect, obesity**

## Introduction

Evolutionary "life history" theory (1, 2) offers a valuable theoretical framework for understanding variability over the life course in health, disease, and human capital. Further advances may be achieved by linking this framework with another conceptual approach that has gained substantial attention during recent decades, the "developmental origins of adult health and disease" (DOHaD) hypothesis (3).

A large volume of research has shown that early-life exposure to adversity (eg poverty, maternal malnutrition, and psychosocial stress) predicts less favourable adult outcomes, and this has now been demonstrated for a wide range of behavioural and physiological traits in numerous populations (4–8). Reducing exposure to early adversity and promoting resilience are thus considered key to decreasing the burden of adult disease and human capital inequalities (9). Some studies have focused on exposure to adverse social experiences within the household during childhood/adolescence (10), however, a range of environmental factors acting during foetal life and infancy also play key roles in these associations (5, 11).

Introducing an evolutionary perspective improves the understanding of *why* such epidemiological associations arise. The key assumption of life history theory is that all organisms are under selective pressure to allocate resources across four specific functions, namely "maintenance", "growth", "reproduction", and "defense", with trade-offs between them (1, 12, 13). For example, allocating more resources to defence (e.g., the stress response, or immune function) reduces the availability of resources for other functions. Ultimately, natural selection is assumed to prioritise "reproductive fitness" (surviving and reproducing) over maintenance and growth. When fewer resources are available, or when environmental risks are higher, selection should favour increased allocation of resources to immediate survival and reproduction, at a cost to maintenance (a proxy for health) and growth (12, 14). This helps understand why poverty, stress, and malnutrition are so detrimental to health and the development of human capital.

This broad conceptual framework can then be used to help explain why adverse outcomes cluster in specific subgroups of a population. For humans, such clustering was first reported in a New Zealand cohort, where a relatively small segment of the adult population was found to account disproportionately for a range of adverse outcomes, spanning ill-health, risky behaviour, low educational attainment, and criminal convictions (15). This finding was subsequently replicated in larger samples from New Zealand and Denmark (16), however, these studies did not explain why such clustering was occurring.

It is well known that multiple risk factors coalesce around the composite stress of poverty, and their combined effects might potentially explain the clustering of adverse outcomes. For example, poverty is associated with young parental age, maternal malnutrition and infection, parental psychosocial stress, low household income, and lack of parental education (9). These family characteristics may combine with a greater likelihood of other factors outside the household, such as inadequate housing quality, poor public infrastructure, and inadequate access to healthcare and education opportunities. These interactions can be explored using the evolutionary framework we outlined above.

In linking life history theory with the DOHaD hypothesis, however, two issues take on particular importance. First, many of the adverse outcomes can be seen as the product of trade-offs not only between life history functions but also between the present and the future (13, 17, 18). When long-term future benefits appear less attainable, due to higher levels of ecological threat or shorter life expectancy, selection favours "future discounting", in other words steering resources towards more immediate ends. Second, during foetal life, all ecological stimuli and stresses are transduced through maternal phenotype, and this occurs partially during early postnatal life if the mother is breastfeeding (19, 20), meaning that mothers play a unique role in shaping early trade-offs in their offspring. Third, while early reproduction is not favoured from a policy perspective, it is the primary trait under selective pressure and may indicate an adaptive response to environmental constraints. All of these issues may be particularly relevant to understanding the clustering of adverse outcomes in individuals.

To investigate the developmental origins of clustering of adverse outcomes, we previously analysed data from a Brazilian birth cohort, considering only females in the study (14). We developed a composite score integrating several maternal traits that may shape offspring development (maternal height, BMI, education, and household income). Building on the "embodied capital" model of Kaplan and colleagues (21), all of these traits represent markers of "maternal capital" that underpin the capacity for investment in offspring (14). We showed that low levels of maternal capital shaped life history trade-offs in the daughters that were evident at 18 years of age (14). Specifically, low maternal investment was associated with "future discounting" by the daughter, resulting in investment in traits relevant to defence and reproduction (central fatness, early childbearing) being prioritised over traits that might produce more benefits in the longer term, including better early growth, taller stature, longer education, and less risky behaviour. The results for direct markers of cardio-metabolic health were null, but this might reflect the young age of the cohort (18 years), with low levels of non-communicable disease. Nonetheless, low maternal capital in the offspring's early developmental period already predicted an elevated risk of developing non-communicable disease at later ages, indicated by the clustering of risk markers such as low birth weight, short adult height, higher central fatness and smoking. Because reproduction is expected to reduce the availability of resources for other outcomes, we considered the association of maternal capital with early reproduction especially important in driving trade-offs.

Similar tests have rarely been conducted for sons, indeed substantially less research has been conducted under an evolutionary lens on developmental trajectories in males compared to females, in part, because it is less easy to quantify reproductive outcomes in young adult males (22). Effects of low maternal capital on life history trade-offs might be different for sons compared to daughters, for several reasons. First, the physical investment required for reproduction is different. Whereas female physical investment in reproduction involves the storage of energy in adipose tissue, in order to nourish the offspring during lactation (23, 24), and the metabolic costs and risks of pregnancy, male investment in reproduction is primarily directed towards acquiring "embodied capital" (eg muscle mass, social status), which may promote mating opportunities and paternal investment in the broader sense, rather than the direct provisioning of the offspring (25, 26). As such, while high extrinsic mortality risk in both sexes may be expected to favour early reproduction (27), it is less obvious for males whether this should be traded off against physical growth. Conversely, males on average grow up to be larger than females and have a different anatomical distribution of body fat stores (25), hence there may be costs to health associated with growing and maintaining larger tissue mass in males that are less evident in females. Since males may be subject to weaker trade-offs between growth and reproduction and can delay reproduction to later ages than can women, it is possible that the association between trade-offs and inter-generational stresses might also be different in males, as indicated by previous studies in high-income populations (28–30).

We therefore undertook in sons the previous analyses we performed for daughters (summarised in Figure 1 and described in detail below).

## Methods

The birth cohort we studied is located in the city of Pelotas (~334,000 inhabitants), in Rio Grande do Sul, the southern state of Brazil. According to data for 1991, shortly before the cohort was established, 91.6% of Pelotas inhabitants lived in urban areas, where the crude birth rate was 19.3 births per 1,000 population, the Human Development Index was 0.558, and the Gini index for income distribution was 0.59 (Atlas of Human Development in Brazil). The profile of the birth cohort itself has been described previously (31, 32) and updated in our previous analysis on the daughters (14).

Offspring birth weight and length were measured at the hospital by the research team. Weight and length at 12 months were measured in a subsample, with an over-representation of those with low birth weight, in the cohort participant's household. At 18 years, weight and height were measured to calculate body mass index (BMI). Waist circumference was measured using a non-elastic measuring tape. Fat-free and fat mass were assessed using air-displacement plethysmography.

Cardiovascular risk markers measured in sons and daughters at 18 years of age follow-up included glucose, glycated haemoglobin (HbA1c), total cholesterol (TC), HDL-cholesterol (HDL-C), LDL-cholesterol (LDL-C), triglycerides (TGL), and systolic (SBP) and diastolic (DBP) blood pressure. The ratio of total cholesterol to HDL was also calculated, with higher values indicating a less favourable cholesterol profile. Venous blood samples were collected regardless of fasting status, left at room temperature for 30min and then centrifuged for 15min at 2,000 g. Serum aliquots were stored at −80°C until analysis. Blood samples were not taken in pregnant or suspected pregnant participants ($n = 59$). Random glucose was

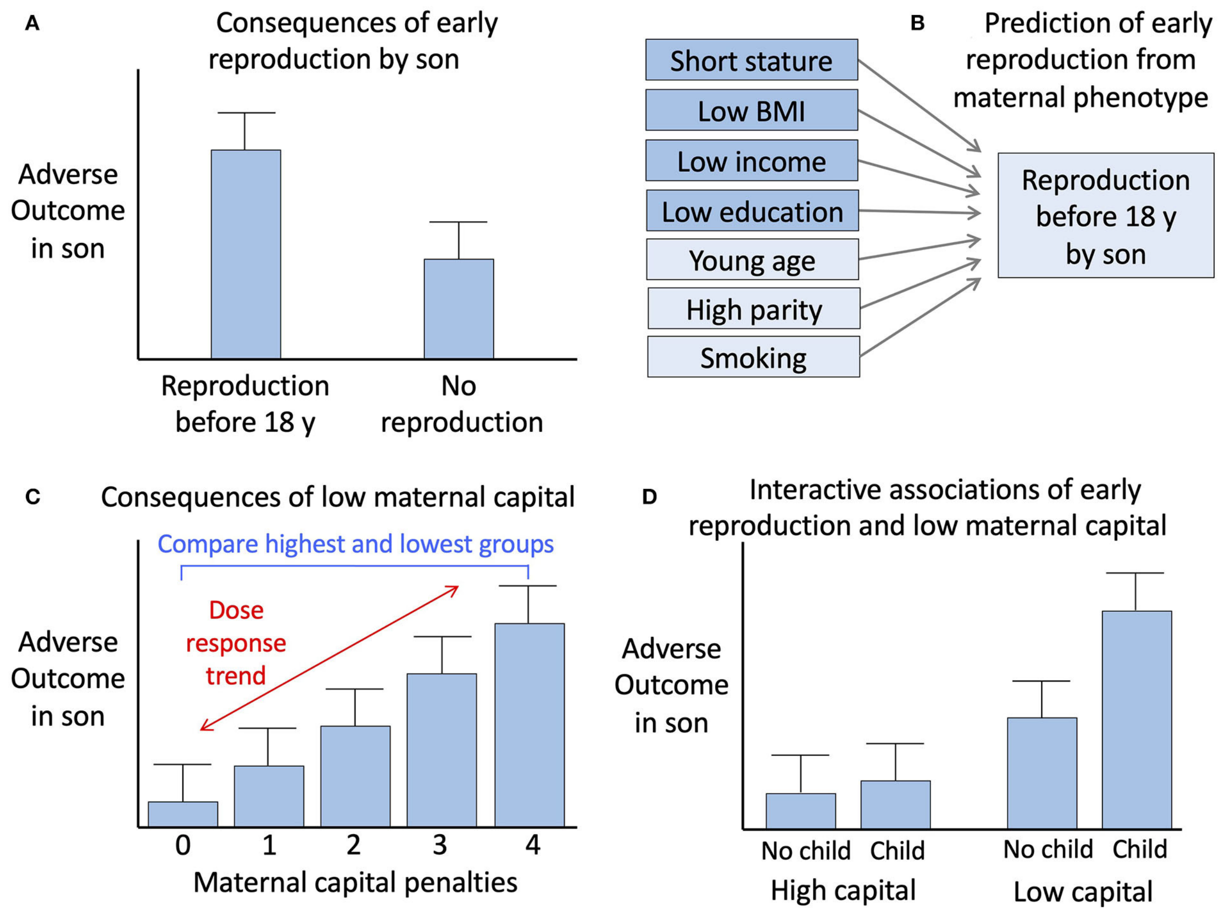


FIGURE 1
Conceptual diagram of the analysis. **(A)** Comparison of outcomes between sons who reproduced before 18 years vs. those who did not. **(B)** Prediction of early reproduction by sons from components of maternal capital, including those used to generate the maternal capital index and three other maternal traits. **(C)** Analysis of the association of adverse son outcomes with maternal capital, involving assessment of a dose-response trend across the range of maternal capital penalties. **(D)** Analysis of the interactions of early son reproduction and low maternal capital with adverse son outcomes. Reproduced with permission from reference (14).

measured using an automatic enzymatic colorimetric method. HbA1c was measured using the Variant (Bio-Rad, Hercules, CA) ion-exchange high-performance liquid chromatography (HPLC) method. Lipids were measured using an automatic enzymatic colorimetric method in a biochemistry analyzer (BS-380 Mindray; Shenzhen Mindray Bio-Medical Electronics, China). Systolic and diastolic blood pressures were recorded in the seated position using a calibrated digital wrist monitor (Omron HEM-629, Beijing, China) at the start and end of the visit, with a margin of error of 1 mmHg, and the mean of the two measurements was used in the analysis (33).

A questionnaire was used to ascertain behavioural and human capital outcomes in participants at 18 years of age. Reproductive status was established through the question Have you ever made a girl pregnant? Schooling status was assessed by collecting both categorical data (whether studying now; whether studied in the last year) and continuous data (completed years of education). For those not studying, participants were asked to select from a list of 10 possible reasons accounting for this: difficulty learning; illness; work; no school or travel available; education not considered important; having children; married; violence; failed vestibular examination; other. Participants were asked if they received any income from work, or an allowance (usually from parents) and the amount in Reais (Rs). Questionnaires were also used to establish smoking behaviour (current smoker; had smoked at least 1 cigarette in the last week), and whether the participant had committed a violent crime in the previous year.

## Data processing

We categorised sons according to whether or not they had reproduced early (by 18 years). This age was selected because the follow-up was conducted at this timepoint, and because reproduction before 18 years is widely considered to be early, reflected in the UN definition of early marriage in both sexes as <18 years (34).

We categorised mothers according to their maternal capital at the time the sons were born. This approach combined markers of somatic capital (height and pre-pregnancy BMI) and social or material capital (maternal education and family income) into a composite index. Each of these four traits has been widely associated with phenotypic variability in the next generation (35–38). In Brazil, household income is measured in units of "minimum wages", where in 1993, 1 minimum wage = US$ 31.4 per month). We treated maternal height as a marker of the mother's own development in early life, maternal BMI as a marker of her current nutritional status, household income as a marker of maternal access to goods and services, and maternal education as a marker of her ability to access beneficial opportunities in society (14).

For each maternal trait, a cut-off was identified defining approximately the lower third in the population, in order to identify those substantially below the median, as described previously (14):

Height: <157 cm
Pre-pregnancy BMI: <21 $kg/m^2$
Maternal education: <6 years
Family income: <3 minimum wages

Mothers scored a "capital penalty" for each criterion satisfied, and the penalties were summed to give a total maternal capital score, ranging from 0 to 4 (note that a score of 0 indicates high maternal capital). We used this capital penalty variable to explore continuous associations of maternal capital with son outcomes. For logistic regression analyses, we also divided maternal age into three groups, namely <22 years, 22–28 years, and >28 years. For the same purpose, we divided the sons into three groups in relation to maternal parity, namely first-borns, second-borns, and third-borns or more. However, for descriptive analysis, we also generated a category for high maternal parity, defined as the son being fourth/fifth-born.

To assess the clustering of adverse traits among the sons, we defined three categorical variables at 18 years: obesity as BMI >30 $kg/m^2$, short stature as height <171 cm, and school dropout as not studying in secondary school during the previous year. Self-reported current smoking and convictions for violent crime were additional adverse outcomes. Finally, we included low birth weight (defined as <2,500 g) as an adverse outcome, as those with this characteristic remain at elevated risk of non-communicable disease through adult life (39).

## Analytical steps

We undertook several analytical steps, which are summarised in a conceptual diagram (Figure 1). These analyses were identical to those previously undertaken with the cohort daughters, making the results directly comparable.

(A) We first tested whether sons' early reproduction was associated with adverse outcomes, using independent samples *t*-tests or $\chi^2$ tests. We also examined sons' outcomes in relation to the characteristics of their mothers. We started with this analysis because a key tenet of life history theory is that reduced investment in early life favours the allocation of resources towards early reproduction, at a cost to investment in health and longevity.
(B) To understand how early reproduction by sons was shaped by maternal investment in early life, we tested whether markers of maternal capital predicted sons' reproduction by 18 years. We fitted logistic regression models to test which individual maternal trait predicted the reproductive status of the sons. These models included the four variables defining the composite index of maternal capital, but also additional markers of the capacity for maternal investment (age and parity) as well as risky maternal behaviours (consuming alcohol and smoking during pregnancy) that might constrain maternal investment.
(C) We next fitted regression models to test for dose-response associations of sons' traits with the number of maternal capital penalties. Outcomes included the sons' gestational age and early growth trajectory, breast-feeding experience, adult size and body composition, cardio-metabolic risk markers, risky behaviour (smoking, violent crime) educational attainment, and reproduction status, as well as maternal traits (parity, smoking, alcohol intake).
(D) Finally, we evaluated the extent to which adverse outcomes were clustered among the sons who had reproduced by 18 years of age and also among those who had been exposed to low maternal capital. This was to test whether, as found in daughters, the clustering of adverse traits could be partly attributed to life history trade-offs driven by low maternal capital. We analysed dichotomous outcomes for obesity, short stature, current smoking, school dropout, violent crime, and low birth weight, as justified above. The cut-off for obesity is standard in nutrition research, however, the cut-off for height was selected to define the shortest third of the sample. We also explored the interactions of low maternal capital and sons' early reproduction with these adverse outcomes.

Associations between sons' early reproduction and adverse outcomes might potentially be confounded by direct mother–son transmission of the outcome, due to shared genes or household environments. To exclude this possibility, we fitted regression models (linear or logistic as appropriate) in which associations of the son's early reproduction with outcomes were held constant for the mother's value for the same outcome.

## Statistical analysis

Categorical variables were compared between groups using $\chi^2$ tests. We tested for normality in the continuous variables, using Q-Q plots and Shapiro–Wilk tests. Not all outcomes were normally distributed, hence we conducted two-group comparisons using both independent *t*-tests and Mann–Whitney U-tests. To adjust for the over-representation of those with low birth weight in the subsample assessed at 1 year, weighted regression was used in the relevant models. Biochemical data were reviewed for potential outliers, resulting in implausibly high values being excluded for glucose (>300, $n = 3$) and triglycerides (>700, $n = 1$). Continuous outcomes reported in the main figures were all natural-log transformed so that subsequent independent samples *t*-tests or Mann–Whitney U-tests express differences (multiplied by 100) in percentage terms (40). Conditional growth was calculated as regression residuals of final size on initial size, divided by the standard error of the estimate (SEE) of the regression model to generate conditional *z*-scores.

To establish which maternal factors independently predicted sons' reproduction status at 18 years, logistic regression models were fitted. Maternal capital variables were divided into two or three groups as follows, in order to identify high-risk groups and test for threshold effects:

Age <22, 22-<28, $28^+$ years
Height <155, 155-<162, $162^+$ cm
Education 0–4, 5–7, $8^+$ years
Income 0–2, 3–4, $5^+$ minimum wages
Parity First-born, second-born, third$^+$-born
Smoking in pregnancy Yes, no
Maternal BMI <21, 21–<23.5, $23.5^+$ kg/m$^2$

Logistic regression models were also fitted to test the association of the son's phenotype with the odds of early reproduction, without or with adjustment for the equivalent trait in the mother.

To test for associations of low maternal capital and early son reproduction with adverse son outcomes, we conducted $\chi^2$ tests on dichotomous variables (e.g. being short, out of school etc). We then tested for independent associations of the two predictors, using multiple logistic regression analysis. Due to the small numbers, we defined the low maternal capital group for this analysis as having 3 or 4 capital penalties and compared it against those with no capital penalties. As our previous analysis of this issue using a different method (comparing $\chi^2$ tests using the likelihood ratio), we also ran these models for the sons. Four individuals had high outlying values for both HbA1c and blood glucose, but the group comparisons were unaffected by whether these individuals were excluded or not.

All analyses were conducted in SPSS version 24 (IBM Corporation, Armonk, New York) and R version 3.6.3 (The R foundation for Statistical Computing, Vienna).

# Results

Of the 2,603 male participants included at birth, 2,024 (78%) participated in the follow-up at the age of 18 years and provided questionnaire responses, of whom 1,970 were measured for anthropometry and body composition, 1,988 for blood pressure, and 1,933 had a blood test. Compared to those followed up, those not followed up had lower birth weight (−135 g, 95%CI −27, −188), birth length (−0.3 cm, 95%CI −0.5, −0.0), gestational age (−0.2 weeks, 95%CI −0.3, −0.0), and maternal pre-pregnancy BMI (−0.5 kg/m$^2$, 95%CI −0.9, −0.2). Though statistically significant, these differences were all small, and there were no other differences in baseline maternal or child characteristics (Supplementary Table 1). Likewise, among those followed up, there was little missing data, and those missing data showed either small differences or no differences, in background characteristics, compared to those available for analysis (Supplementary material). The subsample visited at 1 year comprised 652 boys.

## Life-history trade-offs in association with early reproduction of sons

The comparison of sons who had or had not reproduced by 18 years is summarised in Figure 2. The results were near-identical, whether independent samples *t*-tests or Mann–Whitney U-tests were used (Supplementary Table 2). Sons who had reproduced by 18 years ($n = 150$) were shorter (−2.5 cm, 95%CI −3.5, −1.4), lighter in weight (−2.7 kg, 95%CI −5.1, −0.3), and had lower fat mass (−2.0 kg, 95%CI −3.4, −0.7) and triceps skinfold (−0.7 mm, 95%CI −1.9, 0.4) compared to those who had not reproduced. However, they did not differ in fat-free mass or fat distribution, as measured by the residual of subscapular skinfold adjusted for triceps skinfold (Figure 3). These patterns indicated that constraints on linear growth and fat deposition are associated with early reproduction.

Despite these differences in adult size, there were no differences in size at birth or in infancy. Figure 4 contrasts the growth trajectories of the two groups, using data on weight and height z-score at birth, 1 year and 18 years. Neither group differed from the growth reference or each other at birth and 1 year. However, from 1 year, the early reproducing group showed poorer growth in both weight and height, reflected in significantly lower z-scores at 18 years of age. After adjusting for maternal capital, the deficit in the son's stature associated with early reproduction (−2.5 cm, 95%CI −3.6, −1.3) was

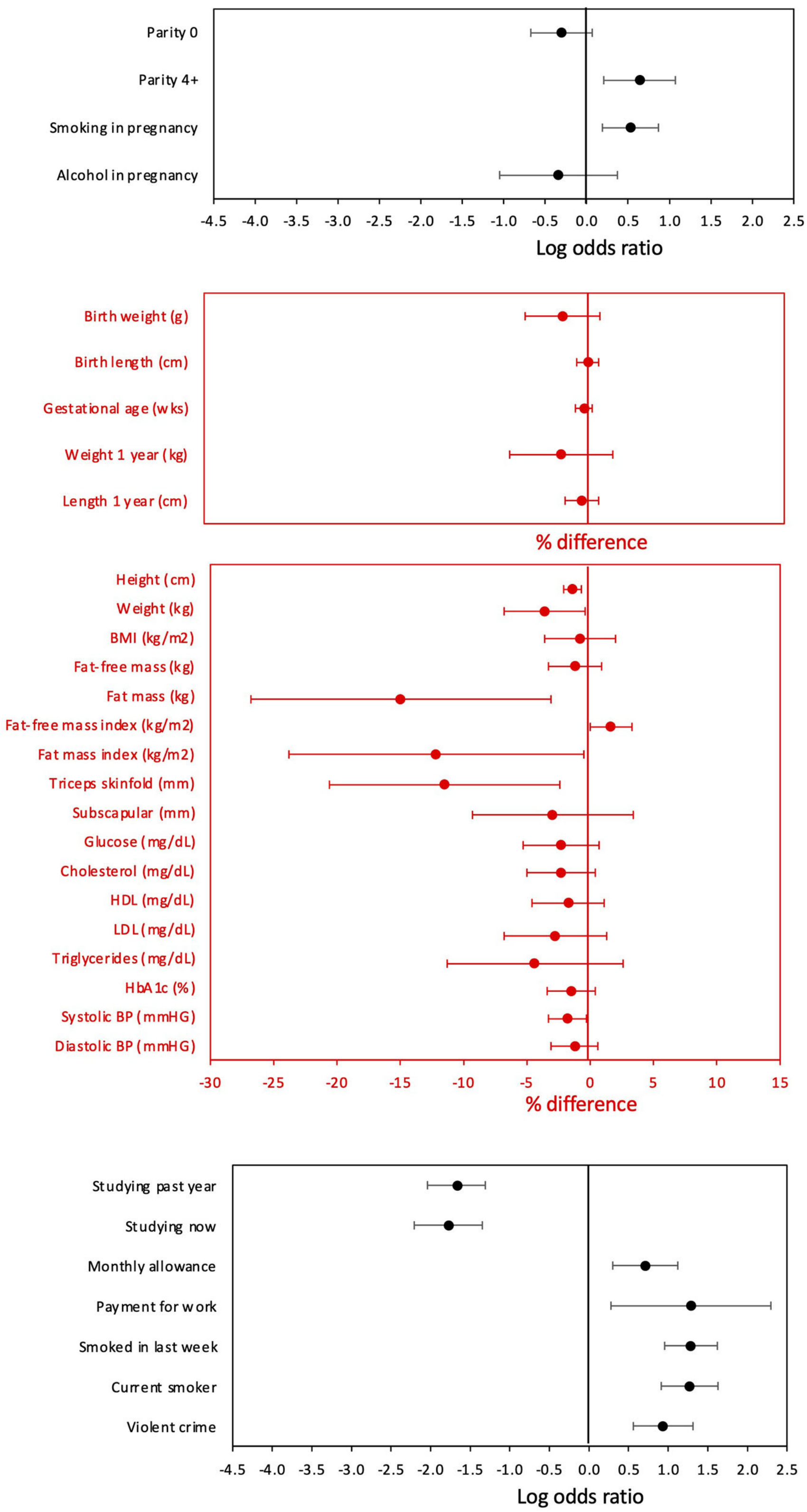


FIGURE 2
Differences in maternal and son traits from pregnancy to adulthood between sons with or without offspring by 18 years. Categorical variables are shown as odds ratios on a log-scale and 95% confidence intervals. Continuous variables are shown as percent differences and 95% confidence intervals, calculated from natural log-transformed variables. Numerical values for all comparisons are given in Supplementary Table 2.

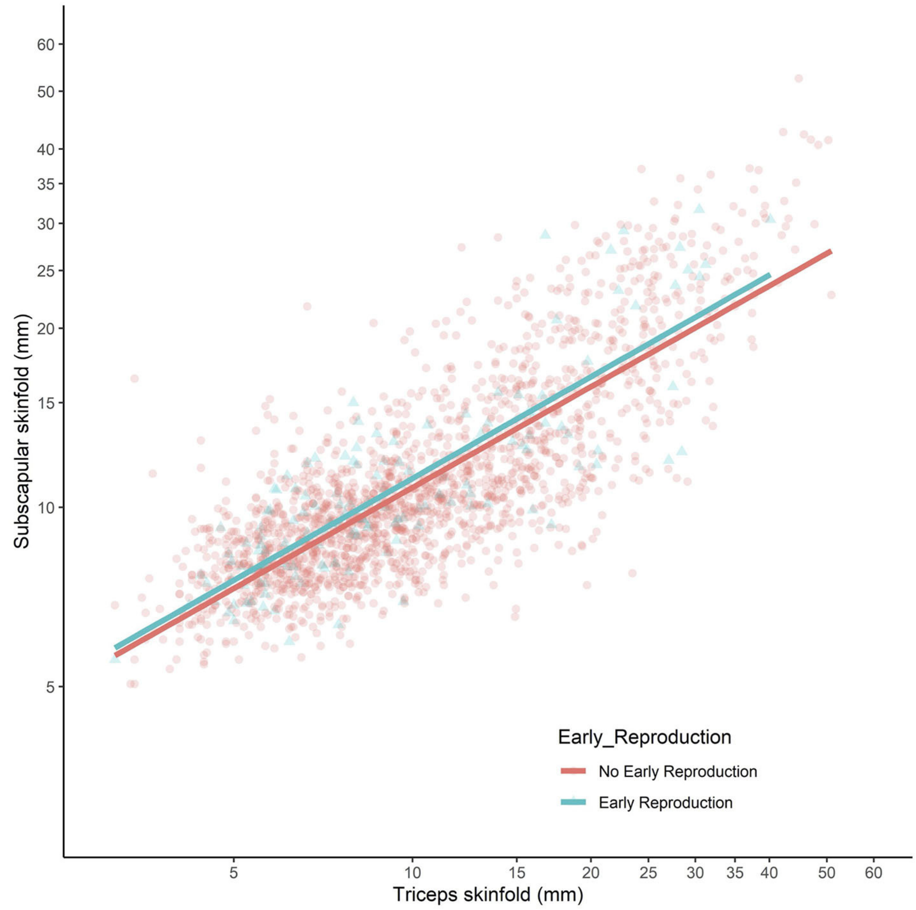


FIGURE 3
Subscapular skinfold plotted against triceps skinfold in the adult sons, stratified by whether they had reproduced by 18 years (blue scatter and line) or not (red scatter and line). Both axes present log-scales. Early reproducing sons did not differ in their subscapular skinfold (Δ = 0.4 mm, 95% CI −0.2, 0.9) for a given triceps skinfold, indicating no difference in central fat deposition.

reduced by 1 cm but was still significant (−1.4 cm, 95%CI −2.5, −0.2), implicating a direct association of the son's own growth trajectory with early reproduction, independent of maternal size. Sons who reproduced early had lower total cholesterol and lower systolic BP, but no other differences in cardiovascular risk.

Regarding their behaviour, early-reproducing sons were more likely to be a current smokers (OR 3.6, 95%CI 2.5, 5.1) and to be receiving payment for work (OR 3.6, 95%CI 1.3, 10), less likely to have been studying in the last year (OR 0.19, 95%CI 0.13, 0.27), and more likely to have committed violent crime (OR 2.5, 95%CI 1.7, 3.7). Among a subset of those out of school ($n$ = 420), the most common reason for not being in school for both groups was work – this was slightly more common among early-reproducing than non-reproducing sons (62% and 56%, respectively) (Table 1). Beyond that, 18% of non-reproducing sons did not consider education important, compared to only 10% of the early-reproducing sons. Conversely, 10% of the early-reproducing sons listed "having children" as the main reason for not being in school. When those giving this response were omitted from the analysis, as it was only relevant to one group, there was no difference between the groups in the reason for leaving school.

Sons who had reproduced by 18 years of age were more likely to have been born to high parity mothers (OR 1.9, 95%CI 1.2, 2.9). Their mother was more likely to have smoked in pregnancy (OR 1.7, 95%CI 1.2, 2.4), but was no more likely to have drunk alcohol (OR 0.7, 95%CI 0.3, 1.4).

Using logistic regression analysis, however, the only maternal traits that independently predicted early reproduction by the son were lower/middle levels of maternal education, and smoking during pregnancy (Table 2).

## Associations of maternal capital with son traits

The maternal capital score is the sum of penalties across the four traits, ranging from 0 to 4. The characteristics of individual maternal traits varied in a dose-response manner in association

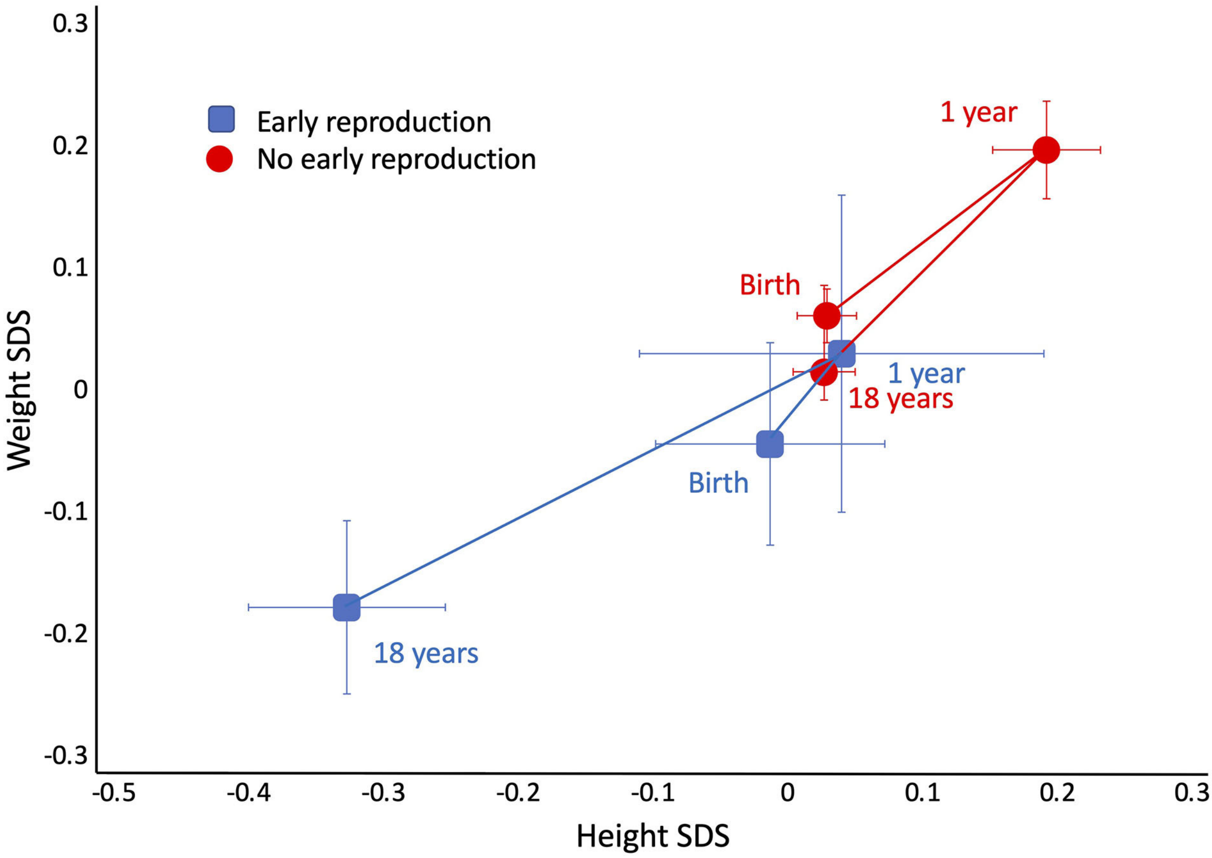


FIGURE 4
Trajectories of growth in length/height $z$-score and weight $z$-score in the sons, stratified by whether they had reproduced by 18 years (blue points) or not (red points). Early reproducing sons were similar to their non-reproducing sons at birth, and both groups showed a small degree of catch up between birth and 1 year. From this time point, early reproducing sons showed poorer growth, resulting in lower weight and height at 18 years.

with the composite score (Supplementary Table 3). Thus, as expected, the fewer the penalties, the greater the mother's height, BMI, income, and education. The composite index also showed an inverse dose-response association with maternal age, but a positive association with the frequency of high parity. Thus, low capital mothers were younger and of higher parity, and their sons had on average to compete with more siblings for maternal investment.

The composite maternal capital index showed a dose response association with the vast majority of outcomes in sons. The lower the level of maternal capital, the higher the proportion of sons that had reproduced early, were out of school, and were current smokers; however, there was no association with the proportion who were being paid an allowance or for work, or who had committed a violent crime (Table 3; Figure 5).

Maternal capital was positively associated in a dose-response manner with the son's adult size, and fat and fat-free components of adult body composition. These associations had their origins in foetal life, as similar associations were evident for size at birth and during infancy (Figure 5). In all cases, the higher the level of maternal capital, the greater the magnitude of the growth trait or tissue mass in the son. Gestational age was also greater among sons of higher-capital mothers, and the duration of exclusive breastfeeding was longer (test for trend $p < 0.004$), though the magnitude of the effect was small.

Contrasting with the pattern seen for other outcomes, cardio-metabolic risk markers showed an unfavourable association with maternal capital: the higher the maternal capital, the higher the son's total cholesterol, HDL, LDL, triglycerides, and systolic BP, with a weaker trend also evident for diastolic BP. However, the associations for glucose, HbA1c, and the HDL/cholesterol ratio were null. When these associations were adjusted for the son's total fat mass, a clear trend remained evident only for HDL (Supplementary Table 4), indicating that adiposity was a strong mediator of the association of higher maternal capital with elevated cardio-metabolic risk. Adjusting for triceps skinfold, however, subscapular skinfold showed no association with maternal capital ($p = 0.4$),

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TABLE 1 Reasons for sons not studying ($n = 420$), stratified by their reproduction status at 18 years.

| Reason for not studying[a,b] | Has reproduced ($n = 81$) N | % | Has not reproduced ($n = 339$) N | % |
|---|---|---|---|---|
| Difficulty learning | 4 | 5 | 16 | 5 |
| Illness | 0 | 0 | 9 | 3 |
| Work | 50 | 62 | 189 | 56 |
| No school or travel available | 1 | 1 | 9 | 3 |
| Education not considered important | 8 | 10 | 61 | 18 |
| Having children | 8 | 10 | 0 | 0 |
| Married | 1 | 1 | 0 | 0 |
| Violence | 0 | 0 | 6 | 2 |
| Failed vestibular examination | 0 | 0 | 11 | 3 |
| Other | 9 | 11 | 38 | 11 |

[a]Cohort subsample with detailed data on education status.
[b]Group difference $p < 0.0001$ if "having children" included as a response, but $p = 0.076$ if this option excluded.

TABLE 2 Logistic regression of son reproducing by 18 years on components of maternal capital ($n = 1,922$).

| Maternal capital component | Nagelkerke's $r^2 = 0.16$ Odds ratio | 95% CI | $p$-value |
|---|---|---|---|
| **Age** | | | |
| <22 years | 1.2 | 0.7, 2.0 | 0.4 |
| 22–28 years | 1.0 | 0.6, 1.6 | 0.9 |
| 28+ years (reference) | 1 | - | - |
| **Height** | | | |
| <155 cm | 1.1 | 0.7, 1.7 | 0.6 |
| 155–162 cm | 0.8 | 0.6, 1.3 | 0.3 |
| 162+ cm (reference) | | - | - |
| Education | 1 | | |
| 0–4 years | 2.6 | 1.5, 4.3 | 0.001 |
| 5–7 years | 2.1 | 1.3, 3.5 | 0.004 |
| 8+ years (reference) | 1 | - | - |
| **Income** | | | |
| 0–2 minimum wages | 1.4 | 0.8, 2.4 | 0.2 |
| 3–4 minimum wages | 0.7 | 0.4, 1.4 | 0.3 |
| 5+ minimum wages (reference) | 1 | - | - |
| **Parity** | | | |
| First-born (reference) | 1 | - | - |
| Second-born | 0.9 | 0.6, 1.5 | 0.7 |
| Third-born or higher | 1.4 | 0.8, 2.33 | 0.2 |
| **Smoking in pregnancy** | | | |
| No (reference) | 1 | - | - |
| Yes | 1.4 | 1.0, 2.1 | 0.045 |
| **Maternal BMI** | | | |
| <20 kg/m$^2$ | 1.2 | 0.8, 2.0 | 0.3 |
| 20–23.49 kg/m$^2$ | 1.3 | 0.9, 2.0 | 0.2 |
| 23.5+ kg/m$^2$ (reference) | 1 | - | - |

Grey shading indicates association significant at $p < 0.05$.

indicating that low maternal investment was not associated with a more central fat distribution (Figure 6).

## Clustering of adverse outcomes

We considered two possible drivers of clustering of adverse outcomes among the sons: early reproduction and low maternal capital. Regarding early reproduction, sons who had reproduced by 18 years comprised 7.4% of the population and accounted for 6.3% of obesity, 9.9% of short stature, 13% of violent crime, 18% of current smoking, and 19% of school dropout. Early reproduction, therefore, contributed only modestly to the clustering of adverse adult traits among sons, and the affected outcomes (ie those with greater frequency than expected given the numbers who had reproduced early) were all behavioural (violent crime, smoking, and school dropout). The one biological outcome that appeared in the cluster among early-reproducing sons was the low birth weight (12%), indicating that poor foetal growth might be a marker of early reproduction in later life.

To evaluate the second potential driver of clustering, maternal capital, we compared the sons with low maternal capital (3 or 4 penalties, $n = 442$), with the remainder of the cohort. The low capital group comprised 23% of the population and accounted for 14% of obesity, 24% of violent crime, 29% of smoking, 32% of school dropout, 35% of short stature, 39% of low birth weight, and 43% of early reproduction. Thus, compared to early reproduction, there was a greater degree of clustering of adverse outcomes in association with exposure to low maternal capital, and the outcomes affected spanned both biology (short stature, low birth weight) and behaviour (school dropout, smoking, violent crime, and early reproduction).

We then tested for independent associations of low maternal capital and early son reproduction with these adverse outcome variables, using logistic regression analysis. As shown in Table 4, both low maternal capital and early son reproduction independently predicted sons being out of school and being current smokers. Low maternal capital was associated with an increased risk of the son being of low birth weight and short stature, but a reduced risk of being overweight or obese, however early reproduction showed no association with short stature. Sons who had reproduced early were more likely to be receiving support, whereas low maternal capital was not associated with this outcome. Neither low maternal capital nor early reproduction was an independent predictor of the son having committed a violent crime.

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TABLE 3 Dose response associations of maternal or sons' traits according to the number of penalties in maternal capital.

| Predictor | 0 penalties ($n = 389$) | | 1 penalty ($n = 617$) | | 2 penalties ($n = 573$) | | 3 penalties ($n = 299$) | | 4 penalties ($n = 69$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Maternal Traits** | *N* | % | *N* | % | *N* | % | *N* | % | *N* | % | *p*–value[a] |
| First–born | 132 | 40.4 | 233 | 39.2 | 195 | 34.5 | 108 | 29.9 | 27 | 32.5 | 0.017 |
| Fourth[+]–born | 20 | 6.1 | 47 | 7.9 | 83 | 14.7 | 59 | 16.3 | 9 | 10.8 | <0.0001 |
| Maternal smoking | 73 | 22.3 | 161 | 27.1 | 191 | 33.7 | 157 | 43.5 | 36 | 43.4 | <0.0001 |
| Maternal alcohol | 15 | 4.6 | 29 | 4.9 | 20 | 3.5 | 19 | 5.3 | 5 | 6.0 | 0.6 |
| | **Coeff** | **95%CI** | **Coeff** | **95%CI** | **Coeff** | **95%CI** | **Coeff** | **95%CI** | **Coeff** | **95%CI** | |
| Maternal age (y) | 28.0 | 27.3, 28.7 | −1.7 | −2.6, −0.8 | −2.3 | −3.2, −1.4 | −2.8 | −3.8, −1.9 | −4.8 | −6.4, −3.3 | <0.0001 |
| | **Constant** | | **1 penalty[$]** | | **2 penalties[$]** | | **3 penalties[$]** | | **4 penalties[$]** | | *p*–value[b] |
| **Son Traits** | **Coeff** | **95%CI** | **Coeff** | **95%CI** | **Coeff** | **95%CI** | **Coeff** | **95%CI** | **Coeff** | **95%CI** | |
| Birth weight (g) | 3,441 | 3,385, 3,497 | −134 | −204, −64 | −211 | −282, −141 | −311 | −388, −233 | −569 | −64, −445 | <0.0001 |
| Birth length (cm) | 49.7 | 49.5, 50.0 | −0.3 | −0.6, −0.0 | −0.5 | −0.8, −0.2 | −1.0 | −1.4, −0.7 | −1.9 | −2.4 −1.3 | <0.0001 |
| Gestational age (w) | 39.0 | 38.8, 39.2 | −0.3 | −0.5, 0.1 | −0.3 | −0.5, 0.1 | −0.4 | −0.6, −0.2 | −0.6 | −0.9, −0.2 | <0.0001 |
| Excl. breastfed (d)* | 29.7 | 23.5, 35.8 | −8.7 | −16.2, −1.2 | −16.5 | −24.1, −9.0 | −17.5 | −26.0, −9.0 | −17.8 | −30.9, −4.8 | <0.0001 |
| Weight 1 year (kg)* | 11.0 | 10.7, 11.2 | −0.6 | −0.9, −0.2 | −1.0 | −1.3, −0.7 | −1.2 | −1.6, −0.9 | −1.8 | −2.4, −1.2 | <0.0001 |
| Length 1 year (cm)* | 77.4 | 76.8, 78.0 | −1.6 | −2.4, −0.8 | −2.3 | −3.1, −1.6 | −3.2 | −−4.1, −2.3 | −4.6 | −6.0, −3.2 | <0.0001 |
| Height (cm) | 177.0 | 176.2, 177.7 | −2.2 | −3.1, −1.3 | −3.1 | −4.0, −2.2 | −5.9 | −6.9, −4.9 | −8.8 | −10.4, −7.2 | <0.0001 |
| Weight (kg) | 78.3 | 76.8, 79.8 | −6.4 | −8.2, −4.5 | −8.4 | −−10.3, −6.5 | −12.7 | −14.7, −10.6 | −16.7 | −20.0, −13.3 | <0.0001 |
| BMI (kg/m$^2$) | 24.9 | 24.5, 25.4 | −1.4 | −2.0, −0.9 | −1.8 | −2.4, −1.2 | −2.5 | −3.2, −1.9 | −3.2 | −4.2, −2.2 | 0.020 |
| Triceps (mm) | 14.7 | 13.9, 15.6 | −2.2 | −3.2, −1.2 | −3.0 | −4.0, −1.9 | −4.7 | 5.8, −3.5 | −6.1 | −7.9, −4.3 | <0.0001 |
| Subscapular (mm) | 13.8 | 13.2, 14.4 | −1.7 | −2.5, −1.0 | −2.0 | −2.7, −1.2 | −3.2 | −4.1, −2.4 | −4.0 | −5.3, −2.6 | <0.0001 |
| Fat–free mass (kg) | 61.7 | 60.9, 62.4 | −3.0 | −3.9, −2.0 | −4.1 | −5.0, −3.1 | −6.6 | −7.6, −5.5 | −8.6 | −10.3, −6.9 | <0.0001 |
| Fat mass (kg) | 16.6 | 15.6, 17.7 | −3.4 | −4.7, −2.1 | −4.3 | −5.6, −3.0 | −6.1 | −7.5, −4.7 | −8.1 | −10.4, −5.8 | <0.0001 |
| Glucose (mg/dL) | 93.2 | 91.4, 94.9 | −0.4 | −2.6, 1.8 | −0.4 | −2.6, 1.8 | 0.9 | −1.5, 3.3 | 2.1 | −1.7, 5.9 | 0.6 |
| Cholesterol (mg/dL) | 159.0 | 156.3, 161.7 | −5.4 | −8.7, −2.0 | −7.9 | −11.2, −4.5 | −9.5 | −13.2, −5.8 | −10.0 | −15.9, −4.1 | <0.0001 |
| HDL (mg/dL) | 52.9 | 51.9, 53.9 | −0.8 | −2.1, 0.4 | −1.4 | −2.6, −0.2 | −1.4 | −2.8, −0.1 | −3.5 | −5.6, −1.4 | 0.001 |
| LDL (mg/dL) | 88.1 | 85.9, 90.4 | −3.4 | −6.2, −0.7 | −4.7 | −7.5, −1.9 | −6.4 | −9.4, −3.3 | −5.2 | −10.1, −0.4 | <0.0001 |
| HDL/Cholesterol ratio | 0.64 | 0.61, 0.66 | 0.01 | −0.01, 0.04 | 0.02 | −0.01, 0.04 | 0.02 | −0.01, −0.05 | −0.02 | −0.02, 0.02 | 0.6 |

*(Continued)*

TABLE 3 (Continued)

| Son Traits | Constant | | 1 penalty[$] | | 2 penalties[$] | | 3 penalties[$] | | 4 penalties[$] | | p–value[b] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coeff | 95%CI | Coeff | 95%CI | Coeff | 95%CI | Coeff | 95%CI | Coeff | 95%CI | |
| Triglycerides (mg/dL) | 87.7 | 82.7, 92.7 | −4.8 | −11.0, 1.5 | −8.8 | −15.1, −2.5 | −11.4 | −18.3, −4.5 | −11.5 | −22.5, −0.6 | <0.0001 |
| HbA1c (%)[¥] | 4.97 | 4.91, 5.03 | 0.03 | −0.05, 0.11 | 0.00 | −0.08, 0.08 | −0.04 | −0.12, 0.05 | −0.05 | −0.2, 0.08 | 0.1 |
| Systolic BP (mmHg) | 132.6 | 131.3, 133.9 | −2.0 | −3.6, −0.3 | −1.4 | −3.0, 0.3 | −3.9 | −5.7, −2.1 | −4.9 | −7.7, −2.0 | <0.0001 |
| Diastolic BP (mmHg) | 71.7 | 70.8, 72.5 | −0.8 | −1.9, 0.2 | −0.1 | −1.2, 1.0 | −1.6 | −2.8, −0.4 | −1.9 | −3.8, 0.1 | 0.027 |
| Education (y) | 9.7 | 9.5, 10.0 | −0.9 | −1.2, −0.6 | −2.1 | −2.4, −1.8 | −2.4 | −2.8, −2.1 | −3.2 | −3.7, −2.7 | <0.0001 |
| Monthly allowance (Rs) | 436 | 355, 516 | 120 | 19, 221 | 125 | 24, 226 | 121 | 9, 233 | 195 | 11, 378 | 0.025 |
| Gross monthly pay (Rs) | 542 | 476, 609 | −43 | −38, 123 | 85 | 5, 165 | 44 | −42, 130 | 83 | −49, 215 | 0.1 |
| | 0 penalties | | 1 penalty | | 2 penalties | | 3 penalties | | 4 penalties | | |
| | *N* | % | *N* | % | *N* | % | *N* | % | *N* | % | *p*–value[a] |
| Reproduction by 18 y | 9 | 2.8 | 36 | 6.1 | 36 | 6.4 | 47 | 13.1 | 14 | 16.9 | <0.0001 |
| Studying past year | 302 | 92.9 | 491 | 82.9 | 428 | 75.9 | 262 | 73.0 | 56 | 67.5 | <0.0001 |
| Studying now | 233 | 71.7 | 338 | 57.1 | 244 | 43.3 | 141 | 39.3 | 28 | 33.7 | <0.0001 |
| Allowance last month | 223 | 68.6 | 390 | 65.9 | 389 | 69.0 | 234 | 65.2 | 52 | 62.7 | 0.5 |
| Pay last year | 205 | 88.7 | 434 | 90.8 | 458 | 91.2 | 301 | 93.2 | 68 | 90.7 | 0.4 |
| Smoked last week | 47 | 14.5 | 117 | 19.8 | 155 | 27.5 | 84 | 23.4 | 30 | 36.1 | <0.0001 |
| Current smoker | 21 | 6.5 | 81 | 13.7 | 105 | 18.6 | 64 | 17.8 | 20 | 24.1 | <0.0001 |
| Violent crime | 62 | 22.0 | 105 | 19.9 | 123 | 24.6 | 77 | 24.4 | 13 | 19.4 | 0.3 |

p-value[a] chi-square test; p-value[b] test for trend across the maternal capital groups, by regressing each outcome on a single variable coded 0–4 capital penalties.
[*]subsample, with analysis adjusted for over-recruitment of low birth weight infants.
[$]Each outcome was regressed on four dummy variables, whereby the son's mother was identified as having 1, 2, 3, or 4 capital penalties (0 penalties = reference group).
The mean coefficient and its 95% CI intervals are shown for each dummy variable. Penalties refer to maternal short stature, low BMI, low education or low family income.
[¥] HbA1c shown as percentage of total haemoglobin.
n = 2,024, small level of missing data for body composition and cardio-metabolic outcomes as described in text.
Grey shading indicates association significant at $p < 0.05$.



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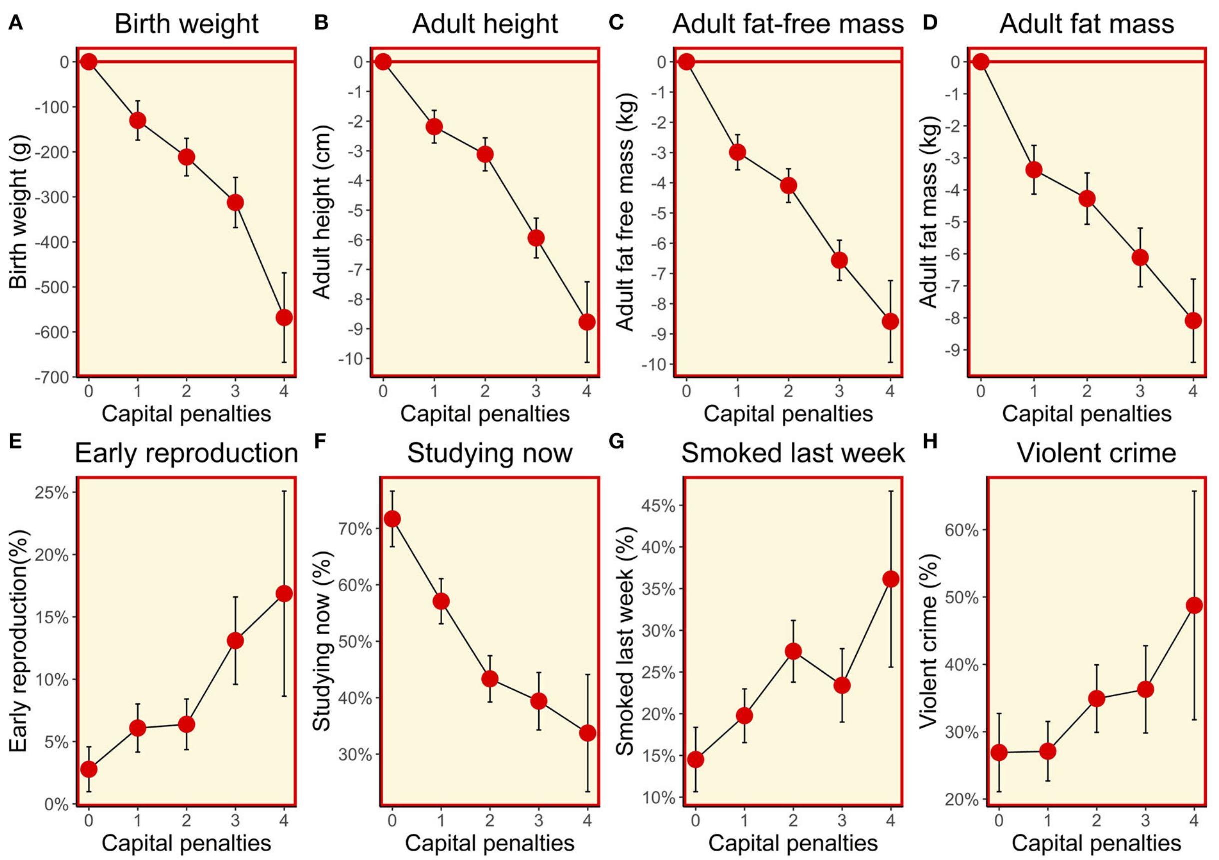


FIGURE 5
**(A–H)** Dose-response associations between sons' traits and the magnitude of maternal capital, categorised in terms of a total composite score of "penalties" (ranging from 0 to 4) selected from the categories "short stature", "low body mass index", "low education" and "low family income". See text for details of how the index and its categories are defined.

Overall, these analyses support our earlier findings, that sons demonstrate primarily behavioural trade-offs in association with early reproduction, whereas exposure to low maternal capital is associated with both behavioural and physical trade-offs.

## Adjusting for direct mother-son transmission of traits

Given that early-reproducing sons were both shorter themselves and had shorter mothers, maternal phenotype should be controlled for when testing the association of early reproduction with the son's growth trajectory. Such associations might be driven by shared genetic factors or non-genetic inter-generational transmission. A similar scenario applies to behavioural traits, which might be replicated across generations due to shared family habits or opportunities.

Size at birth was not a predictor of early reproduction in bivariate analysis. However, after taking maternal weight into account, higher birth weight and BMI reduced the risk of the son reproducing early. Conversely, it was greater maternal stature, rather than the son's birth length, that showed a significant protective effect against the son's early reproduction (Table 5).

By adulthood, greater weight and height of the son were associated with a reduced risk of early reproduction, and this remained after adjustment for maternal size. Greater adiposity and fat-free mass also reduced the risk of early reproduction. These results persisted if adjusted for maternal capital: neither the son's adult weight nor fat mass predicted early reproduction, whereas both short stature and higher fat-free mass of the son were associated with increased odds (Supplementary Table 5). Overall, these findings suggest that maternal short stature indexed one pathway to the son's early reproduction, indicating an intergenerational effect, whereas the son's poor growth in childhood (but not in foetal life), indexed another pathway that was independent of maternal phenotype.

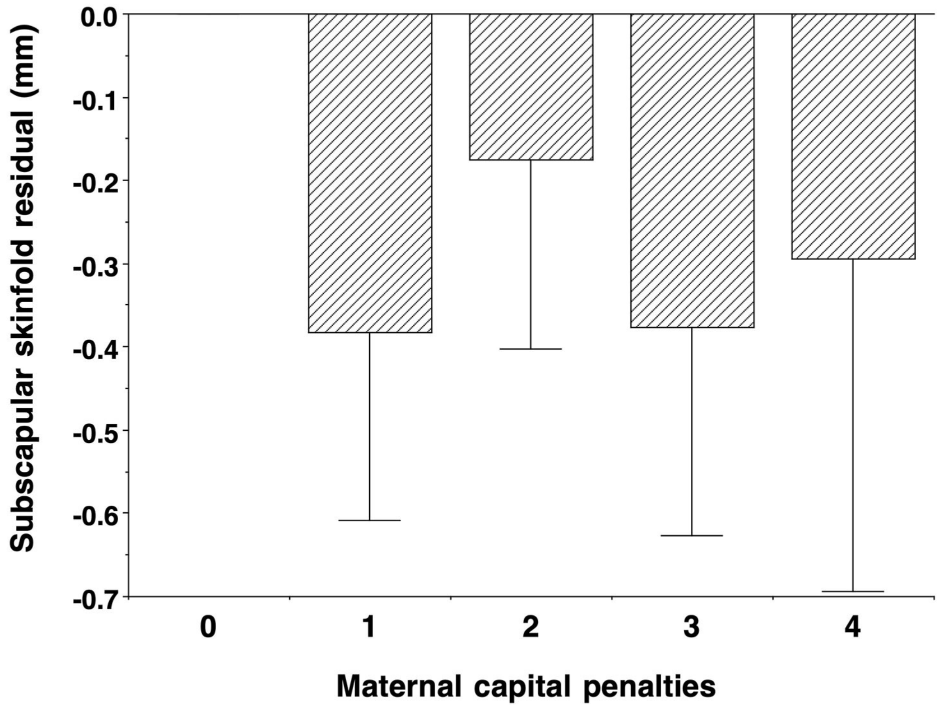


FIGURE 6
Dose-response associations of subscapular skinfold, adjusted for triceps skinfold, according to the number of "penalties" in maternal capital, relative to 0 penalties as the reference group. Lower maternal capital was not associated with a more central fat distribution. Test for trend $p = 0.3$.

TABLE 4 Multiple logistic regression models of independent associations of low maternal capital and early son reproduction with adverse son outcomes.

| | Low maternal capital | | | Early son reproduction | | | |
|---|---|---|---|---|---|---|---|
| Adverse outcome | OR | 95% CI | *p*-value | OR | 95% CI | *p*-value | Nagelkerke $r^2$ |
| Studying last year | 0.22 | 0.13, 0.35 | <0.001 | 0.26 | 0.15, 0.45 | <0.001 | 0.17 |
| Studying now | 0.27 | 0.20, 0.37 | <0.001 | 0.28 | 0.15, 0.52 | <0.001 | 0.17 |
| Receiving support | 0.75 | 0.55, 1.07 | 0.07 | 2.88 | 1.50, 5.51 | <0.001 | 0.02 |
| Paid for work | 1.51 | 0.86, 2.66 | 0.1 | 1.99 | 0.60, 6.63 | 0.2 | 0.02 |
| Smoked last week | 1.77 | 1.20, 2.60 | 0.004 | 3.15 | 1.87, 5.28 | <0.001 | 0.06 |
| Current smoker | 3.03 | 1.82, 5.04 | <0.001 | 2.36 | 1.33, 4.19 | 0.003 | 0.08 |
| Low birth weight | 6.16 | 2.75, 13.79 | <0.001 | 1.41 | 0.67, 2.95 | 0.3 | 0.09 |
| Overweight | 0.28 | 0.20, 0.40 | <0.001 | 1.18 | 0.63, 2.21 | 0.5 | 0.10 |
| Obesity | 0.29 | 0.17, 0.49 | <0.001 | 0.65 | 0.19, 2.17 | 0.4 | 0.07 |
| Short stature | 5.32 | 3.73, 7.60 | <0.001 | 1.22 | 0.73, 2.05 | 0.4 | 0.18 |
| Violent crime | 1.05 | 0.72, 1.55 | 0.8 | 1.43 | 0.78, 2.63 | 0.2 | 0.00 |

Grey shading indicates association significant at $p < 0.05$.

Similarly, we analysed whether early reproduction by the son predicted poor schooling outcomes, or the risk of being a smoker, taking into account maternal education and smoking in pregnancy respectively (Table 6). While lower maternal educational attainment was associated with the same outcome in the son, early reproduction by the son was also an independent predictor. Likewise, while maternal smoking was associated with son smoking, early reproduction by the son was also an independent predictor. These results persisted if adjusted for maternal capital score (Supplementary Table 6).

TABLE 5 Logistic regression models analysing the association of son's growth phenotype with the odds of early reproduction, without/with adjustment for maternal phenotype.

| Predictor | Model 1 (unadjusted) | | Model 2 (adjusted) | |
|---|---|---|---|---|
| | Odds ratio | 95% CI | Odds ratio | 95% CI |
| Birth weight (kg) | 0.81 | 0.60, 1.11 | 0.62 | 0.48, 0.79 |
| Maternal weight (kg) | | | 0.98 | 0.97, 1.00 |
| Weight 1 y (kg) | 0.87 | 0.68, 1.11 | 0.90 | 0.69, 1.18 |
| Maternal weight (kg) | | | 1.01 | 0.94, 1.01 |
| Weight 18 y (kg) | 0.98 | 0.97, 0.99 | 0.99 | 0.97, 1.00 |
| Maternal weight (kg) | | | 0.97 | 0.97, 1.00 |
| Birth length (cm) | 0.98 | 0.92, 1.05 | 0.99 | 0.92, 1.06 |
| Maternal height (cm) | | | 0.97 | 0.95, 1.00 |
| Length 1 y (cm) | 0.95 | 0.86, 1.05 | 1.00 | 0.89, 1.11 |
| Maternal height (cm) | | | 0.92 | 0.88, 0.98 |
| Height 18 y (cm) | 0.95 | 0.93, 0.97 | 0.95 | 0.92, 0.98 |
| Maternal height (cm) | | | 0.99 | 0.97, 1.02 |
| Birth BMI (kg/m$^2$) | 0.90 | 0.80, 0.94 | 0.90 | 0.78, 1.01 |
| Maternal BMI (kg/m$^2$) | | | 0.98 | 0.93, 1.03 |
| BMI 18 y (kg/m$^2$) | 0.98 | 0.80, 1.00 | 0.99 | 0.95, 1.03 |
| Maternal BMI (kg/m$^2$) | | | 0.97 | 0.92, 1.02 |
| Fat mass index 18 y (kg/m$^2$) | 0.93 | 0.88, 0.99 | 0.94 | 0.88, 1.00 |
| Maternal BMI (kg/m$^2$) | | | 0.97 | 0.93, 1.02 |
| Fat-free mas index 18 y (kg/m$^2$) | 1.08 | 0.99, 1.18 | 1.11 | 1.01, 1.22 |
| Maternal BMI (kg/m$^2$) | | | 0.95 | 0.91, 1.00 |

BMI, body mass index.
n = 2,014 for all except weight at 1 year (n = 554) and length at 1 year (n = 546).
Grey shading indicates association significant at $p < 0.05$.

TABLE 6 Linear regression models analysing associations of early reproduction with components of son phenotype, without/with adjustment for the same or similar component of maternal phenotype.

| Outcome in son | Predictor | Model 1 (unadjusted) | | Model 2 (adjusted) | |
|---|---|---|---|---|---|
| | | Coeff | 95% CI | Coeff | 95% CI |
| Years of education | Early reproduction | −1.64 | −2.03, −1.25 | −1.05 | −2.40, −0.71 |
| | Maternal education (y) | | | 0.33 | 0.30, 0.35 |
| | | OR | 95% CI | OR | 95% CI |
| Studying now | Early reproduction | 0.17 | 0.11, 0.26 | 0.20 | 0.13, 0.32 |
| | Maternal education 1 | | | 0.28 | 0.22, 036 |
| | Maternal education 2 | | | 0.42 | 0.34, 0.52 |
| Current smoker | Early reproduction | 3.56 | 2.49, 5.10 | 3.36 | 2.31, 4.84 |
| | Maternal smoking | | | 1.84 | 1.43, 2.37 |

Maternal education group 1: 0–4 years, group 2: 5–7 years; reference group 8+ years.
Maternal income group 1: 0–2 minimum wages, group 2: 3–4 minimum wages, reference group 5+ minimum wages.
n = 2,014.
Grey shading indicates association significant at $p < 0.05$.

In general, therefore, early reproduction was associated with unfavourable trade-offs relating to childhood growth, health, education, and risk-taking, independent of the potential direct maternal transmission of phenotypic traits.

## Discussion

As in daughters (14), our analysis of sons has shown that exposure to low maternal capital in early life is associated with

| | Daughters | | Sons | |
|---|---|---|---|---|
| | Maternal Predictors | Associated outcomes | Maternal Predictors | Associated outcomes |
| **Early reproduction** | | | | |
| | Young age | ⇩ Fetal growth | | ⬄ Fetal/infant growth |
| | Short height | ⬄ Gestational age | | ⬄ Gestational age |
| | Low education | ⬄ Duration of breastfeeding | Low education | ⬄ Duration of breastfeeding |
| | Low income | ⇩ Infant growth | | ⬄ Infant growth |
| | High parity | ⇩ Height | | ⇩ Height |
| | Smoking | ⇩ Adult fat-free mass | Smoking | ⬄ Adult fat-free mass |
| | | ⇧ Adult fat mass | | ⇩ Adult fat mass |
| | | ⇧ Central fat distribution | | ⬄ Central fat distribution |
| | | ⬄ Cardiometabolic risk | | ⬄ Cardiometabolic risk |
| | | ⇩ Schooling | | ⇩ Schooling |
| | | ⇧ Smoking | | ⇧ Smoking |
| | | ⇧ Violent crime | | ⇧ Violent crime |
| **Low maternal capital** | | | | |
| | | ⇩ Fetal growth | | ⇩ Fetal growth |
| | | ⇩ Gestational age | | ⇩ Gestational age |
| | | ⇩ Duration of breastfeeding | | ⇩ Duration of breastfeeding |
| | | ⇩ Child growth | | ⇩ Child growth |
| | | ⇩ Height | | ⇩ Height |
| | | ⇩ Adult fat-free mass | | ⇩ Adult fat-free mass |
| | | ⇩ Adult fat mass | | ⇩ Adult fat mass |
| | | ⇧ Central fat distribution | | ⬄ Central fat distribution |
| | | ⬄ Cardiometabolic risk | | ⇩ Cardiometabolic risk |
| | | ⇩ Schooling | | ⇩ Schooling |
| | | ⇧ Smoking | | ⇧ Smoking |
| | | ⇧ Violent crime | | ⬄ Violent crime |
| | | ⇧ Early reproduction | | ⇧ Early reproduction |

FIGURE 7
Summary table for results of associations of early reproduction and exposure to low maternal capital with outcomes in both sons and daughters. Maternal predictors of early reproduction are also indicated. Blue cells indicate an association, green cells indicate where one sex shows the opposite direction of effect compared to the other sex. Overall, sons show fewer associations of physical traits with early reproduction, and in contrast to daughters, low maternal capital is associated with lower cardiometabolic risk in sons.

future discounting, indicated by trade-offs between competing life history functions of growth, metabolic health, risky behaviour, and education and work. More explicitly, early life adversity is associated with prioritising early reproduction at the expense of investing in growth or other aspects of human capital. These trade-offs associated with maternal capital levels might emerge, depending on the outcome, either through behavioural decisions of the offspring, through physiological responses involving no conscious deliberation, or through a combination of both mechanisms. However, at a more detailed level, the pattern of trade-offs showed several differences compared to those of daughters, indicating that sons and daughters respond differently to low levels of maternal investment (Figure 7). Moreover, the role of early reproduction in mediating the association of low maternal capital with adverse outcomes in the offspring is weaker in sons compared to daughters, and sons pay fewer physical costs in association with early reproduction.

A key finding, similar to that in daughters (14), was that exposure to low maternal capital was associated with an increased likelihood of early reproduction by sons. Only 3% of sons in the highest maternal capital group reproduced early, compared to 17% in the lowest group. As this is a key tenet of life history theory—that less investment in early life, a marker of reduced longevity, favours allocating resources away from other life history functions towards earlier reproduction (27)—we first evaluated how reproduction itself was associated with adverse outcomes. Similar to our findings for daughters, early reproduction by sons were associated with poorer physical growth, less education, and more risky behaviour. This indicates that those who grew poorly in early life were more likely to reproduce early. However, unlike in the daughters, the reduced investment in physical growth did not occur in foetal life or infancy, and instead emerged only during childhood. Moreover, unlike in daughters, early reproduction was not associated with a more central fat distribution, a marker of investment in immune defence. Overall, early reproduction in sons appeared to involve little physical cost, whereas daughters who reproduced early demonstrated poor quality growth much earlier in the life course (foetal life) and more extensive somatic penalties in adult life (14).

Another contrast between the sexes was that almost every individual marker of low maternal capital was independently associated with an increased likelihood of daughters reproducing early, whereas only low maternal education and maternal smoking in pregnancy were independent predictors of sons reproducing early. Maternal parity 3+ was not a predictor of early reproduction, whereas parity 5+ was, indicating that earlier reproducing sons tended to come from relatively large families, and might themselves have wanted to have started a family earlier, a finding reported in a UK study of adolescent women (41). Overall, it appears that the "pathway" to early reproduction is less sensitive to maternal physical traits in sons than daughters and that the key period of exposure for sons may be childhood rather than foetal life.

In daughters in this cohort (14), similar to other studies on girls (42, 43), school dropout and early pregnancy were related. In girls, these outcomes demonstrate a two-way street, whereby poor school performance may lead to early reproduction, while early pregnancy may cause girls to leave school (44, 45). Fewer studies have addressed this dynamic in boys, but some studies find similar associations of poor school performance with boys' early marriage or the initiation of sexual behaviour (46–48). In this cohort, we replicated our findings for daughters, showing that early reproduction in sons was associated with less education, and an increased likelihood of two types of risky behaviour (smoking, violent crime). Such correlations of adverse behavioural outcomes have been reported in other studies and settings (15, 49, 50), and have also been explored using an evolutionary life history lens in other species (51). As with the daughters (14), however, early-reproducing sons were more likely to consider education important compared to their non-reproducing peers and were more likely to cite work as the main reason for being out of school and to be earning wages from paid labour. Whereas the daughters in this cohort traded off school directly with bearing children (14), the sons, therefore, demonstrated a trade-off between learning (with potentially greater future returns) and more immediate wage-earning. This is consistent with men's lack of direct parental investment in pregnancy and lactation, indicating that they require other strategies for parental investment (52).

Overall, therefore, early reproduction contributed primarily to the clustering of a set of adverse behavioural outcomes among sons (school dropout, smoking, and violent crime) but was poorly predictive of adverse physiological outcomes. This may indicate that early-reproducing sons live in households that already demonstrate "future discounting" at a behavioural level, and replicate this pattern in their own life-course. Low maternal education was the strongest predictor of the sons reproducing early and was also an independent predictor in daughters. This may indicate an intergenerational pattern of reduced schooling, whereby women trade off education for early reproduction, and similar trade-offs are then made by their offspring of both sexes. Nevertheless, we emphasise that the majority of those not in school did not indicate that they considered education unimportant; the main reason given for having left school being either having children (women: 69%; men: 10%) or working (men: 62%).

These findings help explain the associations of maternal capital with sons' life history trade-offs. Low maternal capital was associated with sons' poor growth from foetal life onwards, and with smaller body size, and lower fat and fat-free mass in adulthood. Individual associations of maternal traits (eg nutritional status, education, wealth, smoking) with physical growth patterns in both sexes have been widely reported previously (35, 53–56). Several studies from low and middle-income countries have shown that higher birth weight is associated with greater FFM in males, but with greater fat mass in females (57), however, we observed similar associations of low maternal capital with reduced FFM and fat mass patterns in both sexes in this cohort. Exposure to lower maternal capital was also associated with a higher risk of school dropout, early reproduction, and smoking, but not with financial income or violent crime. Other studies have linked maternal undernutrition, smoking, and lack of education with adverse social outcomes in the offspring, involving both physical and behavioural mechanisms (45, 58–61). Overall in our study, exposure to low maternal capital in early life was more successful in explaining both physical (low birth weight, short stature) and behavioural traits, compared to early reproduction which explained only behavioural outcomes.

For daughters, we previously found that neither early reproduction nor exposure to low maternal capital was strongly predictive of cardio-metabolic risk profile, except for central fatness which was elevated in both risk groups (14). Although several markers of higher metabolic risk (low birth weight, short stature, obesity, and central fat) were evident for daughters reproducing early or exposed to low maternal capital, this did not propagate to the direct metabolic measurements, and in some cases, risk markers such as cholesterol and triglycerides were lower in the groups that had invested more in survival/reproduction. In sons, the association of early reproduction with cardio-metabolic risk was again broadly null, though markers of adiposity were lower in early-reproducing sons. However, there was a much stronger pattern for maternal capital, whereby the lower the level of maternal capital the lower the son's cardio-metabolic risk profile. The only traits that did not show this finding were markers of glycemic control (glucose, HbA1c) and central fat distribution.

This indicates that while the sons of high capital mothers may achieve better growth and adult size, and delay the onset of reproduction to capitalise on these traits (potentially benefitting from the opportunity to reproduce with partners of higher socio-economic status), they do so at a cost of poorer cardio-metabolic health. This may be in part explained by the greater opportunity for wealthier families to access palatable but fattening processed foods, and hence higher body fat levels, as widely reported in Brazil (62). These effects are strongly mediated by higher overall levels of fat, but not a more central fat distribution.

From a life history perspective, high capital sons have greater energy reserves but have not allocated them disproportionately to immune defence.

We emphasise that at this age, overt levels of cardio-metabolic risk are low in this population; for example, only 2% of the sons had hypertension as defined by diastolic blood pressure. In the longer term, sons and daughters of low capital mothers have lower birth weight and shorter stature, while also being more likely to smoke. According to the logic of the "capacity-load" model (63), this may make them more susceptible to non-communicable diseases in later life, especially if they become overweight. Our findings, therefore, suggest that the pathway to elevated cardio-metabolic risk may be different, depending on exposure to maternal capital and developmental trajectory. High capital sons have elevated fatness (metabolic load) but also developed better metabolic capacity in early life. Low capital sons have a low metabolic load but developed poorer metabolic capacity in early life. In turn, different interventions may be required to reduce long-term disease risk.

Our results highlight an important sex difference in the way adiposity mediates physical trade-offs. Generically, females have more body fat than males, particularly at around 18 years. In both sexes, exposure to low maternal capital was associated with less total body fat, but whereas this was associated with a more central fat distribution in daughters, it was not in sons. The contrast was even greater for early reproduction: early reproducing daughters had more body fat than their non-reproducing peers who had not reproduced, though lower triceps skinfold, and again a more central fat distribution. For women, body fat is well-established to fund lactation, and hence benefits reproductive investment (24). Conversely, early reproducing sons had substantially less body fat than their non-reproducing peers, and no evidence of a more central fat distribution, and they had preserved their fat-free mass, which has been associated with reproductive success in men (26). From a life history perspective, this indicates reduced resilience against future infections/famines in low capital and early reproducing sons, and hence future discounting similar to that demonstrated by the clustering of early reproduction, school dropout, and smoking.

Our markers of risky behaviour (smoking, violent crime) are best considered not as direct investment in any of the four life history functions, but rather as an indication of future discounting (13). Smoking reduces maintenance in health and may potentially reduce longevity, but in the short term may be used as a palliative to mitigate psychosocial stress. Violent crime might produce short-term pay-offs at cost of the longer-term capacity to invest in offspring (the possibility of social punishment such as prison). Of particular relevance, levels of the hormone testosterone have been linked with aggressive behaviour and violent crime in men (64, 65), and the same hormone has well-established associations with secondary sexual characteristics and sexual behaviour (66, 67).

Our analyses of early reproduction included adjustment for maternal traits, to improve confidence that sons' trade-offs were a direct consequence of their own developmental trajectory and not simply the replication of maternal phenotype. The findings broadly supported this hypothesis, but this does not mean that genetic susceptibility to adverse outcomes plays no role. Recent analysis suggests that key early life "environmental" influences, relating to parents or neighbourhoods, also correlate with genetic markers of the child's propensity to adverse outcomes, examples including alleles associated with education, BMI, and schizophrenia (68). In our analysis, an intriguing finding was that maternal short stature indexed one pathway to the son's early reproduction, indicating an intergenerational effect, whereas the son's poor growth in childhood indexed an additional pathway that was independent of maternal phenotype. Further work will be needed to explore the contribution of genetic and environmental factors to the kinds of trade-offs we have reported.

## Strengths and limitations

Many of the strengths and limitations of this analysis are the same as those we described in detail for the daughters' analysis (14). Briefly, strengths include the rich dataset and the large sample size from a middle-income country, and the prospective collection of data on maternal capital and the offspring in early life. Moreover, a major strength is the opportunity to interrogate maternal investment and developmental and reproductive outcomes in men, as the majority of work to date has focused on women.

Among the limitations are the 22% cohort attrition by 18 years, small amounts of missing data, the lack of data on paternal phenotype or the overall reproductive career of the mothers, and the fact that our analysis is necessarily observational, meaning that we cannot demonstrate causality in the trade-offs we describe. As with the daughters' analyses, none of these limitations is substantial, indicating that our findings are likely to be robust.

A different limitation, of particular relevance to the current analysis, is that since men start to reproduce later than women on average, a direct comparison of men and women at 18 years is difficult to interpret. Whereas 15% of the cohort of women had a child by 18 years of age (14), only 7% of the men did. However, since the cohort was followed up at 18 years, this was the only comparison that was possible. Moreover, the sample size of 150 men was still adequate to identify some predictors and some associated outcomes. A contrasting limitation is that not all men may have been willing to admit in the questionnaire that they had been responsible for a pregnancy. This may make our findings conservative.

## Conclusions

In conclusion, we found that, as in the daughters in this birth cohort, both early reproduction and exposure to markers of low maternal investment are associated with phenotypic patterns in sons that indicate trade-offs between life history functions. Our work, therefore, helps understand why adverse outcomes may cluster within susceptible subsets in a population, with low maternal capital appearing as a more important driver of this clustering than early reproduction. Our primary finding was that, as in daughters, the patterns indicated a degree of future discounting, with both reduced maternal investment and early reproduction associated with less investment in growth and maintenance along with greater risky behaviour. Lower maternal investment was associated with a greater likelihood of early reproduction by sons.

However, we also found several notable contrasts compared to our earlier analyses of daughters. First, early reproduction appeared to be a weaker mediator of the associations of low maternal capital with adverse sons outcomes. Second, sons paid fewer physical costs in association with early reproduction. Third, sons with high-capital mothers had worse cardio-metabolic outcomes, mediated by higher fatness; however, in the longer-term, sons of low-capital mothers may still be more susceptible to both infectious and non-communicable diseases.

Overall, sons appear to suffer fewer penalties than daughters in association with reduced maternal investment. Sons of low capital mothers were shorter and leaner than their high capital peers but had managed to preserve their lean mass, a trait of value in male reproduction. They had avoided cardio-metabolic costs, but also had lower energy reserves, potentially constraining immune function. They were less educated but had transitioned to wage work which could offer immediate opportunities to invest in their families. Further work is needed to investigate how these trade-offs accumulate through the life-course, as cohort members complete their reproduction and become at greater risk of overt non-communicable disease in association with ageing.

Our results have several implications for policy. First, low maternal capital accounted for a substantial degree of clustering of adverse outcomes among sons. Interventions to promote maternal capital may therefore represent the most effective pathway to improve sons' outcomes, as indicated also for daughters (14). Maternal capital is the first environmental niche to which the offspring is exposed, and responses to all other environmental exposures are made under the imprint of this initial developmental exposure (69).

Second, to improve offspring outcomes comprehensively, both multi-sectoral and specific education and health interventions are needed, ideally initiated before women conceive and persisting during the early critical windows of offspring development (70–74). This composite and early approach may be more effective in disrupting the accumulation of penalties across the life-course than interventions that are provided only during childhood and adolescence (15).

Third, to be most effective in breaking inter-generational cycles of disadvantage, interventions should target both mothers and their offspring, as post-natal interventions (promoting exclusive breast-feeding, immunizations, education etc) may be able to ameliorate some of the adverse consequences of exposure to poor maternal nutritional status *in utero*. In that context, broader societal gender inequality must also be addressed, because of its cumulative adverse impacts on the offspring through the life-course. Importantly, gender inequality has been linked with adverse outcomes in offspring of both sexes, including low birth weight, early child development, child malnutrition and mortality risk, and attitudes to education (75–78).

However, given that the associations of maternal factors with outcomes varied between daughters and sons (Figure 7), we should recognise that the benefits of interventions to improve maternal capital may also differ by offspring sex, because of inherent biological differences between boys and girls that have been shaped by natural or sexual selection, and which drive differential investment across life history functions. This hypothesis requires testing using an experimental approach such as individual level or cluster randomised control trials. From an intergenerational perspective, moreover, many interventions have targeted adolescent girls as "future mothers" to improve components of maternal capital (79, 80), but much less is known about the potential benefits to offspring health of targeting boys as "future fathers", to improve paternal capital.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors for the purposes of replicating these analyses, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by Medical School Ethics Committee of the Federal University of Pelotas. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

## Author contributions

JW, TC, MC-B, and AAM designed the analysis. The Pelotas 1993 birth cohort is overseen by AMM, who steered the 18-year follow-up conducted by FW, PO, HG, and IO. Initial statistical analysis was undertaken by JW, TC, and MC-B and revised in light of feedback from AMM, JM, AAM, RS, and DL. All authors reviewed draughts, provided critical feedback, and approved the final manuscript.


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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.914965/full#supplementary-material

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# The relationship between duration of subjective poverty and health among Chinese adults: Evidence from the China Family Panel Study

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**Introduction:** The disadvantaged socioeconomic status could have accumulated negative effects on individual. In the Chinese context, studying subjective and relative poverty is more important under the implementation of the Targeted Poverty Alleviation campaign. This study aims to provide evidence of the relationship between the duration of subjective poverty and both physical and mental health among Chinese adults, using nationally longitudinal data from 2010 to 2018.

**Materials and methods:** Data were extracted from a nationally representative survey database—the China Family Panel Study (CFPS). The total sample size contains 12,003 adults, with 3,532 in the urban area and 8,471 in the rural area. Self-rated health and depressive symptoms were set as indicators of physical health and mental health, respectively. The duration of subjective poverty was measured by self-rated income level in the local area from 2010 to 2016. A series of ordinary least square regression was adopted to measure the relationship between duration of subjective poverty and health.

**Results:** For the urban residents, the average duration of subjective poverty is 1.99 time points, while 1.98 time points for the rural residents. Net of objective poverty, duration of subjective poverty has a significantly negative association with individual's self-rated health in the rural sample (Coef. = −0.10, $p < 0.001$). Compared with those who have not experienced subjective poverty, the self-rated health score of people who experienced four time points is likely to decrease by 0.54 in the rural area and 0.30 in the urban area. In terms of mental health, 1 unit increase in the duration of subjective poverty is related to 0.15 unit increase in Center for Epidemiologic Studies Depression Scale-8 (CES-D8) scores in the urban sample and 0.46 in the rural sample. Compared with those who have not experienced subjective poverty, the CES-D8 scores of people who experienced four time points are likely to increase by 1.47 in the rural area and 0.95 in the urban area.

**Conclusion:** A longer duration of subjective poverty has a cumulatively negative effect on Chinese residents' physical and mental health, especially in rural area. Our study advocates researchers and policymakers pay more attention to the cumulative effect of subjective poverty on health.

KEYWORDS

subjective poverty, health, self-rated health (SRH), depressive symptoms, China

## Introduction

Income level and socioeconomic status (SES) have long been a research focus, as they may be related to a series of health outcomes. Low income or lack of material resources is defined as poverty (1). One of the most important outcomes caused by socioeconomic inequality is health inequality. Plenty of literature has documented that there was a considerable gap in not only health status but also health utilization and related expenditure between the poor and the rich (2–4). It was proposed that the poverty population was found to die earlier and to be more vulnerable to ill health (5). In developing countries, health inequality caused by low income and low SES is more severe. Disadvantaged SES could have accumulate negative effects on individuals (6). People with low SES possess fewer resources such as education, health, and social capital; on the contrary, people with high SES have more access to better resources which can be accumulated through their life course.

From the life course perspective, it is important to investigate the health damage of not only the present disadvantaged SES but also the duration of socioeconomic disadvantage in the past (7, 8). On one hand, long duration of poverty could have different effects on health compared with a short duration of poverty; on the other hand, health inequity is cumulatively shaped by present and past SES (9). Research focusing on contemporary poverty analysis may neglect those who have experienced poverty for a long time, while their living materials are kept being deprived (10). People who expose to chronic poverty are strongly predicted to have poor mental health and functional impairment (11). Krysia reported that a longer duration of poverty was related to a heavy drinker and more frequent heavy drinking in later life, which were both risk factor for physical health (8).

The world has been dedicated to reducing poverty over the past decades. China has also implemented an anti-poverty program called the Targeted Poverty Alleviation campaign (TPA) since 2014. The government employed several efforts to directly target the poor households; for example, the village cadres would visit households and interview them to accurately identify the poor (12). In addition, the government also made a detailed poverty alleviation plan for each poor household, including a series of subsidies in agriculture and health utilization (12). In 2021, China announced that it had achieved the goal of the anti-poverty program and eliminated absolute poverty. In such context, studying objective and absolute poverty has less significance than subjective and relative poverty in China. Subjective social status (SSS) captures not only the disadvantaged social resources but also *psychological pain* of people which could also affect health (13). It is usually assessed by asking about the individual's sense of their standing or economic status on the social ladder (14). SSS is a more comprehensive measure of individual's social status than objective social status (OSS) (15).

It has been largely documented that SSS is a great contributor to physical and mental health (16, 17). For example, Kim and colleagues found that in Hong Kong, lower SSS-community scores were significantly associated with greater cognitive decline among older adults (18). Another research conducted in rural South Africa also found that higher subjective social position predicted higher cognitive scores (19). A study conducted in both Japan and USA indicated that SSS could negatively affect self-rated health, while neuroticism and sense of control mediated this relationship (20). In terms of mental health, a population-based study from Hong Kong suggested that the subjective poverty population had severer mental distress and thus had worse mental health; it also implied that reducing subjective poverty could be a more effective way to improve mental health than reducing objective poverty (21). The most common explanation to theoretically support the relationship between subjective poverty and health is the social psychological mechanism. Subjective poverty reflects individual subjective economic status when compared with others. Therefore, low SSS or subjective poverty may be related to loneliness and social isolation (22) and thus affect the mental health of individual, such as depressive symptoms. Additionally, the negative effect subjective poverty brings to personal emotion and psychological conditions may furtherly influence one's immune system (23).

SSS could be different at different time points, and previous studies had already documented that it could have a cumulative relationship with cognitive function decline for older adults in China (24). Despite the ample evidence of the relationship between SSS and health, there are several research gaps. First, research on SSS in China is rather limited, although it became more important with the implementation of TPA (25). Second, evidence of the duration of SSS and physical and mental health is insufficient, especially in developing countries like China, where health inequity is severer. Existing literature cares more about cross-sectional subjective poverty, instead of using longitudinal data measuring chronic subjective poverty. Therefore, this study aims to provide evidence of the relationship between the duration of subjective poverty and both physical and mental health among Chinese adults, using a nationally longitudinal data from 2010 to 2018; such evidence will help to better understand whether subjective poverty has cumulative effects in health in China's context.

# Materials and methods

## Data sources

Data used in this study was extracted from a nationally representative survey database conducted by Peking University—the China Family Panel Study (CFPS) 2010–2018. It covered 25 provinces or municipalities and autonomous regions in China (26). A multistage probability proportional to size sampling method was used in CFPS. The first-stage sampling unit was district or county; the second-stage sampling unit was community or village; and the third-stage sampling unit was household. Education experiences, marriage, work, retirement and pension, daily activities, social network, health, and behaviors were all surveyed in CFPS.

The baseline survey was conducted in 2010, and subsequent surveys were conducted in 2011, 2012, 2014, 2016, 2018, and 2020. The 2011 survey was a small-scale interview survey, and the 2020 database has not been fully released to the public. Therefore, 2010, 2012, 2014, 2016, and 2018 surveys were adopted in this current study. Data from 2010 to 2016 were used to assess the duration of subjective poverty and objective poverty. After excluding those who were lost follow-up, who were under 18, and whose subjective poverty status in any wave was missed value, our total sample size contains 12,003 adults, with 3,532 in the urban area and 8,471 in the rural area.

## Dependent variables

### Self-rated health in 2018

We measured the self-rated health (SRH) of Chinese adults in 2018 as the indicator of present physical health. SRH is a strong and widely used predictor of illness and physical health (13). It has been validated to be related to physical functioning and mortality (27, 28), and it has also been adopted in a previous study studying the relationship between SSS and health using CFPS (29). In CFPS, respondents were asked by the question "How do you rate your overall health status?". The answer to this question contains five categories, "poor," "fair," "good," "very good," and "excellent," with values from 1 to 5.

### Depressive symptoms in 2018

Depressive symptoms in 2018 are used to measure present mental health. It has been proved to be an effective indicator to measure individual's mental health (30). In CFPS 2018, the Center for Epidemiologic Studies Depression Scale-8 (CES-D8) was deployed to measure the depressive symptoms of respondents. In CES-D8, respondents are asked to answer how often in the past week they felt for eight items, including feeling depressed, feeling everything he did was an effort, sleeping restless or not, happy, feeling lonely, enjoying life, feeling sad, and unable to get going. The choices are ranging from "none or almost none of the time" to "all or almost or all of the time," with values 0–3. Total scale scores are from 0 to 24, with higher scores representing a higher frequency of depressive symptoms. The reliability and validity have been documented in previous studies (31, 32).

## Independent variables

*Duration of subjective poverty from 2010 to 2016* We measured the duration of subjective poverty using CFPS 2010 to 2016. In each wave, the respondents were surveyed with the question: "How do you rate your income level in your local area?" The five available options are from "the lowest" to "the highest" with values from 1 to 5. We categorized individuals whose answers were "the lowest" as experiencing subjective poverty (24). With four waves from 2010 to 2016, the duration of subjective poverty is grouped as zero/never, one time point, two time points, three time points, and four time points.

## Control variables

### Present subjective poverty

We also controlled the present subjective poverty status in 2018 wave in our regression. A binary variable measures whether the respondents rated their income level in the lowest level (income level in the lowest level: present subjective poverty = 1).

### Duration of objective poverty from 2010 to 2016

We also measured the duration of objective poverty using CFPS 2010 to 2016, to evaluate the effect of subjective poverty independent of objective poverty. The objective poverty was defined as the respondents' annual household income per capita being below the mean value of the lowest income quintile in each survey wave, consistent with a previous study (24). With four waves from 2010 to 2016, the duration of objective poverty is grouped as zero/never, one time point, two time points, three time points, and four time points. The mean values of the lowest income quintile in each survey wave were derived from the

China Statistical Yearbooks. Urban residents and rural residents were grouped separately, due to the large income gap between urban and rural areas in China. For urban residents, the average value of the lowest 20% household income per capita was 7617 CNY in 2010, 10,354 CNY in 2012, 11,219 CNY in 2014, and 13,004 CNY in 2016; for rural residents, the average value of the lowest 20% household income per capita was 1,870 CNY in 2010, 2,316 CNY in 2012, 2,768 CNY in 2014, and 3,007 CNY in 2016[1].

### Present objective poverty

The present objective poverty in 2018 was also included in our regression. A binary variable measures whether the respondent's household income per capita was below the mean values of the lowest income quintile in 2018 (household income per capita below the mean values of the lowest income quintile: present objective poverty = 1). For urban residents, the average value of the lowest 20% household income per capita was 14,387 CNY in 2018; for rural residents, the average value of the lowest 20% household income per capita was 3,666 CNY in 2018, also obtained from the China Statistical Yearbook[1].

### Other covariates

Some other covariates that may potentially affect physical and mental health were also included in our analysis (32, 33). Marital status was categorized into three groups: unmarried, married, and other statuses. Body mass index (BMI) was grouped into four groups, with 18.5–23.9 as standard for Chinese people, $< 18.5$ as underweight, 24–27.9 as overweight, and $\geq$ as obese (34, 35). Variable education contained four groups according to respondent's highest education qualification: illiterate or semi-illiterate, junior school and below, high school and technical secondary school, and junior college and above. Age was categorized into five groups, including 18–35, 36–45, 46–55, 56–65, and 66 and above. Rural residents were identified using the hukou system. Other variables included currently working, region, and gender.

## Statistical analysis

We conducted a series of ordinary least square (OLS) regression models to analyze the relationship between the duration of subjective poverty and health. Due to the different living contexts in rural and urban areas, both rural and urban samples were analyzed separately. During the analyzing process, first, we controlled covariates in the regression model to see the coefficient of the duration of subjective poverty. Second, we added the present subjective poverty as a control variable to see whether the coefficient would change. Third, we furtherly added the duration of objective poverty and present objective poverty. All data analyses were conducted using Stata 15.0.

In each regression model, we calculated the variance inflation factor (VIF) to examine the collinearity. The results are shown in Supplementary Tables A1, A2 in the appendix. The VIFs are always $<10$, indicating that there is no collinearity in our models.

# Results

## Descriptive results

The definition and descriptive results in 2018 are shown in Table 1. The average value of SRH of the total sample is 2.80, with 2.78 in the urban area and 2.81 in the rural area. The mean CES-D8 score of the total sample is 5.47, and that of the urban sample is 4.71, and rural sample, 5.80. The average duration of subjective poverty is 1.99 time points for the urban residents, and 1.98 time points for the rural residents. About 27.1% of urban residents were experiencing subjective poverty in 2018, and 27.3% of rural residents were experiencing subjective poverty in 2018. In terms of objective poverty, the average duration of objective poverty from 2010 to 2016 is 1.05 time points for the urban residents and 0.58 time points for the rural residents, respectively. About 14.4% of urban residents were objectively impoverished in 2018, while 11.3% were rural. The average age of the total sample is 54.17 years old, with 55.55 in the urban area and 53.59 in the rural area.

Figure 1 shows the rate of subjective poverty and objective poverty from 2010 to 2018. The solid line represents the subjective poverty rate, while the dotted line is the rate of objective poverty every year. Both the rate of subjective poverty and objective poverty have decreased a lot in the past decade, with subjective poverty from 30.75% to 11.34% and objective poverty from 21.31% to 11.86%. However, the rate of subjective poverty is higher than that of objective poverty in most years, except for 2014 and 2018, while in these 2 years, the rate of subjective poverty is slightly lower than that of objective poverty.

## Duration of subjective poverty and physical health

Table 2 exhibits the OLS models 1–3 in the total sample examining the relationship between the duration of subjective poverty (2010–2016 wave) and SRH (2018 wave). The results in model 1 suggest that the duration of subjective poverty negatively predicts SRH (Coef. $= -0.11$, $p < 0.01$), net of working status, marriage, education BMI, gender, age, and rural. The results in model 2 show that after controlling present subjective poverty status in 2018, the duration of subjective

1 http://www.stats.gov.cn/

TABLE 1 Characteristics in 2018.

| Variable | Definition | Total sample | | Urban sample | | Rural sample | |
|---|---|---|---|---|---|---|---|
| | | Observation | Mean (S.D.) | Observation | Mean (S.D.) | Observation | Mean (S.D.) |
| Self-rated health status | Ranges from 1 to 5 from *very bad* to *very good* | 1,2002 | 2.80 (1.22) | 3,532 | 2.78 (1.07) | 8,470 | 2.81 (1.28) |
| Depressive symptoms | Ranges from 0 to 24 | 1,1914 | 5.47 (4.08) | 3,514 | 4.71 (3.76) | 8,400 | 5.80 (4.16) |
| Duration of subjective poverty | Ranges from 0 to 4 | 1,2003 | 1.98 (1.31) | 3,532 | 1.99 (1.41) | 8,471 | 1.98 (1.27) |
| Present subjective poverty | =0 if not*; =1 if yes | 1,1848 | 0.27 (0.45) | 3,503 | 0.27 (0.45) | 8,345 | 0.27 (0.45) |
| Duration of objective poverty | Ranges from 0 to 4 | 9,753 | 0.73 (1.06) | 3,056 | 1.05 (1.51) | 6,697 | 0.58 (0.89) |
| Present objective poverty | =0 if not*; =1 if yes | 1,2000 | 0.12 (0.33) | 3,529 | 0.14 (0.35) | 8,471 | 0.11 (0.32) |
| Working status | =0 if not working*; =1 if currently working | 1,2003 | 0.77 (0.42) | 3,532 | 0.57 (0.50) | 8,471 | 0.85 (0.36) |
| Education level | =0 if illiterate or semi-illiterate*; =1 if junior school and below; =2 if high school and technical secondary school; =3 if junior college; =4 if bachelor and above | 1,2003 | 1.01 (0.83) | 3,532 | 1.55 (0.93) | 8,471 | 0.78 (0.66) |
| Marital status | =0 if unmarried*; =1 if married; =2 if others | 1,1973 | 0.18 (0.56) | 3,526 | 0.22 (0.62) | 8,447 | 0.17 (0.54) |
| BMI group | =0 if normal*; =1 if underweight; =2 if overweight; =3 if obese | 1,2003 | 1.03 (1.13) | 3,532 | 1.08 (1.13) | 8,471 | 1.01 (1.12) |
| Gender | =0 if female*; =1 if male | 1,2003 | 0.51 (0.50) | 3,532 | 0.52 (0.50) | 8,471 | 0.50 (0.50) |
| Region | =0 if western area*; =1 if middle area; =2 if eastern area | 1,1994 | 1.22 (0.81) | 3,531 | 1.40 (0.72) | 8,463 | 1.15 (0.84) |
| Age | | 1,2003 | 54.17 (12.55) | 3,532 | 55.55 (13.36) | 8,471 | 53.59 (12.15) |
| Age group | =0 if ≥18 and ≤35*; =1 if ≥36 and ≤45; =2 if ≥46 and ≤55; =3 if ≥56 and ≤65; =4 if ≥66 | 1,2003 | 3.41 (1.19) | 3,532 | 3.52 (1.22) | 8,471 | 3.37 (1.18) |
| Rural | =0 if in urban area* =1 if in rural area | 1,2003 | 0.71 (0.46) | | | | |

*Reference group for all regressions.


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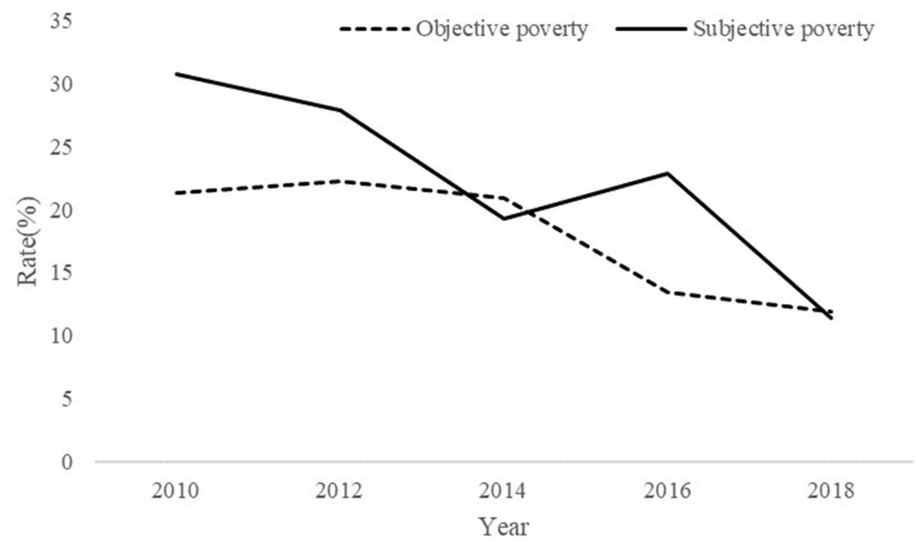


FIGURE 1
Rate of subjective poverty and objective poverty from 2010 to 2018.

poverty still has a significantly negative effect on SRH (Coef. $= -0.09$, $p < 0.01$). Model 3 furtherly controls the duration of objective poverty and present objective poverty status. The results in model 3 indicate that net of objective poverty, duration of subjective poverty still has a significantly negative association with individual's SRH (Coef. $= -0.07$, $p < 0.01$). The coefficients of duration objective poverty and present objective poverty are not statistically significant, indicating that subjective poverty is a stronger predictor than objective poverty.

We furtherly computed the regression models in urban and rural samples separately. Table 3 exhibits the results in the urban sample. Model 1 indicates that the duration of subjective poverty negatively predicts personal SRH (Coef. $= -0.06$, $p < 0.01$). After controlling the present subjective poverty in model 2, the duration of subjective poverty still has a negative effect on SRH (Coef. $= -0.03$, $p < 0.1$). However, the results in model 3 suggest that the relationship between the duration of subjective poverty and SRH becomes insignificant after controlling the duration of objective poverty and present objective poverty status in the urban sample.

The results in Table 4 show the regression model in the rural sample. Model 1 indicates that the duration of subjective poverty negatively predicts SRH (Coef. $= -0.14$, $p < 0.01$) in the rural sample, net of working status, marriage, education BMI, gender, and age. The results in model 2 show that after controlling present subjective poverty status in 2018, the duration of subjective poverty still has a significantly negative effect on SRH (Coef. $= -0.11$, $p < 0.01$) for rural residents. The results in model 3 indicate that net of objective poverty, duration of subjective poverty has a significantly negative association with individual's SRH (Coef. $= -0.10$, $p < 0.01$). Consistent with the results in the total sample, the coefficients of duration objective poverty and present objective poverty are not statistically significant, indicating that subjective poverty is a stronger predictor than objective poverty in the rural sample.

Table 5 furtherly exhibits the relationship between experiencing different time points of subjective poverty and SRH in total, urban, and rural samples, respectively. The reference group is those who have not experienced subjective poverty in any of the survey waves. The results in the total sample indicate that as the time points increase, the negative effect of duration of subjective poverty on SRH also increases. Compared with those who have not experienced subjective poverty, the SRH score of people who experienced four time points is likely to decrease by 0.43. In the rural area, the effect could be even greater (Coef. $= -0.54$, $p < 0.01$). However, in the urban area, compared with those who did not experience subjective poverty from 2010 to 2016, those who experienced one, two, or three time points of subjective poverty have not been observed to have significantly worse health. Only those who experienced four time points of subjective poverty have significantly worse health (Coef. $= -0.30$, $p < 0.01$). In total, the duration of subjective poverty damages rural residents' physical health more than the urban residents, and the duration of subjective poverty is a stronger predictor of SRH than the duration of objective poverty.

## Duration of subjective poverty and mental health

Table 6 exhibits the OLS models 1–3 in the total sample examining the relationship between the duration of subjective

TABLE 2 Duration of subjective poverty and SRH in the total sample.

| | Model 1 | | Model 2 | | Model 3 | |
|---|---|---|---|---|---|---|
| | Coef. | S.E. | Coef. | S.E. | Coef. | S.E. |
| Duration of subjective poverty (2010∼2016) | −0.11*** | 0.01 | −0.09*** | 0.01 | −0.07*** | 0.01 |
| Present subjective poverty (2018) | | | −0.35*** | 0.04 | −0.34*** | 0.04 |
| Duration of objective poverty (2010∼2016) | | | | | −0.01 | 0.01 |
| Present objective poverty (2018) | | | | | −0.07 | 0.04 |
| Currently working | 0.32*** | 0.03 | 0.29*** | 0.03 | 0.29*** | 0.03 |
| **Education** | | | | | | |
| Junior school and below | 0.04 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| High school and technical secondary school | 0.02 | 0.04 | 0.02 | 0.04 | 0.02 | 0.04 |
| Junior college and above | −0.05 | 0.05 | −0.02 | 0.05 | 0.04 | 0.06 |
| **Marital status** | | | | | | |
| Unmarried | −0.07 | 0.08 | −0.07 | 0.08 | −0.02 | 0.09 |
| Other statuses | 0.03 | 0.04 | 0.04 | 0.04 | 0.05 | 0.05 |
| **BMI group** | | | | | | |
| Underweight | −0.27*** | 0.05 | −0.25*** | 0.05 | −0.28*** | 0.06 |
| Overweight | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | 0.03 |
| Obesity | −0.10*** | 0.04 | −0.11*** | 0.04 | −0.13*** | 0.04 |
| Male | 0.15*** | 0.02 | 0.15*** | 0.02 | 0.15*** | 0.03 |
| **Region** | | | | | | |
| Middle | 0.10*** | 0.03 | 0.11*** | 0.03 | 0.14*** | 0.03 |
| Eastern | 0.12*** | 0.03 | 0.13*** | 0.03 | 0.15*** | 0.03 |
| **Age group** | | | | | | |
| 36∼45 | −0.28*** | 0.05 | −0.28*** | 0.05 | −0.30*** | 0.05 |
| 46∼55 | −0.49*** | 0.05 | −0.48*** | 0.05 | −0.49*** | 0.05 |
| 56∼65 | −0.62*** | 0.05 | −0.61*** | 0.05 | −0.61*** | 0.05 |
| 66 and above | −0.72*** | 0.05 | −0.72*** | 0.05 | −0.71*** | 0.06 |
| Rural | −0.07** | 0.03 | −0.05** | 0.03 | −0.04** | 0.03 |
| R2 | 0.0725 | | 0.0765 | | 0.0731 | |
| Observations | 11,963 | | 11,808 | | 9,604 | |

** and ***: significantly different from zero at the 0.05 and 0.01 level, respectively.

TABLE 3 Duration of subjective poverty and SRH in the urban sample.

| | Model 1 | | Model 2 | | Model 3 | |
|---|---|---|---|---|---|---|
| | Coef. | S.E. | Coef. | S.E. | Coef. | S.E. |
| Duration of subjective poverty (2010∼2016) | −0.06*** | 0.02 | −0.03* | 0.02 | −0.03 | 0.02 |
| Present subjective poverty (2018) | | | −0.31*** | 0.07 | −0.31*** | 0.07 |
| Duration of objective poverty (2010∼2016) | | | | | 0.01 | 0.02 |
| Present objective poverty (2018) | | | | | −0.14** | 0.07 |
| Currently working | 0.31*** | 0.05 | 0.31*** | 0.05 | 0.31*** | 0.05 |
| **Education** | | | | | | |
| Junior school and below | 0.14** | 0.07 | 0.13* | 0.07 | 0.16** | 0.07 |
| High school and technical secondary school | 0.09 | 0.07 | 0.10 | 0.07 | 0.12 | 0.08 |
| Junior college and above | 0.11 | 0.08 | 0.10 | 0.08 | 0.14 | 0.09 |
| **Marital status** | | | | | | |
| Unmarried | −0.41*** | 0.13 | −0.39*** | 0.13 | −0.44*** | 0.14 |
| Other statuses | 0.09 | 0.06 | 0.11* | 0.06 | 0.10 | 0.07 |
| **BMI group** | | | | | | |
| Underweight | −0.32*** | 0.10 | −0.32*** | 0.10 | −0.32*** | 0.10 |
| Overweight | 0.02 | 0.04 | 0.02 | 0.04 | 0.01 | 0.04 |
| Obesity | −0.14** | 0.06 | −0.13** | 0.06 | −0.16** | 0.06 |
| Male | 0.09** | 0.04 | 0.09** | 0.04 | 0.10** | 0.04 |
| **Region** | | | | | | |
| Middle | −0.04 | 0.06 | −0.03 | 0.06 | −0.01 | 0.06 |
| Eastern | −0.05 | 0.05 | −0.06 | 0.05 | −0.05 | 0.06 |
| **Age group** | | | | | | |
| 36∼45 | −0.27*** | 0.08 | −0.27*** | 0.08 | −0.25*** | 0.09 |
| 46∼55 | −0.40*** | 0.08 | −0.38*** | 0.08 | −0.37*** | 0.09 |
| 56∼65 | −0.47*** | 0.08 | −0.46*** | 0.08 | −0.46*** | 0.09 |
| 66 and above | −0.59*** | 0.09 | −0.58*** | 0.09 | −0.57*** | 0.10 |
| R2 | 0.0785 | | 0.0834 | | 0.0879 | |
| Observations | 3,525 | | 3,496 | | 3,024 | |

*, **, and ***: significantly different from zero at the 0.1, 0.05, and 0.01 level, respectively.

poverty (2010–2016 wave) and depressive symptoms (2018 wave). The results in model 1 suggest that the duration of subjective poverty positively predicts depressive symptoms (Coef. = 0.53, $p < 0.01$), net of working status, marriage, education BMI, gender, age, and rural. The results in model 2 show that after controlling present subjective poverty status in 2018, the duration of subjective poverty is still positively related to depressive symptoms (Coef. = 0.45, $p < 0.01$). Model 3 furtherly controls the duration of objective poverty and present objective poverty status. The results in model 3 indicate that net of objective poverty, duration of subjective poverty has a significantly positive association with individual's depressive symptoms (Coef. = 0.35, $p < 0.01$). One time point increase in duration of subjective poverty is likely related to a 0.35 increase in CES-D8 scores, while one time point increase in the duration objective poverty is related to a 0.18 increase in CES-D8 scores. It is apparent from our results that duration of subjective poverty has a greater effect on individual's mental health than the duration of objective poverty.

Table 7 shows the results of OLS regression of duration of subjective poverty and depressive symptoms in the urban

TABLE 4 Duration of subjective poverty and SRH in the rural sample.

| | Model 1 | | Model 2 | | Model 3 | |
|---|---|---|---|---|---|---|
| | Coef. | S.E. | Coef. | S.E. | Coef. | S.E. |
| Duration of subjective poverty (2010∼2016) | −0.14*** | 0.01 | −0.11*** | 0.01 | −0.10*** | 0.02 |
| Present subjective poverty (2018) | | | −0.37*** | 0.05 | −0.36*** | 0.05 |
| Duration of objective poverty (2010∼2016) | | | | | −0.04 | 0.02 |
| Present objective poverty (2018) | | | | | −0.04 | 0.06 |
| Currently working | 0.35*** | 0.03 | 0.31*** | 0.04 | 0.30*** | 0.05 |
| **Education** | | | | | | |
| Junior school and below | 0.01 | 0.03 | −0.02 | 0.03 | −0.03 | 0.04 |
| High school and technical secondary school | 0.01 | 0.05 | 0.001 | 0.05 | −0.01 | 0.06 |
| Junior college and above | −0.07 | 0.10 | −0.85 | 0.10 | −0.11 | 0.11 |
| **Marital status** | | | | | | |
| Unmarried | 0.08 | 0.10 | 0.07 | 0.10 | 0.18 | 0.11 |
| Other statuses | −0.003 | 0.06 | −0.003 | 0.06 | 0.02 | 0.06 |
| **BMI group** | | | | | | |
| Underweight | −0.24*** | 0.06 | −0.23*** | 0.06 | −0.26*** | 0.07 |
| Overweight | 0.02 | 0.03 | 0.02 | 0.03 | 0.01 | 0.03 |
| Obesity | −0.09* | 0.05 | −0.10** | 0.05 | −0.10* | 0.05 |
| Male | 0.18*** | 0.03 | 0.18*** | 0.03 | 0.18*** | 0.03 |
| **Region** | | | | | | |
| Middle | 0.13*** | 0.04 | 0.14*** | 0.04 | 0.16*** | 0.04 |
| Eastern | 0.18*** | 0.03 | 0.19*** | 0.03 | 0.21*** | 0.04 |
| **Age group** | | | | | | |
| 36∼45 | −0.25*** | 0.06 | −0.28*** | 0.06 | −0.32*** | 0.07 |
| 46∼55 | −0.54*** | 0.05 | −0.53*** | 0.05 | −0.56*** | 0.06 |
| 56∼65 | −0.69*** | 0.06 | −0.68*** | 0.06 | −0.69*** | 0.07 |
| 66 and above | −0.76*** | 0.06 | −0.76*** | 0.06 | −0.75*** | 0.07 |
| R2 | 0.0761 | | 0.0800 | | 0.0748 | |
| Observations | 8438 | | 8312 | | 6580 | |

*, **, and ***: significantly different from zero at the 0.1, 0.05, and 0.01 level, respectively.

sample. Different from SRH, the results in Table 7 indicate that the duration of subjective poverty plays a positive role in individual's depressive symptoms in the urban sample (Coef. = 0.15, $p < 0.05$), after controlling present subjective poverty, the duration of objective poverty, present objective poverty, and other covariates.

The results in Table 8 show the regression models in the rural sample. Model 1 indicates that the duration of subjective poverty positively predicts depressive symptoms (Coef. = 0.61, $p < 0.01$) in the rural sample, net of working status, marriage, education BMI, gender, and age. The results in model 2 show

TABLE 5 Different durations of subjective poverty and SRH.

| | Total sample | | Urban sample | | Rural sample | |
|---|---|---|---|---|---|---|
| | Coef. | S.E. | Coef. | S.E. | Coef. | S.E. |
| Time points of subjective poverty (2010∼2016) | | | | | | |
| 1 time point of subjective poverty | −0.08*** | 0.03 | 0.01 | 0.05 | −0.12*** | 0.04 |
| 2 time points of subjective poverty | −0.14*** | 0.04 | 0.01 | 0.06 | −0.21*** | 0.05 |
| 3 time points of subjective poverty | −0.13** | 0.05 | −0.01 | 0.08 | −0.19*** | 0.07 |
| 4 time points of subjective poverty | −0.43*** | 0.08 | −0.30*** | 0.10 | −0.54*** | 0.11 |
| Present subjective poverty (2018) | −0.34*** | 0.04 | −0.30*** | 0.07 | −0.35*** | 0.06 |
| Duration of objective poverty (2010∼2016) | −0.01 | 0.01 | 0.01 | 0.02 | −0.04 | 0.02 |
| Present objective poverty (2018) | −0.07 | 0.04 | −0.13* | 0.07 | −0.04* | 0.06 |
| Currently working | 0.29*** | 0.04 | 0.31*** | 0.05 | 0.30*** | 0.05 |
| **Education** | | | | | | |
| Junior school and below | 0.03 | 0.03 | 0.15** | 0.07 | −0.02 | 0.04 |
| High school and technical secondary school | 0.02 | 0.04 | 0.12 | 0.08 | −0.01 | 0.06 |
| Junior college and above | −0.04 | 0.06 | 0.14 | 0.09 | −0.11 | 0.11 |
| **Marital status** | | | | | | |
| Unmarried | −0.02 | 0.09 | −0.43*** | 0.14 | 0.18 | 0.11 |
| Other statuses | 0.06 | 0.05 | 0.10 | 0.07 | 0.02 | 0.06 |
| **BMI group** | | | | | | |
| Underweight | −0.28*** | 0.06 | −0.32*** | 0.11 | −0.26*** | 0.07 |
| Overweight | 0.01 | 0.03 | 0.01 | 0.04 | 0.01 | 0.03 |
| Obesity | −0.13*** | 0.04 | −0.17*** | 0.06 | −0.11* | 0.05 |
| Male | 0.15*** | 0.03 | 0.10*** | 0.04 | 0.18*** | 0.03 |
| **Region** | | | | | | |
| Middle | 0.14*** | 0.03 | −0.01 | 0.06 | 0.16*** | 0.04 |
| Eastern | 0.15*** | 0.03 | −0.05 | 0.06 | 0.21*** | 0.04 |
| Age group | | | | | | |
| 36∼45 | −0.30*** | 0.05 | −0.24*** | 0.09 | −0.32*** | 0.07 |
| 46∼55 | −0.49*** | 0.05 | −0.36*** | 0.09 | −0.56*** | 0.06 |
| 56∼65 | −0.61*** | 0.05 | −0.45*** | 0.09 | −0.69*** | 0.07 |
| 66 and above | −0.71*** | 0.06 | −0.57*** | 0.10 | −0.75*** | 0.07 |
| Rural | −0.04 | 0.03 | | | | |
| R2 | 0.0739 | | 0.0901 | | 0.0755 | |
| Observations | 9,604 | | 3,024 | | 6,580 | |

*, **, and ***: significantly different from zero at the 0.1, 0.05, and 0.01 level, respectively.

that after controlling present subjective poverty status in 2018, the duration of subjective poverty still has a significantly negative effect on depressive symptoms (Coef. = 0.53, $p <$

TABLE 6 Duration of subjective poverty and depressive symptoms in the total sample.

| | Model 1 | | Model 2 | | Model 3 | |
|---|---|---|---|---|---|---|
| | Coef. | S.E. | Coef. | S.E. | Coef. | S.E. |
| Duration of subjective poverty (2010∼2016) | 0.53*** | 0.04 | 0.45*** | 0.04 | 0.35*** | 0.04 |
| Present subjective poverty (2018) | | | 1.11*** | 0.15 | 1.05*** | 0.16 |
| Duration of objective poverty (2010∼2016) | | | | | 0.18*** | 0.05 |
| Present objective poverty (2018) | | | | | 0.78*** | 0.15 |
| Currently working | −0.10 | 0.11 | −0.05 | 0.11 | −0.17 | 0.12 |
| **Education** | | | | | | |
| Junior school and below | −0.69*** | 0.10 | −0.66*** | 0.10 | −0.54*** | 0.11 |
| High school and technical secondary school | −0.94*** | 0.13 | −0.92*** | 0.13 | −0.72*** | 0.14 |
| Junior college and above | −0.47*** | 0.17 | −0.45*** | 0.17 | −0.13 | 0.19 |
| **Marital status** | | | | | | |
| Unmarried | 0.94*** | 0.30 | 0.93*** | 0.30 | 0.76** | 0.33 |
| Other statuses | 1.69*** | 0.16 | 1.67*** | 0.16 | 1.59*** | 0.17 |
| **BMI group** | | | | | | |
| Underweight | 0.83*** | 0.18 | 0.80*** | 0.18 | 0.83*** | 0.20 |
| Overweight | −0.30*** | 0.08 | −0.30*** | 0.08 | −0.27*** | 0.09 |
| Obesity | −0.29** | 0.12 | −0.27** | 0.13 | −0.26* | 0.14 |
| Male | −0.85*** | 0.08 | −0.86*** | 0.08 | −0.86*** | 0.08 |
| **Region** | | | | | | |
| Middle | −0.79*** | 0.10 | −0.80*** | 0.10 | −0.81** | 0.11 |
| Eastern | −1.02*** | 0.09 | −1.02*** | 0.09 | −0.96*** | 0.10 |
| **Age group** | | | | | | |
| 36∼45 | 0.36** | 0.15 | 0.35** | 0.15 | 0.38** | 0.17 |
| 46∼55 | 0.32** | 0.14 | 0.26* | 0.14 | 0.33* | 0.17 |
| 56∼65 | 0.37** | 0.15 | 0.34** | 0.15 | 0.44** | 0.17 |
| 66 and above | −0.05 | 0.16 | 0.07 | 0.16 | −0.05 | 0.19 |
| Rural | 0.81*** | 0.09 | 0.79*** | 0.09 | 0.73*** | 0.11 |
| R2 | 0.1001 | | 0.1049 | | 0.1094 | |
| Observations | 11,876 | | 11,730 | | 9,551 | |

*, **, and ***: significantly different from zero at the 0.1, 0.05, and 0.01 level, respectively.

TABLE 7 Duration of subjective poverty and depressive symptoms in the urban sample.

| | Model 1 | | Model 2 | | Model 3 | |
|---|---|---|---|---|---|---|
| | Coef. | S.E. | Coef. | S.E. | Coef. | S.E. |
| Duration of subjective poverty (2010∼2016) | 0.30*** | 0.06 | 0.23*** | 0.07 | 0.15** | 0.07 |
| Present subjective poverty (2018) | | | 0.88*** | 0.26 | 0.89*** | 0.27 |
| Duration of objective poverty (2010∼2016) | | | | | 0.18*** | 0.07 |
| Present objective poverty (2018) | | | | | 0.92*** | 0.23 |
| Currently working | −0.01 | 0.17 | 0.003 | 0.17 | −0.16 | 0.18 |
| **Education** | | | | | | |
| Junior school and below | −0.87*** | 0.24 | −0.84*** | 0.24 | −0.56** | 0.26 |
| High school and technical secondary school | −1.27*** | 0.25 | −1.25*** | 0.26 | −0.89*** | 0.28 |
| Junior college and above | −1.12*** | 0.27 | −1.10*** | 0.28 | −0.42 | 0.31 |
| **Marital status** | | | | | | |
| Unmarried | 1.52** | 0.63 | 1.47** | 0.63 | 1.55** | 0.66 |
| Other statuses | 1.57*** | 0.25 | 1.51*** | 0.25 | 1.41*** | 0.26 |
| **BMI group** | | | | | | |
| Underweight | 1.08*** | 0.39 | 1.11*** | 0.39 | 1.14*** | 0.44 |
| Overweight | −0.25* | 0.13 | −0.24* | 0.13 | −0.17 | 0.14 |
| Obesity | −0.48** | 0.21 | −0.51** | 0.21 | −0.49** | 0.22 |
| Male | −0.76*** | 0.13 | −0.77*** | 0.13 | −0.88*** | 0.14 |
| **Region** | | | | | | |
| Middle | −0.51** | 0.20 | −0.54*** | 0.20 | −0.62*** | 0.22 |
| Eastern | −0.79*** | 0.19 | −0.80*** | 0.19 | −0.64*** | 0.21 |
| **Age group** | | | | | | |
| 36∼45 | 0.83*** | 0.27 | 0.28*** | 0.27 | 0.94*** | 0.30 |
| 46∼55 | 0.54** | 0.27 | 0.51* | 0.27 | 0.85*** | 0.30 |
| 56∼65 | −0.001 | 0.29 | −0.01 | 0.30 | 0.48 | 0.32 |
| 66 and above | −0.35 | 0.31 | −0.35 | 0.32 | 0.13 | 0.35 |
| R2 | 0.0769 | | 0.0806 | | 0.0933 | |
| Observations | 3,507 | | 3,480 | | 3,011 | |

*, **, and ***: significantly different from zero at the 0.1, 0.05, and 0.01 level, respectively.

0.01) for rural residents. The results in model 3 indicate that net of objective poverty, duration of subjective poverty has a significantly negative association with individual's depressive symptoms (Coef. = 0.46, $p < 0.01$). One unit increase in the duration of subjective poverty is related to 0.46 units increase in CES-D8 scores, while that of the duration of objective poverty is related to 0.20 units increase in CES-D8 scores.

Table 9 furtherly exhibits the relationship between experiencing different time points and subjective poverty and depressive symptoms in total, urban, and rural samples, respectively. The reference group is those who have not experienced subjective poverty in any of the survey waves. The results in the total sample indicate that as the time points increase, the negative effect of duration of subjective poverty on depressive symptoms also increases. Compared with those who have not experienced subjective poverty, the CES-D8 scores of people who experienced four time points are likely to increase by 1.26. In rural area, the effect could be even greater (Coef. = 1.47, $p < 0.01$).

TABLE 8 Duration of subjective poverty and depressive symptoms in the rural sample.

| | Model 1 | | Model 2 | | Model 3 | |
|---|---|---|---|---|---|---|
| | Coef. | S.E. | Coef. | S.E. | Coef. | S.E. |
| Duration of subjective poverty (2010~2016) | 0.61*** | 0.05 | 0.53*** | 0.05 | 0.46*** | 0.05 |
| Present subjective poverty (2018) | | | 1.18*** | 0.18 | 1.11*** | 0.20 |
| Duration of objective poverty (2010~2016) | | | | | 0.20*** | 0.06 |
| Present objective poverty (2018) | | | | | 0.66*** | 0.19 |
| Currently working | −0.38*** | 0.15 | −0.32** | 0.15 | −0.32* | 0.17 |
| **Education** | | | | | | |
| Junior school and below | −0.58*** | 0.11 | −0.55*** | 0.11 | −0.49*** | 0.12 |
| High school and technical secondary school | −0.79*** | 0.17 | −0.77*** | 0.17 | −0.57*** | 0.19 |
| Junior college and above | −0.32 | 0.31 | −0.28 | 0.31 | −0.08 | 0.37 |
| **Marital status** | | | | | | |
| Unmarried | 0.71** | 0.34 | 0.73** | 0.34 | 0.43 | 0.37 |
| Other statuses | 1.75*** | 0.21 | 1.75*** | 0.21 | 1.72*** | 0.23 |
| **BMI group** | | | | | | |
| Underweight | 0.71*** | 0.20 | 0.65*** | 0.20 | 0.71*** | 0.22 |
| Overweight | −0.31*** | 0.10 | −0.32*** | 0.10 | −0.31*** | 0.11 |
| Obesity | −0.23 | 0.15 | −0.20 | 0.15 | −0.18 | 0.17 |
| Male | −0.89*** | 0.09 | −0.90*** | 0.09 | −0.86*** | 0.10 |
| **Region** | | | | | | |
| Middle | −0.91*** | 0.12 | −0.90*** | 0.12 | −0.83*** | 0.13 |
| Eastern | −1.12*** | 0.11 | −1.12*** | 0.11 | −1.09*** | 0.12 |
| **Age group** | | | | | | |
| 36~45 | 0.17 | 0.18 | 0.16 | 0.18 | 0.16 | 0.21 |
| 46~55 | 0.28* | 0.17 | 0.21 | 0.17 | 0.17 | 0.20 |
| 56~65 | 0.53** | 0.17 | 0.49*** | 0.17 | 0.47** | 0.21 |
| 66 and above | 0.17 | 0.19 | −0.18 | 0.19 | −0.15 | 0.23 |
| R2 | 0.0974 | | 0.1033 | | 0.1040 | |
| Observations | 8,369 | | 8,250 | | 6,540 | |

*, **, and ***: significantly different from zero at the 0.1, 0.05, and 0.01 level, respectively.

However, in the urban area, compared with those who did not experience subjective poverty from 2010 to 2016, those who experienced one, two, or three time points of subjective poverty have not been observed to have significantly higher CES-D8 scores. Only those who experienced four time points of subjective poverty have significantly higher CES-D8 scores (Coef. = 0.95, $p < 0.05$). In total, consistent with physical health, the duration of subjective poverty damages rural residents' mental health more than the urban residents.

TABLE 9 Different durations of subjective poverty and depressive symptoms.

| | Total sample | | Urban sample | | Rural sample | |
|---|---|---|---|---|---|---|
| | Coef. | S.E. | Coef. | S.E. | Coef. | S.E. |
| **Time points of subjective poverty (2010~2016)** | | | | | | |
| 1 time point of subjective poverty | 0.38*** | 0.10 | 0.26 | 0.18 | 0.44*** | 0.12 |
| 2 time points of subjective poverty | 0.60*** | 0.13 | 0.14 | 0.21 | 0.81*** | 0.15 |
| 3 time points of subjective poverty | 1.21*** | 0.18 | 0.29 | 0.29 | 1.68*** | 0.23 |
| 4 time points of subjective poverty | 1.26*** | 0.29 | 0.95** | 0.43 | 1.47*** | 0.39 |
| Present subjective poverty (2018) | 1.05*** | 0.16 | 0.87*** | 0.27 | 1.11*** | 0.20 |
| Duration of objective poverty (2010~2016) | 0.19*** | 0.05 | 0.18** | 0.07 | 0.20*** | 0.06 |
| Present objective poverty (2018) | 0.78*** | 0.15 | 0.92*** | 0.23 | 0.66*** | 0.19 |
| Currently working | −0.17 | 0.12 | −0.16 | 0.18 | −0.32* | 0.17 |
| **Education** | | | | | | |
| Junior school and below | −0.54*** | 0.11 | −0.56** | 0.26 | −0.49*** | 0.12 |
| High school and technical secondary school | −0.73*** | 0.14 | −0.87*** | 0.28 | −0.58*** | 0.19 |
| Junior college and above | −0.13 | 0.19 | −0.42 | 0.31 | −0.07 | 0.37 |
| **Marital status** | | | | | | |
| Unmarried | 0.76** | 0.33 | 1.52** | 0.66 | 0.44 | 0.37 |
| Other statuses | 1.60*** | 0.17 | 1.42*** | 0.26 | 1.72*** | 0.23 |
| **BMI group** | | | | | | |
| Underweight | 0.83*** | 0.20 | 1.12** | 0.44 | 0.71*** | 0.22 |
| Overweight | −0.27*** | 0.09 | −0.17 | 0.14 | −0.31*** | 0.11 |
| Obesity | −0.26* | 0.14 | −0.48** | 0.22 | −0.18 | 0.17 |
| Male | −0.86 | 0.08 | −0.88*** | 0.14 | −0.85*** | 0.10 |
| **Region** | | | | | | |
| Middle | −0.80*** | 0.11 | −0.63*** | 0.22 | −0.82*** | 0.13 |
| Eastern | −0.96*** | 0.10 | −0.64*** | 0.21 | −1.09*** | 0.12 |
| **Age group** | | | | | | |
| 36~45 | 0.38** | 0.18 | 0.93*** | 0.30 | 0.15 | 0.21 |
| 46~55 | 0.32* | 0.17 | 0.85*** | 0.30 | 0.16 | 0.20 |
| 56~65 | 0.44** | 0.17 | 0.48 | 0.33 | 0.47** | 0.21 |
| 66 and above | −0.06 | 0.19 | −0.13 | 0.35 | −0.16 | 0.23 |
| Rural | 0.97*** | 0.11 | | | | |
| R2 | 0.1097 | | 0.0942 | | 0.1047 | |
| Observations | 9551 | | 3011 | | 6540 | |

*, **, and ***: significantly different from zero at the 0.1, 0.05, and 0.01 level, respectively.

## Discussion

Most previous studies evaluated the effect of subjective poverty on health at one point of time, while from the life course perspective, the past duration of subjective poverty is as important as present subjective poverty to individual's health. Using longitudinal data to measure the duration of subjective poverty on individual's physical and mental health is of important significance. This current study fills in the research gap and provides evidence from China using a nationally representative database. We controlled present subjective poverty status, present objective poverty status, and duration of objective status to examine whether the duration of subjective poverty still had an impact on subsequent health. Both physical and mental health were measured in our analysis, and the heterogeneity between rural and urban areas was also analyzed. To the best of our knowledge, this is the first study to systematically measure the relationship between the duration of subjective poverty and individual's subsequent physical and mental health in China, net of present subjective poverty status and objective poverty status.

Our results contribute evidence that the duration of subjective poverty has a significantly negative effect on individual's physical health, especially for rural residents. The SRH scores of individuals who have experienced four time points of subjective poverty are likely to decrease by 0.30 in urban and 0.54 in rural, compared with those who have not experienced subjective poverty. The negative effect of the duration of subjective poverty is independent of that of objective poverty. Our results of subjective poverty on health are consistent with previous studies (13, 36). It has been largely documented that SSS or subjective poverty could be negatively related to personal physical health. Our finding confirms the existing ideas and provides more evidence from life course perspective. According to the life course perspective, chronically disadvantaged social status causes a quite different life course and capability to damage (37). On the one hand, a low social position could lead to a series of psychological stress (24). Being exposed to stress and lack of life resources for a long time make people who are in subjective poverty even more vulnerable when faced with diseases and other life events. A previous study published in the BMJ reported that stress-related disorders were robustly associated with a series of types of cardiovascular diseases, and the relationship was independent of family factors and disease history (38). On the other hand, being chronically subjective poverty could lead to unhealthy living habits, such as drinking because people usually choose to drink heavily as a way to cope with stress (39, 40). In addition, perceived stress has been documented to be significantly associated with other health-risk behaviors including low intake of fruit or vegetables, smoking, and physical inactivity (41). In this way, long standing of subjective poverty could induce long-term health-risk behaviors and indirectly engender bad physical health.

Our results also suggest that the duration of subjective poverty has a significantly negative effect on individual's mental health. The CES-D8 scores of individuals who have experienced four time points of subjective poverty are likely to increase by 0.95 in urban and 1.47 in rural, compared with those who have not experienced subjective poverty. The SSS is regarded to affect health through a psychological pathway (29). Self-perception of poverty or low income could bring multiple negative emotions such as stress, anxiety, and low self-esteem (42), while relatively higher social comparison engenders better self-esteem and fosters a sense of control, purpose, and meaningfulness in life (43). Emotion is strongly associated with mental health. Depression is related to reductions in positive emotion (44). Except for negative emotions, people who chronically live in subjective poverty have limited social support as well (45), while social support is an important contributor to mental health (46). In addition, another study also reported that people with low SSS usually had low level of health literacy and in case generated worse mental health (47). Beyond these studies focusing on cross-sectional subjective poverty or low SSS, our study provides evidence that long duration of subjective poverty can also negatively influence subsequent mental health, and the relationship is independent of present subjective poverty status, present objective poverty status, and duration of objective poverty status.

In addition, the findings of this study suggest that rural residents are more vulnerable to long duration of subjective poverty both in physical health and mental health than urban residents in China. In the rural area, residents who experienced one to four time points of subjective poverty appear to have an upgradient decrease in physical and mental health, while in the urban area, only those who experienced four time points of subjective poverty have significantly worse health, compared with those who did not experience subjective poverty from 2010 to 2016. It has been proposed earlier that rural poverty is more debilitating than urban poverty (48). From the aspect of the psychological pathway, in the rural area, poverty is regarded as more shameful than in the urban area (49). The poor living in the rural area has a greater feeling of isolation and failure. In this context, although long enduring subjective poverty brings damage to the health of both urban and rural residents, urban residents feel less stress, anxiety, and social isolation than the rural residents, which could help them to resist health restriction generated by subjective poverty. What is more, the living conditions in urban and rural areas are quite different in China. Although China's health system has developed a lot in the past decades, and the health service utilization and health supply have been greatly improved both in urban and rural areas, there is an increasing gap in health utilization between urban and rural residents (50). Rural residents are disadvantaged in all kinds of healthcare services, because of unbalanced health service supply (51). Health accessibility is vital for enhancing health equity. Therefore, we propose two possible explanations for the different vulnerability to the duration of subjective poverty for rural and urban residents. The first possible explanation is that in rural area, subjective poverty engenders more stress and shameful feeling than in the urban area; the second possible explanation is that urban residents have better access to health services which can help them defend against the health damages generated by subjective poverty.

Consistent with previous studies, this current research implies that subjective poverty is a stronger predictor of self-rated health than objective poverty. Our results indicate that after controlling for present subjective poverty and duration of subjective poverty, present objective poverty and duration of objective poverty have not observed significant effect on SRH in the rural area, and duration of objective poverty has not observed significant effect on SRH in the urban area. Plenty of studies have documented that subjective social status is more closely related to health outcomes than objective social status (13). Therefore, subjective social position and subjective poverty have gained more and more attention these years in certain western counties. The results of our study indicate that in most years, people with subjective poverty are much more than objective poverty. The past studies focusing only on objective poverty would neglect a large body of population who also lack multiple living resources. A study conducted in Pakistan found that measuring objective poverty only would miss some important information that subjective could include (52). For example, marital status is much more related to subjective poverty rather than objective poverty, and food insecurity is more likely to happen subjectively poor households according to the above research. Consequently, we propose subjective poverty should be attached more importance in the Chinese context. China has eliminated absolute poverty in 2020. The subjective poverty measurement would be a better and more powerful way to understand the poverty status of Chinese residents (25).

We want to caution against several limitations in this study. First, we only measured two health outcomes—SRH and depressive symptoms. Other health indicators were not included in our analysis. Although SRH and depressive symptoms are the two most acknowledged and widely used indicators to measure physical and mental health, our conclusion should be carefully generalized to other health outcomes. Second, our study could not provide a causal analysis so far. Future studies should try to provide causal analysis and explore the influencing mechanism between the duration of subjective poverty and health. Third, some potential confounding variables may not be included in our analysis, although we have included as many as variables according to existing literature.

# Conclusion

This study investigates whether the duration of subjective poverty predicts physical and mental health, after controlling present subjective poverty status, duration of objective poverty, present objective poverty status, and other covariates. The results show that a longer duration of subjective poverty negatively affects Chinese residents' physical and mental health, especially in rural area. Our study advocates researchers and policymakers pay more attention to the cumulative effect of subjective poverty on health in the Chinese context.

# Data availability statement

The datasets generated and analyzed during the current study were derived from the China Family Panel Study (CFPS). Researchers who want to use these data can visit: http://www.isss.pku.edu.cn/cfps/.

# Author contributions

DC and ZZ processed the data and were major contributors in writing the manuscript. GL and YR participated in the design of this study. CS and DZ acquired data and provided administrative support for data analysis. YZ, QD, and XZ were involved in revising the manuscript critically for important intellectual content. All authors have read and approved the final manuscript.

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# Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.939569/full#supplementary-material

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# Risk factors for alcohol use among adolescents: The context of township high schools in Tshwane, South Africa

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**Background:** Risk factors for alcohol use originate from many interconnected factors to an interplay of social and physical environments. However, there is a scarcity of data on the contextual risk factors of alcohol use among the adolescents regarding high schools located in townships in South Africa. This study aimed to determine the risk factors for alcohol use among adolescents attending selected township high schools in Tshwane, South Africa.

**Method:** A validated researcher-administered questionnaire was used to collect data on the demographics, as well as current alcohol use, types, quantity, and frequency among adolescents ($n = 403$) in the three high schools. Data were analyzed using STATA 17.

**Results:** The response rate was 97%, with the mean age of $16 \pm 2$ years for the adolescents. Forty-eight % (48%) of the adolescents reported current alcohol use, which was associated with sex, age, number of children, school grade, repeated grade, spare time job and types, having a pocket money to school, child social grant, transport mode to school, and smoking. The odds of current alcohol use were higher for adolescents in grade 10 [AOR = 6.71; 95% CI: 3.16–14.24], grade 11 [AOR = 4.45; 95% CI: 2.21], grade 12 [AOR = 3.05; 95% CI: 1.47–6.31], repeating a grade [AOR =2 .20; 95% CI: 1.32–3.67), and working during a spare time [AOR = 2.91; 95% CI: 1.33–6.37]. Both sexes had higher odds of alcohol use in the ages of 15–17 and 18–21 years, than adolescents aged 13–14 years.

**Conclusion:** Key risk factors for alcohol use among learners were sex, age, school grade, repeated grade, and working during a spare time. More evidence-based interventions that would have a greater impact in addressing alcohol use among adolescents, such as focusing on availability, marketing, and taxation of alcoholic beverages, are necessary.

KEYWORDS
**alcohol use, risk factors, adolescents, township high schools, Tshwane, South Africa**

## Introduction

Globally, alcohol remains the drug of choice among adolescents, mostly accompanied by other substance abuse (1, 2). The World Health Organization's Global Burden of Disease has reported alcohol and illicit drug use as the main risk factors for cause-specific disability-adjusted life years for young people aged 10–24 years (3). Hence, underage drinking has become a pressing public health issue leading to destructive behaviors that threaten their lives and others (1, 4–6). Almost half of the school-age adolescents (49.6%) in South Africa have at least consumed alcoholic beverage in their lifetime (5, 7). The prevalence of alcohol use among school adolescents in the country ranges from 22 to 53.8% (8, 9). Binge drinking is a rapid and excessive drinking over a short period of time (10) and has been estimated at 15–32% (11–14). Notwithstanding that 12% of the young generation has reported alcohol use before the age of 13 years, despite the South African National Liquor Act prohibiting alcohol sale to individuals younger than 18 years of age (15).

Substantial discrepancies in the prevalence of alcohol use among school adolescents in the 9 provinces (Eastern Cape, Free State, Gauteng, KwaZulu-Natal, Limpopo, Mpumalanga, Northern Cape, North West, and Western Cape), different settings, and racial groups in South Africa have been reported, which suggests that there are variances in the contributing factors of alcohol use, such as socio-cultural and demographic factors (4, 13, 16–18). Some of the socio-demographic factors implicated on alcohol use include age, race, smoking, missing school because of illness, self-reported academic/education, repeated school class/grade, difficulty use of leisure time, a lack of healthy recreational activities, low socioeconomic status, and attending religious services (13, 16, 19–21). However, as most of these earlier studies were conducted in urban and rural settings, the extent to which these findings are relevant for adolescents from townships (i.e., peri-urban) communities is limited. The lifestyle behavior of alcohol use in adolescents is a result of the influences of risk factors, which may be personal factors, suggesting that continuous scientific research to study them is imperative (22).

Adolescents are prone to making changes to the extent that they feel socially accepted (23). As a result, their emotional instability by unfamiliarity and fear of new experiences or decision-making and low self-esteem can lead them to alcohol and illicit drug use, school problems, unprotected sex, legal problems, emotional changes, traffic accidents, suicides, and homicides (24). Furthermore, the risk of damage to organs, such as the brain, liver, and kidneys, and sexual dysfunction due to alcohol consumption is higher among the adolescents than in adults (25). Literature documents that young people who drink alcohol before the age of 15 years are more likely to perform poor at schools, drop out, develop alcohol dependence, as well as experiencing mental and social harm, and cardiovascular diseases, later in adulthood (26).

Most concerning is that high schools are believed to create some social and cultural surroundings, which may encourage alcohol use among the adolescents (4, 16, 27, 28). Nonetheless, schools are also known to offer an opportune setting health education and health promotion interventions (29). Worth noting is that adolescence is a suitable age for interventions that can enforce delayed alcohol use and avert the beginning of social and health consequences that are social and health-related during adulthood (7, 30). The importance of healthy lifestyle behaviors to cardiovascular health promotion, risk reduction, as well as disease prevention and management is well established. Health behaviors, including alcohol and tobacco use, in addition to other behaviors, such as patterns of dietary intake, physical activity, and inactivity, have been universally emphasized and embraced as a central component of evidence-based guidelines for various population groups, including adolescents (31).

However, there is a dearth of recent data on the risk factors for alcohol use among adolescents in the South African township setting, except for minimal research (16, 18, 27), compared to several studies conducted in other settings (4, 8, 12, 13). School environments contribute significantly to adolescent alcohol, tobacco, and other substance disorders. A growing body of literature focuses on school connectedness and school climate as substance use determinants (32, 33). This study addressed the phenomenon of alcohol use among adolescents by addressing this research question: What are the contextual risk factors for alcohol use among adolescents studying in township high schools in Tshwane, South Africa, considering that setting has influence on lifestyle? Therefore, this study aimed to determine the risk factors for alcohol use among adolescents attending selected township high schools in Tshwane, South Africa.

## Methods and materials

### Study design and framework

A cross-sectional study anchored on the Socio-Ecological Model (34) as a basis for understanding the risk factors for alcohol use was conducted among the adolescents. This model posits that environmental influences on behavior fall into four broad domains: micro-system, meso-system, exo-system, and macro-system, and interactions within and between these domains determine behavior. For the purpose of this article, we focused on the exo-system, which includes the larger contexts within which the individual operates, such as the neighborhood organization (34, 35). Hence, high schools were considered relevant to access the adolescents.

## Study setting and population

The study was conducted in Soshanguve and Winterveld townships, located in the City of Tshwane municipality, in Gauteng Province. In a South African context, townships are under-developed residential areas that were reserved for mostly Africans to live during apartheid (36). Townships were designed as dormitory towns for the labor required to serve the needs of mining and other industries and had limited social services and even less economic infrastructure. Whether long-established or newly developed, formal or informal, most of these housing settlements still have several challenges in common, including the lack of social and economic facilities required to build sustainable communities, the continued distances, geographically and socioeconomically, from South Africa's economic heartlands (37). The residents in the townships where the study was conducted reside in both formal and informal settlements, with low socioeconomic status (4).

Schools in Soshanguve and Winterveld townships are under the Tshwane Department of Education, which is divided into four districts; Tshwane North, West, and South, and Gauteng North. Soshanguve township, located in Tshwane North, has 16 high schools, while Winterveld township in Tshwane West has six high schools, making a total of 22 high schools. These high schools are situated within 45 km in the North of Pretoria, the Capital City of South Africa (i.e., Pretoria), and are managed by the National Department of Basic Education. Each of the schools has roughly 800–1,100 learners' enrollment number and offers academic and recreational programs. Schools in Soshanguve and Winterveld townships belong to quintile three (Q3), which receive the majority of their funding from the South African government (38).

## Study participants

We adopted the adolescents' age categories from Kids First Pediatric Partners (39), roughly divided into three stages: early adolescence, generally ages (11–14 years); middle adolescence, ages (15–17 years); and late adolescence, ages (18–21 years). Therefore, learners who were attending high schools in Soshanguve and Winterveld townships at the time of the study were considered, from 13 years and above, with a written parental consent to participate in the study, and gave assent. The study excluded learners who could not obtain parental written consent.

## Sample size and sampling techniques

The study used a validated Raosoft® online sample size calculator (Raosoft Inc., Seattle, WA, USA), which takes into consideration the Cochran formula for sample size determination. Sample size estimation was based on a population size of ±24 000 learners in the 22 high schools in Tshwane North and Tshwane West, 5% margin of error, 95% confidence level, and 50% response distribution. A minimum recommended sample for the study was 379, and to cater for a non-response, the sample was buffered with 10% and increased to 416.

A multistage sampling was used to select the high schools and the learners: First, randomly selecting three high schools out of the 22 schools, followed by a random selection of learners from the lists of learners who have obtained parental consent. First, the high schools were stratified by the size of enrollment, and three largest schools were selected. Each selected school was treated as a unit of analysis with a sample size of not <120 learners to avoid disproportionate sampling among the three selected schools. Taking note of parental consent, we grouped participants by their grades and the participating students were randomly selected from each grade. Participants were randomly selected from the lists of learners per grade, and class, who have obtained parental consent in the three high schools. To be noted, the daily running of the three high schools was not interrupted during recruitment and data collection.

## Study instrument

A validated researcher-administered questionnaire used in the study to collect data was adapted from the previous studies conducted on substance abuse (4, 16, 40). The questionnaire was validated through content and face validity, through the use of the two experts in the field of substance abuse. Independent translators who speak Setswana, as their mother tongue and are conversant with English, did forward and backward translations of the questionnaire. Reliability of the instrument was ensured through pilot study in one of the high schools, conducted among 30 adolescents, which is documented as a suitable sample size of a pilot study (41). The results of the pilot study were not included in the data analysis for the main study. Prior to the pilot study, the research assistants who speak Setswana were taken through the process of conducting preliminary interviews in a local language, for training purposes by the main researcher. After pretesting the questionnaire, there were no changes to the content except for minimal clarity of wording, and simplifying layout and style. The questionnaire was comprised of the demographic information of adolescents, such as sex, age, school grade, repeated school grade, mode of transport to school, spare time, and recreational activities, as well as child support grant and religion. Further information was collected on alcohol use, types, quantity, and frequency, as well as tobacco use. Information was collected by the research assistants based on activities in the past 1 month. Research assistants interviewed learners one by one, while they were sitting in their respective classrooms/grades with desks far apart,

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after school. Four hundred and six adolescents responded out of 416 learners recruited, making a 97% response rate. For data analysis, three questionnaires with missing data above 10% were excluded, and the final sample size of 403 was used in the study.

## Procedures

Recruitment of the learners was done through school visits. During the visit, the researcher provided the principals of schools with letters addressed to the school governing bodies, ethical certificate from Sefako Makgatho Health Sciences University Research and Ethics Committee (SMUREC), permission letter from Tshwane Department of Education to access Pretoria North and West high schools, information leaflet, and the research proposal. Following the approval by the school governing bodies, the researcher liaised with the nutrition teacher in each selected school, for the process of obtaining parental consent for learners, as well as selecting learners from classes, and engaging them on the procedure of the study and preparations for data collection.

## Data entry and analysis

STATA 17 (StataCorp. 2015. Stata Statistical Software:Release 17. College Station, TX, USA) was used to analyze data. Complete case analysis was used to identify participants with missing data during analysis. Descriptive statistics in the form of frequencies (n) and percentages (%) were used to describe the sample and to determine the prevalence of current alcohol use and its components. Chi-square ($\chi^2$) was used to test for differences in proportions by gender and current alcohol use. Hierarchical logistic regression analysis was used to assess the associations of current alcohol use with demographic factors. The purposeful selection process began with a univariate analysis of each variable. Any variable having a significant univariate test at some arbitrary level was selected as a candidate for the multivariate analysis. We base this on the Wald test from logistic regression and a $p$-value cut-off point of 0.20 (42), suggested as an appropriate level. Researchers have reported that more traditional levels, such as 0.05, can fail in identifying variables known to be important (43, 44). A stepwise backward elimination process was used, and the iterative process of variable selection entailed removing non-significant from the model. At the end of this iterative process of deleting, refitting, and verifying, the model contained significant covariates (45). The results are presented as adjusted odds ratios (95% confidence interval) (AOR (95%CI). Probability was set at $p < 0.05$.

## Ethical considerations

This study was conducted according to the guidelines laid down in the Declaration of Helsinki (46), and all procedures involving human subjects were approved by Sefako Makgatho Health Sciences University Research and Ethics Committee (SMUREC/H/51/2018: PG). Furthermore, this study received permission from Tshwane Department of Education (Ref 8/4/4/1/2). Written informed consent was obtained from parents of all adolescents, whether younger than 18 years or older, and assent was obtained from the younger adolescents, while those aged 18 years gave written consent, prior to data collection.

# Results

## Characteristics of the adolescents

Four hundred and three adolescents participated in the study, and female adolescents [$n = 218$ (54%)] were more than male adolescents [$n = 185$ (46%)]. The mean age of adolescents was 16 ± 2 years. Adolescents were further divided into three age groups 13–14 years, 15–17 years, and 18–21 years (39). Table 1 shows the demographic characteristics of the adolescents and comparison by sex using a chi-square test. Most of the male adolescents were significantly older (aged 15–17 years and 18–21 years), compared to female adolescents, who were aged between 13 and 14 years ($p = 0.001$). A significant numbers of female adolescents were in Grade 8, compared male adolescents, while most male adolescents were grades 10 and 12 compared to female adolescents ($p = 0.048$). Male adolescents have significantly repeated a grade compared to female adolescents ($p = 0.001$). Female adolescents were doing most of housekeeping, compared to male adolescents who were significantly working at car wash and doing garden during a spare time ($p = 0.004$). Income/week for a job in a spare time was higher (>R150) among male adolescents ($p = 0.016$), who were more into recreational activities ($p = 0.003$) and sports ($p = 0.001$), compared to the female adolescents. More male adolescents had a weekly pocket money of more than R100 ($p = 0.018$) and walked to school ($p = 0.006$), as a mode of transport, as compared to female adolescents.

Table 2 shows the comparison of current alcohol and tobacco use among adolescents by sex. Types of alcoholic beverages reported were beer/cider, wine, spirits, and traditional beer, of which beer/cider [$n = 106$ (26%)] was the commonly used type. The prevalence of current alcohol use among the adolescents was 48%, and more male adolescents were alcohol users (56%) compared to female adolescents (41%) ($p = 0.004$). Smoking was estimated at 18% and more male adolescents were smokers (26%) as compared to female adolescents (8%) ($p = 0.001$), while cannabis was the mostly used smoking products than cigarette ($p = 0.029$).

TABLE 1 Comparison of demographics of the adolescents by sex.

| Variables | All ($n = 403$) $n$ (%) | Female ($n = 218$) $n$ (%) | Males ($n = 185$) $n$ (%) | $\chi^2$ | *P*-value |
|---|---|---|---|---|---|
| Age (years) | | | | | |
| 13–14 | 100 (25) | 67 (30) | 33 (18) | 15.18 | 0.001* |
| 15–17 | 169 (42) | 95 (44) | 74 (40) | | |
| 18–21 | 134 (33) | 56 (26) | 78 (42) | | |
| School grade | | | | | |
| 8 | 92 (23) | 61 (28) | 31 (17) | 9.6 | 0.048* |
| 9 | 90 (22) | 49 (23) | 41 (22) | | |
| 10 | 57 (14) | 25 (11) | 32 (17) | | |
| 11 | 91 (23) | 49 (23) | 42 (23) | | |
| 12 | 73 (18) | 34 (16) | 39 (21) | | |
| Repeated grade | | | | | |
| No | 272 (67) | 168 (77) | 104 (56) | 19.83 | 0.001* |
| Yes | 131 (33) | 50 (23) | 81 (44) | | |
| Dwelling place | | | | | |
| Brick house | 284 (70) | 147 (67) | 136 (73) | 1.58 | 0.454 |
| RDP house | 72 (18) | 43 (20) | 29 (16) | | |
| Shack | 47 (12) | 27 (12) | 20 (11) | | |
| Spare time job | | | | | |
| No | 365 (91) | 203 (93) | 162 (88) | 3.61 | 0.057 |
| Yes | 38 (9) | 15 (17) | 23 (12) | | |
| Types of job in spare time | | | | | |
| Housekeeping | 9 (24) | 8 (53) | 1 (4) | 15.27 | 0.004"* |
| Car Wash | 5 (13) | 0 (0.0) | 5 (22) | | |
| Selling | 8 (21) | 3 (20) | 5 (22) | | |
| Gardening | 4 (10) | 0 (0.0) | 4 (18) | | |
| Other | 12 (32) | 4 (27) | 8 (34) | | |
| Income/week for a job in spare time | | | | | |
| R0 | 15 (39) | 8 (53) | 7 (30) | 8.56 | 0.016* |
| R1–R150 | 5 (13) | 4 (27) | 1 (4) | | |
| >R150 | 18 (47) | 3 (20) | 15 (65) | | |
| Recreation activities | | | | | |
| No | 183 (45) | 114 (52) | 69 (37) | 9.08 | 0.003* |
| Yes | 220 (55) | 104 (48) | 116 (63) | | |
| Type of recreation activity | | | | | |
| None | 183 (45) | 114 (52) | 69 (37) | 26.31 | 0.001* |
| Sports | 145 (34) | 54 (28) | 91 (49) | | |
| Youth groups | 75 (17) | 50 (23) | 25 (14) | | |
| Transport mode to school | | | | | |
| Parents' car | 6 (2) | 6 (3) | 0 (0.0) | 11.98 | 0.006"* |
| Bus | 71 (18) | 46 (21) | 25 (14) | | |
| Taxi | 77 (19) | 45 (20) | 32 (17) | | |
| Walk | 249 (61) | 121 (56) | 128 (69) | | |
| Receiving pocket money/week | | | | | |
| R0 | 68 (17) | 29 (13) | 39 (21) | 8.03 | 0.018* |
| R1–R100 | 281 (70) | 165 (76) | 116 (63) | | |
| >R100 | 54 (13) | 24 (11) | 30 (16) | | |

*(Continued)*

TABLE 1 (Continued)

| Variables | All ($n = 403$) $n$ (%) | Female ($n = 218$) $n$ (%) | Males ($n = 185$) $n$ (%) | $\chi^2$ | $P$-value |
|---|---|---|---|---|---|
| Number of children | | | | | |
| 0 | 381 (94) | 205 (94) | 176 (95) | 1.16 | 0.560" |
| 1 | 19 (5) | 12 (5) | 7 (4) | | |
| 2 | 3 (1) | 1 (0.5) | 2 (1) | | |
| Receiving child social grant | | | | | |
| No | 384 (95) | 207 (95) | 177 (96) | 0.12 | 0.733 |
| Yes | 19 (5) | 11 (5) | 8 (4) | | |
| Religion | | | | | |
| Non-Christian | 305 (76) | 45 (21) | 53 (29) | 3.49 | 0.062 |
| Christian | 68 (24) | 173 (79) | 132 (71) | | |

n stands for number of participants, % stands for percentage, RDP stands for Reconstruction and Development Programme, *stands for $p$-value: significant at 0.05, and " indicates Fisher's exact test used for variables with expected values <5 in a cell.

## Factors associated with current alcohol use

Older learners ($p = 0.001$), learners in grade 11 ($p = 0.001$), and who repeated grade ($p = 0.001$) used alcohol compared to their counterparts. More alcohol users had a spare time job ($p = 0.020$) and worked mostly at car wash and selling ($p = 0.040$). Alcohol users were more of those who walked to school ($p = 0.001$), received pocket money >R100 ($p = 0.001$), received child social grant ($p = 0.032$), had more than one child ($p = 0.038$), and smoking ($p = 0.030$) compared to the non-users (Table 3).

In the unadjusted model at a $p$-value cutoff point of <0.20, sex, age, school grade, repeating a school grade, having a job in a spare time, mode of transport to school, receiving child social grants, and religion were associated with current alcohol use. A multivariate model was built using the covariates (i.e., sex, age, school grade, repeating a school grade, having a job in a spare time, mode of transport to school, child social grants, and religion). The results showed that the odds of alcohol use were 6.71 higher for adolescents in grade 10 [AOR = 6.71; 95% CI: 3016–14.24], 4.45 time higher for those in grade 11 [AOR = 4.45; 95% CI: 2.21], and 3.05 higher for those in grade 12 [AOR = 3.05; 95% CI: 1.47–6.31] than those in grade 8. Repeating a grade predisposed adolescents to alcohol use twice [AOR = 2.20; 95% CI: 1.32–3.67), as much as those who did not repeat a grade. The odds of alcohol use were 2.91 times higher for adolescents who had a job during their spare time [AOR = 2.91; 95% CI: 1.33–6.37]. Female adolescents aged 15–16 years [AOR = 3.55; 95% CI: 1.78–8.31], 18–21 years [AOR = 8.37; 95% CI: 3.56–19.65], and having a job during their spare time [AOR = 4.08; 95% CI: 1.24–13.44] were more likely to use alcohol than adolescents aged 13–14 years and not having a job during spare times, respectively. Male adolescents aged 15–16 years [AOR = 2.84; 95% CI: 1.14–7.04] and 18–21 years [AOR = 4.59; 95% CI: 1.68–12.50] were more likely to use alcohol than adolescents aged 13–14 years (Table 4).

## Discussion

This study gave insight into the risk factors for alcohol use among adolescents attending selected township high schools in Tshwane, South Africa. The key findings were poor demographic status among the adolescents, high prevalence of alcohol use, binging, and beer/cider being the most used alcoholic beverage, as well as cannabis smoking. Further results on the risk factors for alcohol use among adolescents in the township high schools were sex, age, school grade, repeated grade, and working during a spare time. It is well documented that school-age adolescents are faced with alcohol-related harms associated with social, health, and educational problems (10). The high prevalence rates of alcohol use reported in this study are higher than the reported prevalence in several South African studies (4, 13, 27), yet lower compared to the findings in other studies (12, 14). However, almost similar estimates on the prevalence of alcohol use have been reported among school-aged adolescents in South Africa (16). Mohale and Mokwena (16) conducted a quantitative cross-sectional survey among learners in the four high schools of a peri-urban suburb south of Johannesburg and substances were more prevalent in male adolescents at 52%, and alcohol use was 51% among female adolescents. While the pooled prevalence of alcohol use among the adolescents in sub-Saharan countries (SSA) has been estimated at 32.8% (47), in European countries the prevalence has been estimated at 90% among school adolescents in their lifetime (48). This study further showed the gender disparity on alcohol use among the male and female adolescents and that adolescents aged 15–17 years and 18–21 years were using alcohol more than those aged 13–14 years.

TABLE 2 Comparison of current alcohol and tobacco use and products among adolescents by sex.

| Variables | All ($n$ = 403) $n$ (%) | Females ($n$ = 218) $n$ (%) | Males ($n$ = 185) $n$ (%) | $\chi^2$ | $P$-value |
|---|---|---|---|---|---|
| Current alcohol use | | | | | |
| No | 210 (52) | 128 (59) | 82 (44) | 8.31 | 0.004* |
| Yes | 193 (48) | 90 (41) | 103 (56) | | |
| Types of alcoholic beverages | | | | | |
| Beer/cider | 106 (55) | 49 (54) | 57 (55) | 0.29 | 0.962 |
| Wine | 53 (27) | 26 (29) | 27 (26) | | |
| Spirits | 19 (10) | 8 (9) | 11 (11) | | |
| Traditional beer | 15 (8) | 7 (8) | 8 (8) | | |
| Estimated quantity of alcohol use | | | | | |
| 1–2 glasses/week | | | | | |
| 3–4 glasses/week | 65 (34) | 36 (40) | 29 (28) | 3.02 | 0.221 |
| Binge drinking | 38 (20) | 16 (18) | 22 (21) | | |
| | 90 (47) | 38 (42) | 52 (51) | | |
| Frequency of alcohol use | | | | | |
| Occasional drinkers | 146 (76) | 72 (80) | 74 (72) | 3.62 | 0.195” |
| Weekend drinkers | 44 (23) | 18 (20) | 26 (25) | | |
| Everyday drinkers | 3 (2) | 0 (0.0) | 3 (3) | | |
| Smoking | | | | | |
| No | 160 (82) | 83 (92) | 77 (74) | 11.04 | 0.001* |
| Yes | 34 (18) | 7 (8) | 27 (26) | | |
| Smoking products | | | | | |
| Cigarette | 13 (38) | 0 (0.0) | 13 (48) | 5.46 | 0.029”* |
| Cannabis | 21 (62) | 7 (100) | 14 (52) | | |

n stands for number of participants, % stands for percentage, *stands for $p$-value: significant at 0.05, and ” indicates Fisher's exact test used for variables with expected values <5 in a cell.

Significant gender and age differences reported in other studies conducted among adolescents in South Africa, that male and older adolescents, and in higher school grades are more likely to use alcohol and to engage in binge drinking than female and younger adolescents and in low school grades (1, 11, 12, 49). As adolescents grow, they begin to make their own decisions and sometimes engage in unhealthy behaviors, such as drinking alcohol (50). The concern is that early drinking onset is linked to unintentional injuries, motor vehicle crashes, physical fights, unplanned and unprotected sex, nicotine dependence, illicit substance use, antisocial personality, conduct disorder, and academic underachievement (51–53). Further concerns pertain to the negative impact of alcohol use on the schooling progress of the adolescents, including the behavior of using alcohol later in adulthood (24, 26, 54).

In addition, this present study showed a high prevalence of binge drinking, similar to other studies in South Africa (15–32%) and attributed to several factors, such as the socioeconomic and environmental factors, as well as alcohol availability and accessibility (12, 13, 55, 56). In particular, the South Africa Youth Risk Behavior Survey (14) has reported almost similar prevalence for binge drinking to the current study higher among male adolescents than female adolescents. Binge drinking predisposes to diverse acute health harms, such as alcohol poisoning, alcohol-related blackouts and injury, alcohol-related physical and sexual assault, increased risk for sexually transmitted infection, and problems at school. Simultaneous use of other substances (e.g., cannabis) has been attributed to binge drinking (57–59). Given the relatively high numbers of binge drinkers, it would be useful to repeat this study looking at adolescents who engage in binge drinking to see associated risk factors among this higher risk group.

Adolescents in this study commonly consumed beer/cider and wine. The different types of alcoholic beverages reported in the current study are consistent with several studies in South Africa and SSA countries. In SSA, including South Africa, beer and wine, with addition to the spirit, are mostly consumed (60). Similarly, the reported types of alcoholic beverages in the current study are consistent to the findings of other local studies (16, 27, 28, 61, 62), and in African countries, such as Ghana (63) and Ethiopia (64). Easy access to alcohol, cigarette, and cannabis has been reported in South Africa (65), Nigeria (66), and India (66), including alcohol being a sign of maturity among adolescents (67). Cannabis, use in particular, has been implicated on increased risk for impairments in neurocognitive functioning, which may lead to negative consequences in school

TABLE 3 Comparison of characteristics of adolescents by current alcohol use.

| Variables | Alcohol non users ($n = 210$) $n$ (%) | Alcohol users ($n = 193$) $n$ (%) | $\chi^2$ | *P*-value |
|---|---|---|---|---|
| Sex | | | | |
| Females | 128 (59) | 90 (41) | 8.31 | 0.004* |
| Males | 82 (44) | 103 (56) | | |
| Age (years) | | | | |
| 13–14 | 78 (37) | 22 (12) | 45.32 | 0.001* |
| 15–17 | 87 (42) | 82 (43) | | |
| 18–21 | 45 (21) | 89 (46) | | |
| School grade | | | | |
| 8 | 68 (32) | 24 (12) | 63.6 | 0.001* |
| 9 | 66 (31) | 24 (12) | | |
| 10 | 17 (8) | 40 (21) | | |
| 11 | 29 (14) | 62 (32) | | |
| 12 | 30 (14) | 43 (22) | | |
| Repeated grade | | | | |
| No | 167 (80) | 105 (54) | 28.92 | 0.001* |
| Yes | 43 (20) | 88 (46) | | |
| Dwelling place | | | | |
| Brick house | 147 (71) | 137 (71) | 1.22 | 0.544 |
| RDP house | 31 (16) | 31 (16) | | |
| Shack | 25 (13) | 25 (13) | | |
| Spare time job | | | | |
| No | 194 (94) | 168 (87) | 5.39 | 0.020* |
| Yes | 13 (6) | 25 (13) | | |
| Types of job in spare time | | | | |
| Housekeeping | 6 (46) | 3 (12) | 9.27 | 0.040* |
| Car Wash | 1 (8) | 4 (16) | | |
| Selling | 0 | 8 (32) | | |
| Gardening | 2 (15) | 2 (8) | | |
| Other | 4 (31) | 8 (32) | | |
| Income/week for a job in spare time | | | | |
| R0 | 4 (31) | 11 (44) | 5.36 | 0.108 |
| R1–R150 | 4 (31) | 1 (4) | | |
| >R150 | 5 (38) | 13 (52) | | |
| Recreation activities | | | | |
| No | 96 (46) | 87 (45) | 0.02 | 0.898 |
| Yes | 114 (54) | 106 (55) | | |
| Type of recreation activity | | | | |
| None | 96 (46) | 87 (45) | 2.16 | 0.34 |
| Sports | 70 (33) | 75 (39) | | |
| Youth groups | 44 (21) | 26 (13) | | |
| Transport mode to school | | | | |
| Parents' car | 5 (2) | 21 (11) | 15.92 | 0.001* |
| Bus | 50 (24) | 36 (19) | | |
| Taxi | 41 (20) | 1 (1) | | |
| walk | 114 (54) | 135 (69) | | |
| Receiving pocket money/week | | | | |
| R0 | 27 (13) | 41 (21) | 13.02 | 0.001* |

*(Continued)*

TABLE 3 (Continued)

| Variables | Alcohol non users ($n = 210$) $n$ (%) | Alcohol users ($n = 193$) $n$ (%) | $\chi^2$ | *P*-value |
|---|---|---|---|---|
| R1–R100 | 163 (78) | 118 (61) | | |
| >R100 | 20 (10) | 34 (18) | | |
| Number of children | | | | |
| 0 | 204 (97) | 177 (92) | 5.8 | 0.038”* |
| 1 | 5 (2) | 14 (7) | | |
| 2 | 1 (1) | 2 (1) | | |
| Receiving child social grant | | | | |
| No | 205 (98) | 179 (93) | 5.32 | 0.032* |
| Yes | 5 (2) | 14 (7) | | |
| Religion | | | | |
| Non-Christian | 44 (21) | 54 (28) | 2.7 | 0.105 |
| Christian | 166 (79) | 139 (72) | | |
| Smoking | | | | |
| No | 0 | 160 (83) | 4.73 | 0.030”* |
| Yes | 1 (100) | 33 (17) | | |

n stands for number of participants, % stands for percentage, RDP stands for Reconstruction and Development Programme, *stands for *p*-value: significant at 0.05, and ” indicates Fisher's exact test used for variables with expected values <5 in a cell.

(e.g., trouble retaining information), impaired driving, and risky decision-making (68).

The risk factors for alcohol use reported in this study were similar to some studies conducted in different settings in South Africa (4, 13, 27, 69) and other countries (19, 70) based on academic achievement associated with alcohol use. In the present study, drinking was higher in grade 10 than in grades 11 and 12, and this could be due to the fact that adolescents in grade 10 are aged around 13–14 years, an average age range for starting to consume alcohol in South Africa. Data from the South African Youth Risk Behavior Survey found that, nationally, 25.1% (23.3–27.0) of Grade 8–11 learners had drunk five or more drinks of alcohol within a few hours on one or more days in the month preceding the survey (14). With regard to adolescents working during spare time as a risk factor for alcohol use, there is a consensus in the empirical literature that teenage employment, particularly, results in harmful consequences, such as lower school grades and diminished educational ambitions, among others. There is even more consensus that work puts adolescents at great risk of committing delinquent acts and other problem behaviors, such as smoking cigarettes, drinking alcohol, and using marijuana and other drugs (71).

Through a number of different pathways, alcohol use can influence educational outcomes (19, 72–75). These include the three following mediating factors: biological factors, behavioral factors, and emotional or mental health factors. First, alcohol use and related diseases (such as mental health issues) may have a direct biological effect on cognitive function and concentration at school. Alcohol has been shown to cause neurodegeneration and impaired functional brain activity (19) and can create learning and recognition problems (76). Second, alcohol use can lead to behaviors that affect educational performance, such as lower attendance or commitment. For example, alcohol use has been shown to be associated with absenteeism from school (74), less time spent on studying, and lower school attendance (75). Third, emotional or mental health factors related to alcohol use can affect educational performance. Alcohol use has been shown to negatively affect relationships with other students and teachers and commitment to school work (73). For instance, alcohol use by students may increase the odds of disengaging from school (such as through truancy or school suspension), which may in turn favor connections with antisocial peers. However, the relationship between alcohol use and educational outcomes is complex and multidirectional and has inverse relationship, where students who do less well in school may be more likely to engage in binge drinking as a coping mechanism (72).

Adolescents have until recently been overlooked in global health and social policy, one reason why they have had fewer health gains with economic development than other age groups (77). The possibility of this generation of adolescents being the healthiest depends on better childhood health, nutrition, and lifestyle, among others (31, 77). Alcohol use during the rapid transitions and growth of adolescence has implications on health (78). Early initiation of alcohol use might lead to alcohol use disorders in adolescence and later in adulthood, predisposing users to chronic diseases (79–81). Adolescents who drink heavily are at risk for identifiable health problems, with

TABLE 4 Association of alcohol use with covariates among the adolescents.

| | Crude OR (95% CI) | *P*-value | Adjusted OR (95% CI) | *P*-value |
|---|---|---|---|---|
| ALL | | | | |
| School grade | | | | |
| 8 | 1 (Reference) | | | |
| 9 | 1.03 (0.53–1.99) | 0.929 | 0.89 (0.45–1.77) | 0.748 |
| 10 | 6.67 (3.20–13.89) | 0.001* | 6.71 (3.16–14.24) | 0.001* |
| 11 | 6.06 (3.19–11.50) | 0.001* | 4.45 (2.21–8.94) | 0.001* |
| 12 | 4.06 (2.10–7.85) | 0.001* | 3.05 (1.47–6.31) | 0.003* |
| Repeating a grade | | | | |
| No | 1 (Reference) | | | |
| Yes | 2.47 (1.35–4.50) | 0.003* | 2.20 (1.32–3.67) | 0.003* |
| Job during a spare time | | | | |
| No | 1 (Reference) | | | |
| Yes | 3.25 (2.10–5.05) | 0.001* | 2.91 (1.33–6.37) | 0.007* |
| FEMALES | | | | |
| Age (years) | | | | |
| 13–14 | 1 (Reference) | | | |
| 15–17 | 3.29 (1.59–6.82) | 0.001* | 3.55 (1.78–8.31) | 0.001* |
| 18–21 | 6.92 (3.07–15.59) | 0.001* | 8.37 (3.56–19.65) | 0.001* |
| Job during a spare time | | | | |
| No | | | | |
| Yes | 2.26 (0.77–6.58) | 0.136 | 4.08 (1.24–13.44) | 0.021* |
| MALES | | | | |
| Age (years) | | | | |
| 13–14 | 1 (Reference) | | | |
| 15–17 | 3.14 (1.29–7.66) | 0.012* | 2.48 (1.14–7.04) | 0.024* |
| 18–21 | 6.00 (2.43–14.82) | 0.001* | 4.59 (1.68–12.50) | 0.003* |
| Repeating a grade | | | | |
| No | 1 (Reference) | | | |
| Yes | 2.47 (1.35–4.50) | 0.003* | 1.52 (0.75–3.07) | 0.242 |

female adolescents at a greater risk of incurring more severe physical consequences (82). More disturbing is that alcohol use is often considered a gateway to the use of illegal substances because of the likelihood of deciding to use other drugs (83, 84). If alcohol intoxication continues in one's life, that can produce diminished inhibition, increased violent behavior, and poor judgment that can result in being in the wrong place at the wrong time, these factors all contribute to young deaths and injuries due to alcohol-related aggressive behavior (78).

Our study has several limitations. This study could only report on the inferences due to the use of a cross-sectional study design. The low number of schools used in this study constraints on generalizability and moreover that the study was limited to a group of black adolescents in township (i.e., peri-urban) setting. The current study only looked at proximal risk factors and not more distal risk factors, such as pricing, marketing, and availability. Information on alcohol use among the adolescents was self-reported, which may have been subject to recall bias. Response bias was likely because of the problematic nature of self-reported behavior, as some students might not have responded honestly. Social desirability as a bias that lead to underreporting or overreporting socially undesirable attributes might have affected the prevalence of alcohol use and other information. The use of a comprehensive tool that includes the quantitative measure, frequency, and types, to screen for alcohol use, such as the Alcohol Use Disorders Identification Test, should be considered in future prospective studies. There is a need for an analytical approach and rigorous application of standardized methods to assess alcohol use (85), among adolescents. We acknowledge the limitation of not testing the reliability of the questionnaire statistically, as one of the characteristics of a valid questionnaire (86), which was not done in the original studies (4, 16, 40), from where we adapted the questionnaire used in the current study. However, the correspondences of prevalence rates and risk factors with other studies provide support to the current findings.

## Conclusion

The current study reported high prevalence of alcohol use, binging, and cannabis use, especially among the male adolescents in the township high schools. The study further showed early use of alcohol, as well as an increased risk of continued drinking throughout the adolescence phase. In agreement with few studies conducted in the township high schools (16, 18, 27), adolescent drinking should be given a priority as one of the major public health concerns in South Africa. Risk factors for alcohol use among adolescents were sex, age, school grade, repeated grade, and working during spare time. These findings are suggestive of more evidence-based interventions that would have greater impact in addressing alcohol use among adolescents, such as focusing on availability, marketing, and taxation of alcoholic beverages.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by Sefako Makgatho Health Sciences University Research and Ethics Committee (SMUREC/H/51/2018: PG), and received permission from Tshwane Department of Education (Ref 8/4/4/1/2). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

## Author contributions

BM developed the proposal and undertook the data collection, data capturing, and project administration. MM initiated the research concept, supervised the study, and initiated the first draft of the manuscript. LC initiated the first draft of the manuscript and performed the initial data analysis. PM contributed to the first draft of the manuscript, performed the initial data analysis, validated data analysis, and reviewed and approved the final manuscript. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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# Increased endothelial biomarkers are associated with HIV antiretroviral therapy and C-reactive protein among a African rural population in Limpopo Province, South Africa

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In Sub-Saharan Africa (SSA) endothelial dysfunction (ED) and chronic inflammation in the HIV-positive adults population who are on highly active antiretroviral therapy (HAART) are not fully explored. We determined the effect of HAART on chronic inflammation and ED among HAART-exposed adults in a rural setting. Weight and height were measured to quantify the body mass index (BMI). Lipid and Glucose levels were determined. C-reactive protein (CRP), L-selectin, soluble intercellular adhesion molecule (sICAM-1), and soluble vascular cell adhesion molecule (sVCAM-1) in serum samples were tested. The majority of the HAART-exposed group were on treatment for $<5$ years. Soluble intercellular adhesion molecules, sVCAM-1, L-selectin and CRP were elevated in the HIV-infected groups as compared to the control group. The multivariate analysis showed that HIV infection (HAART-naïve) associated with increased sICAM-1 ($\beta = 0.350$; 95% CI: 0.035–0.664, $p = 0.029$) and L-selectin ($\beta = 0.236$; 95% CI: 0.038–0.434, $p = 0.019$) but not sVCAM-1 ($\beta = 0.009$; 95% CI: 0.252–0.270, $p = 0.468$). The HAART-exposed group is associated with sVCAM-1 ($\beta = 0.250$; 95% CI: 0.015–0.486, $p = 0.037$) but not with sICAM-1- ($\beta = 0.253$; 95% CI: −0.083–0.590, $p = 0.14$) and L-selectin ($\beta = 0.119$; 95% CI: −0.016–0.253, $p = 0.084$). sVCAM-1 was associated with decreased alcohol consumption ($\beta = -0.245$; 95% CI: −0.469–0.021, $p = 0.032$) while L-selectin was associated with decreased total cholesterol ($\beta = -0.061$; 95% CI: −0.124–0.002, $p = 0.05$) and increased CRP ($\beta = 0.015$; 95% CI: 0.009–0.022, $p < 0.001$). Increased endothelial biomarkers were associated with HIV disease and HAART in a rural black adult population of African descent after controlling for CVD risk factors. Inflammation (as measured with CRP) may play an important role in endothelial activation. Further studies are needed to explore the association between endothelial dysfunction and inflammation especially among the HIV-positive population on HAART in similar settings.

KEYWORDS

**endothelial activation, endothelial dysfunction, sICAM-1, sVCAM-1, L-Selectin, CRP, HIV, HAART**

# Introduction

Cardiovascular disease (CVD) risk is increased among human immunodeficiency (HIV) infection and it persists even during highly active antiretroviral therapy (HAART) mediated viral suppression (1, 2). Endothelial dysfunction is well-known in several CVD and is a early event in the development atherosclerosis (3, 4). Evidence exists that elevated levels of endothelial biomarkers [soluble intercellular cell adhesion molecule (sICAM-1), soluble vascular cell adhesion molecule (sVCAM-1), L-selectin] are indicative of inflammation, endothelial dysfunction (ED) and may serve as predictors of atherosclerosis and various cardiovascular complications (5, 6). The endothelium plays a crucial role in the maintainance of vascular and metabolic homeostasis (4, 7, 8).

The endothelium plays a critical role in enhancing normal blood perfusion by creating an anti-inflammatory and non-adhesive surface area (9–11). Thus, any perturbations in the vascular endothelium homeostasis as a result of diverse stimuli, such as HIV infection or adverse effects of HAART may result in ED. Endothelial dysfunction is present in several CVD risk factors which involve metabolic disorders such as hypercholesterolemia, insulin resistance (IR), type 2 diabetes mellitus (T2DM), and lifestyle risk factors such as alcohol and tobacco consumption (12–17). Endothelial dysfunction also correlates with unfavorable outcomes in patients with CVD such as myocardial infarction (MI) (5, 18). Endothelial activation, ED and inflammation plays a critical role in the development of CVD and several VCAM-1, ICAM-1, and L-selectin have been reported as biomarkers of ED in atherosclerosis (5, 6, 17, 19–21).

Studies have showed that chronic HIV inflammation may cause endothelial activation and ED which have been proposed as a potential mechanism for HIV and HAART-induced atherosclerosis (22, 23). Inflammation may lead to the release of pro-inflammatory cytokines, such as interleukin-6 (IL-6), CRP, and tumor necrosis factor alpha (TNF-?) which can cause increased expression of selectins and cell adhesion molecules (CAMs) on the surface of the endothelium (24). Endothelial activation has been previously confirmed among HIV-positive populations in Sub-Saharan Africa (SSA) and this persisted even after the initiation of HAART (23, 24). Few studies in the SSA region confirmed HIV-associated endothelial activation and dysfunction while the majority of studies are observed in non-African populations (25–27). This, therefore, necessitated studies exploring the association between endothelial function, HIV disease and antiretroviral (ARV) therapy in the SSA. Since ED is a precursor event of atherosclerotic disease, it is considered a powerful diagnostic tool to predict CVD (5, 6, 28, 29).

In this rural black South African population, the aim of this study was to: (1) determine ED in HIV-positive individuals (HAART or HAART-naïve) and HIV-negative participants; (2) evaluate whether endothelial biomarkers (sICAM-1, sVCAM-1, and L-selectin) are independently associated with HIV status; (3) to assess whether inflammatory biomarker (CRP) is associated with endothelial biomarkers.

# Materials and methods

## Study design and procedures

The cross-sectional study was carried out from January 2017 and March 2019 in the Mankweng hospital under Polokwane Municipality located within the Capricorn District of Limpopo Province. Ethical clearance was obtained from the University of Limpopo Turfloop Research and Ethics Committee (TREC/119/2016:PG) and permission was further granted by the Department of Health and Primary Health Care and Social Development to conduct this study. The study protocol complied with the Declaration of Helsinki as revised in 2013.

We conveniently and purposively selected the Mankweng daycare clinic which falls within Mankweng. The clinic offers services such as family planning, disease detection, immunization, treatment, and management of various diseases. Permission was obtained from the Department of Health (Capricorn District) to conduct this study. The Limpopo Province HIV prevalence was estimated at 8.3% in 2015/2016 among men and women between 15 and 49 years (30). The sample size ($n = 113$) was calculated using the mathematical formula developed by Cochran (31) with a 5% error and a 95% confidence level. A total of 158 participants (100 females and 58 males) who visited the Mankweng day-care clinic between January 2017 and March 2019 were recruited. The total study participants ($n = 158$) consisted of HIV positive participants who were exposed HAART ($n = 71$), HAART-naïve ($n = 36$) and HIV negative ($n = 51$). Consent were requested from all participants and and voluntary HIV testing and counseling was provided by qualified health care practitioners. Individuals with cardiometabolic disorders such as T2DM, hypertension, or dyslipidaemia participants taking medication for cardiovascular-related conditions, women who are pregnant, breastfeeding and co-infections such as tuberculosis (TB) were excluded from the study.

A structured questionnaire was used to gather demographic information (age, gender and ethnicity), HIV status, medical history, type of regimen, alcohol and tobacco consumption. The questionnaire was also designed to record blood pressure and all the anthropometric measurements, and it was available in English and Sepedi (common language in Mankweng District). The systolic blood and diastolic blood pressure were determined using the digital automated Omron M2 blood pressure monitors (Omron Healthcare, Japan). The weight was measured using the electronic body weight scale (Pee Pee

TABLE 1 Demographics of the study participants.

| | Total group $n = 158$ | HAART-exposed $n = 71$ | HAART-naïve $n = 36$ | HIV negative $n = 51$ | $p$-Value |
|---|---|---|---|---|---|
| **Ethnicity (Black) ($n$, %)** | 158 (100) | – | – | – | – |
| **Age, years** | 40.23 ± 12.72 | 43.24 ± 10.19 | 39.06 ± 11.70 | 36.88 ± 15.53 | **0.019** |
| **Gender** | | | | | |
| Female, $n$ (%) | 100 (63.3) | 46 (64.8) | 20 (55.6) | 34 (66.7) | 0.536 |
| Male, $n$ (%) | 58 (36.7) | 25 (35.2) | 16 (44.4) | 17 (33.3) | |

HAART, highly active antiretroviral therapy.
Data expressed as mean ± standard deviation or sum and percentage.
One-way analysis of variance, Bold text indicates $p < 0.05$.

TABLE 2 HIV and HAART-related characteristics of the study participants.

| | Total Group $n = 158$ | HAART-exposed $n = 71$ | HAART-naïve $n = 36$ | HIV negative $n = 51$ | $p$-Value |
|---|---|---|---|---|---|
| **HIV related parameters** | | | | | |
| NNRTIs use ($n$, %) | – | 57 (80.0) | – | – | – |
| PIs use ($n$, %) | – | 14 (20.0) | – | | – |
| $CD4^+$ cell count (cells/µl) | – | 433.02 (± 214.04) | 341 (± 281.44) | – | **0.053** |
| **HAART duration ($n$, %)** | | | | | |
| <1 year | – | 16 (23.5%) | – | – | – |
| 1–2.9 years | – | 13 (19.2%) | – | – | – |
| 3–4.9 years | – | 12 (17.6%) | – | – | – |
| ≥ 5 years | – | 27 (39.7%) | – | – | – |

NNRTIs, non-nucleotide reverse transcriptase inhibitors; PIs, protease inhibitors; HAART, highly active antiretroviral therapy.
Data presented as mean ± standard deviation or sum and percentage.

Electricals; Delhi, India) and height was measured using the stadiometer (Seca GmbH, & Co. KG, Germany) according to the International Standards for Anthropometric Assessment of the International Society for Advancement of Kinanthropometry (ISAK) (32). The waist circumference (WC) was quantified with the circumference tape measurer (Seca GmbH, & Co. KG, Germany) following the WHO measurement protocol (33).

Fasting venous blood samples were acquired from all the participants. Serum and plasma samples were centrifuged for 20 min at 3,000 revolutions per minute (RPM) according to the appropriate methods. The whole blood samples were immediately used and the serum and plasma were stored at −80°C in the laboratory until further analysis. Participants received counseling before and after HIV testing by a registered counselor. The HIV status of all participants were determined by the serum sample which were performed at the Medical Sciences Laboratory (University of Limpopo) (Alere Determine HIV-1/2, Alere to Abbott Medical Co Ltd., Japan). The CD4+ count in the whole blood samples was determined with the use of Cytomics FC500 Flow Cytometer Multi-Platform loader (MPL) which is an automated tube-based acquisition device for clinical assays at the Lancet Laboratories in Polokwane (Beckman Coulter FC500 MPL/CellMek, Miami, FL). Quantitative determination of glucose, high-density lipoprotein cholesterol (HDL-C), triglycerides (TG) and glucose concentrations in the serum of the participants was done with the Cobas® Integra 400 plus auto-analyser (Roche Holding AG, Basel, Switzerland). The Laboratory information system was used to quantify the low density lipoprotein cholesterol (LDL-C levels.

Bead-based multiplex kits were acquired to quantify the 4 serum biomarkers on a Luminex 200™ device. The human CVD magnetic bead panel 2 were used to determine C-reactive protein and L-selectin concentrations simultaneously in serum samples (EMD Millipore Corporation, Billerica, USA, 2017). The human CVD magnetic bead panel 3 were acquired to determine sICAM-1 and sVCAM-1 concentrations in serum samples (Merck Millipore Corporation, Billerica, MA, USA, 2017). Luminex 200™ instrument system with xPonent 4.2 software (Merck KGaA, Germany) was used to analyse all the biomarkers (bead-based multiplex kits) of interest. All the biomarkers were analyzed at the Center for Vaccines and Immunology under National Institute for Disease Control (NICD) in South Africa.

TABLE 3 CVD risk factors of the study participants.

| | Total Group $n = 158$ | HAART-exposed $n = 71$ | HAART-naïve $n = 36$ | HIV negative $n = 51$ | *p*-Value |
|---|---|---|---|---|---|
| **Body mass index (kg/m$^2$)** | 25.75 ± 5.82 | 25.71 ± 5.97 | 24.10 ± 5.21 | 27.00 ± 5.82 | 0.071 |
| **Cardiovascular measurements (mm Hg)** | | | | | |
| SBP | 121.0 ± 17.86 | 123.69 ± 21.42 | 119.67 ± 14.67 | 118.19 ± 13.65 | 0.216 |
| DBP | 75.02 ± 9.76 | 76.23 ± 10.59 | 74.19 ± 8.97 | 73.92 ± 9.06 | 0.373 |
| MAP | 90.35 ± 11.60 | 92.05 ± 13.46 | 89.35 ± 10.10 | 88.68 ± 9.49 | 0.243 |
| **Lifestyle risk factors (*n*, %)** | | | | | |
| Alcohol users | 33 (21) | 18 (25.3) | 10 (27.8) | 5 (10) | 0.058 |
| Tobacco users | 36 (22.7) | 18 (25.3) | 11 (30.6) | 7 (19.4) | 0.407 |
| **Biochemical measurements** | | | | | |
| Glucose (mmol/L) | 5.21 ± 1.56 | 5.44 ± 1.95 | 5.09 ± 1.45 | 4.95 ± 0.91 | 0.214 |
| HDL-C (mmol/L) | 1.35 ± 0.42 | 1.45 ± 0.35 | 1.22 ± 0.50 | 1.31 ± 0.44 | **0.024** |
| LDL-C (mmol/L) | 2.36 ± 0.92 | 2.47 ± 0.87 | 1.87 ± 0.80 | 2.55 ± 0.98 | **0.001** |
| TC (mmol/L) | 4.28 ± 1.05 | 4.49 ± 0.98 | 3.66 ± 0.87 | 4.43 ± 1.13 | **0.001** |

HAART, highly active antiretroviral therapy; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol, TC, Total Cholesterol.
Data presented as arithmetic mean ± standard deviation, count and percentage.
Bold text indicates $p < 0.05$. A Self-reported smoking and alcohol use. One-way analysis of variance (ANOVA).

## Statistical analysis

All variables underwent descriptive statistical analysis. Variables were presented as mean ± standard deviation (SD) and categorical variables were expressed as frequency and percentages. The *t*-test and one-way analysis of variance (ANOVA) was used to compare the significant differences between the groups. The Shapiro-Wilk test and Gaussian distribution curves were used to test for normality. All the endothelial biomarkers (sVCAM, sICAM and L-section) were not normally distributed. After taking the log transformation, the endothelial biomarkers were now normally distributed. Multiple linear regression analysis was applied to determine the relationship between CVD risk factors (HIV status, smoking, alcohol consumption, Cholesterol, CRP and mean arterial pressure) and endothelial biomarkers (sVCAM, sICAM and L-section). The significance difference and association level were assumed at $p < 0.05$. All the data were analyzed using the IBM statistical package of the social sciences (SPSS) (IBM, Chicago, USA) version 27.

# Results

## General characteristics of the study participants

The study participants ($n = 158$), with a mean age (±SD) of 40.23 ± 12.72 years, consist mainly of an African Black ethnic group (100%) with more females (63.3%) as compared to males (36.7%) (Table 1). The general characteristics of the study participants included three groups respectively, where the control group consisted out of 51 (31.9%), the HAART-naïve group consisted out of 36 (22.5%) and the HAART-exposed group consisted out of 73 (45.6%) (Table 1). The majority of the HAART-exposed participants were on an NNRTI-based regimen (80.0%). Moreover, 60.3% of the patients enrolled were on HAART treatment for <5 years (Table 2). The HAART-exposed group showed significantly higher HDL-C levels compared to both the HAART-naïve and control groups (Table 3). The LDL-C levels were significantly higher in the control group compared to the HAART-naïve group (Table 3). Unadjusted analysis for the endothelial biomarkers, L-selectin ($p = 0.010$) and sICAM-1 ($p = 0.017$) was significantly higher in the HAART-naïve group compared to HAART-exposed and control group (Table 4). However, no significant difference was observed for sVCAM-1 ($p = 0.123$) across the three groups (Table 4). CRP was also significantly higher in the HAART-naïve group ($p = 0.007$) as compared to HAART-exposed and control group (Table 4).

In adjusted analysis, after controlling for CVD risk factors. HIV-naïve group was significantly associated with increased log sICAM (β = 0.350; 95% CI: 0.035–0.664, $p = 0.029$) and increased log L-selectin (β = 0.236; 95% CI: 0.038–0.434, $p < 0.001$) but not with log sVCAM-1 (β = 0.009; 95% CI: 0.252–0.270, $p = 0.468$) (Table 5). Further, HAART-exposed group was significantly associated with increased log sVCAM (β = 0.250; 95% CI: 0.015–0.486, $p = 0.037$) but not with log sICAM (β = 0.253; 95% CI: −0.083–0.590, $p = 0.14$) and log L-selectin (β = 0.119; 95% CI: −0.016–0.253, $p = 0.084$) (Table 5). Alcohol

TABLE 4 Biomarkers of the study participants.

| | Total group $n = 158$ | HAART-exposed $n = 71$ | HAART-naïve $n = 36$ | HIV negative $n = 51$ | $p$-Value |
|---|---|---|---|---|---|
| C-reactive protein (ng/mL | 0.71 (2.05–0.20) | 0.87 (3.90–0.27) | 0.90 (2.71–0.26) | 0.36 (1.05–0.06) | **0.007** |
| L-selectin (ng/mL) | 0.06 (0.11–0.03) | 0.06 (0.13–0.04) | 0.09 (0.17–0.05) | 0.05 (0.08–0.03) | **0.010** |
| sICAM-1 (ng/mL) | 0.71 (1.4–0.28) | 0.68 (2.11–0.26) | 1.00 (1.56–0.65) | 0.49 (0.98–0.19) | **0.017** |
| sVCAM-1 (ng/mL) | 6.83 (11.754.16) | 7.46 (11.12–5.19) | 6.15 (9.65–0.92) | 6.68 (13.47–98) | 0.123 |

HAART, highly active antiretroviral therapy; sICAM-1, soluble intracellular molecule; sVCAM-1, soluble vascular cell adhesion molecule.
Data presented as median and interquartile range. One-way analysis of variance (ANOVA), Bold text indicates $p < 0.05$.

consumption was only associated with decreased log sVCAM (β = −0.245; 95% CI: −0.469– −0.021, $p = 0.032$), however, no association was observed with log sICAM (β = −0.107, 95% CI: −0.435–0.221), $p = 0.524$) and log L-selectin (β = 0.090, 95% CI: −0.080–0.260, $p = 0.301$). Cholesterol significantly associated with decreased log L-selectin (β = −0.061; 95% CI = −0.124–0.002, $p = 0.05$) but not with log sVCAM-1 (β = 0.082, 95% CI: −0.011–0.175, $p = 0.083$) and log sICAM-1 (β = 0.081, 95% CI: −0.069–0.230, $p = 0.291$). CRP associated with increased log L-selectin (β = 0.015; 95% CI: 0.009–0.022, $p < 0.001$) but not with sVCAM-1 (β = 0.004; 95% CI: 0.009–0.001, $p = 0.001$) and sICAM-1 (β = 0.004; 95% CI: −0.010–0.003, $p = 0.305$).

## Discussion

In the present study, HIV status was associated with increased biomarkers of endothelial dysfunction compared to the HIV-negative control, after controlling for CVD risk factors. This finding, therefore, complements the limited reports in Sub-Saharan Africa (23) and is consistent with findings from high-income countries (34). HIV-infected participants, who had never received ART, independently associated with increased serum levels of sICAM-1. Our study did not observe any association between HIV naive and sVCAM-1 as reported previously which may be attributed to locality and gender disparities (35, 36). However, the latter studies (35, 36) support our findings on elevated levels of sICAM-1 among black South Africans and Kenyan women, respectively, following HIV infection. Our findings are further also consistent with high-income countries (37). The mechanism for increased elevation in the present study may be related to inflammation since it was previously reported that pro-inflammatory cytokines, such as IL-6, CRP, and TNF-? are released during HIV-infection and can cause increased expression of CAMs on the surface of the endothelium (26, 36–38). We further observed that HIV-infected participants were independently associated with increased L-selectin. It has been previously reported that L-selectin mediates monocyte attachment to human activated endothelium (39). CRP is a systemic inflammatory marker where it was previously associated with HIV infection (40). Elevated L-selectin has been associated with inflammation (41). The association between HIV infection and L-selectin in the current study may be attributed to chronic inflammation. Chronic HIV inflammation is known to induce endothelial activation and it has been suggested as a possible mechanism for HIV-induced atherosclerosis (22, 42). Further, in the current study, CRP was positively associated with increased L-selectin, which may reiterate the role of inflammation in endothelial activation.

HAART-exposed participants were also associated with an increased sVCAM-1 after controlling for traditional CVD risk factors. Our findings are in support of previous studies performed in South Africa (23), Kenya (41), Botswana (24), and globally (26) where they also found that endothelial activation persists even after ART initiation. The study's findings further emphasize the strong effect of HIV disease on the pathogenesis of ED even after adjusting for traditional CVD risk factors. sICAM-1 was significantly lower in the HAART-exposed group compared to the HAART-naïve. Further, the lack of association between HIV-treated participants and increased sICAM-1 observed in the current study is contrary to previous findings (24, 36, 41). In addition, a lack of association was also observed between the HAART-exposed participants and L-selectin. These observations in the current study may reflect a beneficial role of HAART on endothelial function. We observed an unexpected negative association between alcohol consumption and sVCAM-1. Further, a negative association was also observed between total cholesterol and L-selectin. We are cautious in interpreting the latter findings of the study. Similar future studies are needed to clarify these findings. More studies are needed to elucidate the mechanisms of ARV drugs on endothelial function which will provide insight into cardiovascular disease in the HIV population. The current cross-sectional study did not permit us to infer causation. The findings of the study were restricted to only black South Africans. Other ethnic groups should also be included in the study to establish any variation in the outcome of this study. Unequal sample groups and a strong gender bias could have influenced the outcome of this study. The gender

TABLE 5 Adjusted multivariate analysis between endothelial biomarkers (sVCAM, sICAM and L-section) and CVD risk factors for the entire study participants).

| Variables | Log sVCAM Coefficient (95% CI) | *P*-value | Log SICAM Coefficient (95% CI) | *P*-value | Log L-section Coefficient (95% CI) | *P*-value |
|---|---|---|---|---|---|---|
| HIV Status (ref = Negative) | | | | | | |
| HIV-naïve | 0.009 (−0.252; 0.270) | 0.468 | 0.350 (0.035; 0.664) | **0.029** | 0.236 (0.038; 0.434) | **0.019** |
| HIV-treatment | 0.250 (0.015; 0.486) | **0.037** | 0.253 (−0.083; 0.590) | 0.140 | 0.119 (−0.016; 0.253) | 0.084 |
| Gender (ref = Female) | 0.004 (−0.215; 0.224) | 0.968 | 0.126 (−0.177; 0.430) | 0.415 | 0.052 (−0.091; 0.195) | 0.477 |
| Age | −0.003 (−0.012; 0.005) | 0.468 | 0.001 (−0.008; 0.010) | 0.831 | 0.001 (−0.005; 0.004) | 0.854 |
| Smoke (ref = No) | −0.177 (−0.408; 0.054) | 0.132 | −0.081 (−0.426; 0.264) | 0.646 | −0.015 (−0.179; 0.149) | 0.856 |
| Alcohol consumption (ref = No) | −0.245 (−0.469; −0.021) | **0.032** | −0.107 (−0.435; 0.221) | 0.524 | 0.090 (−0.080; 0.260) | 0.301 |
| Total cholesterol | 0.082 (−0.011; 0.175) | 0.083 | 0.081 (−0.069; 0.230) | 0.291 | −0.061 (−0.124; 0.002) | **0.050** |
| C-reactive protein | −0.004 (−0.009; 0.001) | 0.094 | −0.004 (−0.010; 0.003) | 0.305 | 0.015 (0.009; 0.022) | **<0.001** |
| MAP | −0.005 (−0.014; 0.004) | 0.256 | 0.001 (−0.010; 0.013) | 0.832 | 0.002 (−0.004; 0.007) | 0.590 |

sICAM-1, soluble intracellular molecule; sVCAM-1, soluble vascular cell adhesion molecule; MAP, Mean Arterial Pressure.
Bold text indicates $p < 0.05$. CI, Confidence Intervals.

bias may be due to males being generally the sole provider in the family and hence unable to take time off from work for medical care or to participate in research projects. Also, we were unable to include VL results which could have influenced the outcome of the findings. Future studies should recruit equal amounts of specific ethnic groupings in Limpopo to enhance the quality of conclusions reached. An element of recall bias was evident in this study since there was a level of reliance on information provided by patients and the accuracy of the documented medical files.

## Conclusion

In this rural SSA population in Limpopo province (South Africa), for the first time, we found evidence of ED in the HIV-infected participants despite effective HAART as compared with the HIV-negative participants. HAART associated both positively and negatively with endothelial function after controlling for CVD risk factors. Despite the conflicting findings regarding the association of HIV infection and HAART on the CVD markers, the study succeeded in elucidating that HAART may potentially contribute to endothelial function in this rural black HIV-positive population of African ancestry.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by University of Limpopo Turfloop Research and Ethics Committee (TREC). The patients/participants provided their written informed consent to participate in this study.

## Author contributions

SH was responsible for the literature search, data analysis, interpretation of data, and writing of the manuscript. SH, MS, MM, LE, and PM were responsible for the conception and design, acquisition and interpretation of data, and for revising the article critically for intellectual content. All authors approved the final version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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# Sociodemographic and lifestyle factors and the risk of metabolic syndrome in taxi drivers: A focus on street food

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**Background:** In South Africa, similar to other populous countries, the taxi industry is an important form of transportation that contributes to the country's development. As a result, minibus taxi driving is an occupation characterized by strenuous activities such as long hours of driving, limited rest, and challenges related to securing passengers, among several others. Consequently, to combat stress, some commercial drivers resort to smoking, overeating unhealthy food sold at transportation interchange areas (i.e., taxi ranks), and participating in sedentary behaviors. Most of these activities are risk factors for metabolic syndrome (MetS).

**Aim:** Therefore, this study aimed to investigate the sociodemographic and lifestyle factors that predispose South African taxi drivers who work in the Cape Town Metropole area to the risk of developing MetS.

**Methods:** This cross-sectional study used a convenient sampling method that included 185 male minibus taxi drivers aged 20 years or above. The participants were interviewed using a validated questionnaire to gather information regarding their sociodemographic characteristics and lifestyle practices. They also underwent physical and metabolic assessments, and the International Diabetes Federation (IDF) criteria were used to diagnose people with MetS.

**Results:** Overall, the mean age and driving experience of the taxi drivers were 40.0 years (SD: 10.7) and 9.1 years (SD: 7.4), respectively, with those with MetS being significantly older and having more driving experience than those without. Older participants were 3 and 2.9 times more likely to be diagnosed with MetS than the younger participants. Most taxi drivers (70%) met the IDF diagnostic criteria for MetS. Smokers, those who spent more than 100 ZAR (USD 5.9) and those who spent less than 1.4 MET-minutes per week on physical activity were 1.96, 2.0, and 13.6 times more likely to suffer from MetS that those who were nonsmokers, those who spent less than 100 ZAR and those who spent <1.4 MET-minutes per week on physical activity. Consumption of alcohol and sugar-sweetened beverages (SSBs), as well as takeaway and fried foods, snacks, and sold by the SF vendors, increased the likelihood of developing MetS, abnormal HDL-C, TG, and hypertension, while avoiding takeaway and fried foods decreased this likelihood. Taxi drivers who also avoided consuming fresh fruits had abnormal HDL-C.

**Conclusion:** These findings have significant public health implications, highlighting the need for South African policymakers to adopt a system-level approach to promote lifestyle changes among taxi drivers within the taxi industry.

This can help reduce the health risks faced by these drivers and improve their overall health profile.

KEYWORDS

**street food, metabolic syndrome, male taxi drivers, physical activity, socio-economic status, South Africa, waist circumference**

## Introduction

Several international epidemiological studies have found the prevalence of metabolic diseases to be high among occupational drivers compared to other professionals, such as industrial and office workers (1–3). For example, the majority of professional drivers are at an increased risk of hypertension, myocardial infarction, and hemorrhagic stroke (4). Furthermore, most drivers are in the habit of eating large main meals and consuming snacks (often oily and fried) and fast-food items from street vendors between trips. In addition, many of them resort to alcohol and smoking to overcome stress. It follows logically that they may have an additional risk of developing metabolic diseases. According to Kurosaka et al. (5), taxi driving is characterized by poor eating habits, ongoing stress from driving, and exposure to various health hazards such as air pollution and a lack of physical activity.

In South Africa, taxi drivers and commuters are major consumers of street food (SF) since it is relatively cheap and easily accessible at taxi ranks and bus stations (6, 7). According to Mchiza et al. (8) and Hill et al. (9), the food sold in the streets of Cape Town and surrounding areas seems to be a public health risk since it is energy-dense and high in saturated fat, trans fats, salt, and sugar. Taxi drivers working in these areas may be at risk of developing metabolic syndrome (MetS) as they have been identified to be among the 38% of individuals who consume SF almost daily (6).

Good health is a basic constitutional right for all South African citizens (10). The Occupational Health and Safety Act (OHSA) Section 12(C) (11) requires medical surveillance for all individuals who have high-risk occupations, such as taxi drivers. Similar to other countries, the taxi industry is an important form of transportation in South Africa, contributing to the country's development (12). However, less focus has been given to this industry to ensure that its workers are in good health. To the best of our knowledge, there has never been any health intervention directed at improving the health condition of taxi drivers in South Africa. Substantiated evidence (13–18) suggests that a healthy lifestyle, including healthy eating and regular physical activity, can help to reduce weight, reduce blood pressure, and improve lipid disorders, including raising high-density lipoprotein cholesterol (HDL-C) and lowering triglycerides (TGs). Moreover, unhealthy eating habits and a sedentary lifestyle are known as modifiable risk factors for MetS among taxi drivers (19).

To our knowledge, to date, there are no data on lifestyle and SF consumption in relation to metabolic syndrome (MetS) among minibus taxi drivers in the Western Cape, South Africa. The current study is the first of its kind in South Africa since it investigated the understudied population of minibus taxi drivers, examining their biochemical parameters, sociodemographic characteristics, and lifestyle practices, with a particular focus on SF consumption and the association of these factors with MetS and its components. The results of this study provide valuable insights for further public health research in this neglected field. Moreover, it will contribute to developing targeted interventions to curb the escalation of MetS in adult male South Africans, especially those working in long-duration driving business.

## Materials and methods

### Study participants and sampling size

This cross-sectional study was conducted among 185 professional taxi drivers, who were recruited from taxi ranks in Bellville and Cape Town. They were at least 20 years old. This study used a convenient sampling method, and its aim was not to make generalizations about the entire population but rather to focus on taxi drivers who consume SF. These taxi ranks were chosen because they are the two major transport interchange hubs in the Cape Metropolitan Area in South Africa's Western Cape Province. Some of the data used in this study were used in a previous paper (20). The detailed sample size selection, including the power sampling calculation for the current study, is presented elsewhere (20). The participants of this study were full-time minibus taxi drivers, who had been working in this field for at least 1 year and consumed SF at least three times per week. They donated blood samples that were analyzed in a laboratory to diagnose the presence of MetS. We excluded taxi drivers who had a history of non-communicable diseases (NCDs) such as hypertension, kidney failure, hypo- or hyper- thyroidism, liver diseases, known cardiovascular diseases (CVDs), or diabetes mellitus since their eating habits might have been changed based on the advice given by their health practitioners.

### Data collection

#### Data on sociodemographic and lifestyle practices

A previously validated and structured questionnaire developed and validated for use in South Africans aged 15 years and older, which was successfully used in the first South African National Health and Nutrition Examination Survey (SANHANES-1) (21), was administered by a trained researcher to collect data on sociodemographic characteristics (i.e., age, marital status, race, and education level) and lifestyle practices (i.e., physical activity levels, alcohol consumption, and cigarette smoking) from the taxi drivers *via* face-to-face interviews. Moreover, the duration of sleep, driving experience, and money spent on purchasing SF were assessed using a validated questionnaire used in the study by Hill et al. (6).

The International Physical Activity Questionnaire (IPAQ) (22) was also used to measure the level of physical activity (PA). The results were then based on the calculated physical activity levels (PAL) using the MET-minutes per week criteria. In this case, a sedentary lifestyle was regarded as PAL $< 1.4$ MET-minutes per week, with low being PAL between 1.4 and 1.69 MET-minutes per week, moderate being PAL between 1.7 and 1.9, and vigorous being PAL $\geq 2$ (23).

### Frequency of consuming street food

The SANHANES-1 questionnaire (21) was also used to collect information regarding the frequency of consuming street food (FF). The FF list comprised processed meat (i.e., sausages, polony, and cold cuts, such as Viennas, Frankfurters, Russians, and salami); fast food/takeaway foods, including pizzas, fried chicken, fried fish, and burgers, that were packaged to take home; fried meat and fish dishes (i.e., chips, fried chicken, and fried fish) that were consumed on site; deep-fried snacks (i.e., fries/chips, vetkoek, samoosas, and doughnuts), fresh fruits (i.e., all kinds of fruits, excluding fruit juices and dried fruits), sugar-sweetened beverages (SSBs) (i.e., gas/fizzy and reconstituted cold drinks). Consumption frequency for each food item was measured as "none", "every day", "1–3 times per week", and "4–6 times per week".

### Anthropometric measurements

A nonelastic tape was used to measure the waist circumference (WC) at the narrowest point between the lower rib and the upper iliac crest. A cut-off point of $\geq$94 cm was used to determine abnormal WC levels in men (24).

### Blood pressure

After the participant had been seated for 5 min or longer, three blood pressure (BP) readings were taken from the right arm in a sitting position using an electronic Micronta monitoring kit (25). Normal systolic BP (SBP) was regarded as a BP that was $\leq$ 130 mmHg or a diastolic BP (DBP) that was $\leq$85 mmHg (24).

### Biochemical parameters

The fasting blood glucose (FBG) was estimated using the capillary method with a glucometer (OneTouch®). To measure biochemical parameters, a venous fasting blood sample was obtained. The plasma lipid profile was used for MetS analysis. The concentration of triglycerides was assessed using the phosphoglycerides oxidase peroxidase method, while the HDL-C was analyzed using the colorimetric non-precipitation method. The IDF criterion was used to diagnose MetS (26). According to the IDF definition, abdominal obesity (i.e., an abnormal WC reading) and two or more of the other four metabolic risk factors are required to diagnose MetS. The cutoff points for the five MetS risk factors are as follows: WC $\geq$94 cm for men; TG $\geq$ 1.7 mmol/l; SBP $\geq$ 130mmHg or DBP $\geq$ 85 mmHg; FBG $\geq$ 5.6 mmol/l; and HDL-C $<$ 1.0 mmol/l.

## Statistical analysis

Descriptive statistics were used to describe the basic features such as the categories, distribution, and spread of metabolic status, dietary intake, and lifestyle practices using sociodemographic characteristics. In this case, data were analyzed using the analysis of variance (ANOVA) and the Kruskal–Wallis tests and presented as frequencies, means, medians, and standard deviations, depending on whether they were categorical or continuous. The associations between different variables were analyzed using the Chi-square test. A binary logistic regression analysis was conducted to examine the odds ratios (OR). Multivariate analyses using multiple logistic regression models, which incorporated all risk factors for MetS while adjusting for the effect of possible confounders such as age, employment status, marital status, ethnicity, physical activity, and monthly income, were also applied (AOR). 95% confidence intervals (CIs) that did not overlap and $p$-values that were less than 0.05 indicated significant differences and associations between variable results. All data were analyzed using the statistical package for social sciences (SPSS version 28.0 for Windows; SPSS Inc., Chicago, IL, USA).

# Results

Table 1 presents the sociodemographic characteristics of the study participants based on their MetS status. Overall, the mean age of the participants was 40.0 years (SD: 10.7), with those suffering from MetS being significantly older than those without. There were 10.2% more participants within the age group of 20–39 years. There was a significantly higher prevalence of participants with MetS in the older age group than in the younger age group (61 vs. 39%).

While there were no other significant differences in sociodemographic characteristics in relation to MetS in this cohort, the mean driving experience of the participants was 9.1 years (SD: 7.4). In this case, the participants who presented with MetS had significantly higher driving experience compared to those without. There was also a significantly higher prevalence of participants with MetS who had a driving experience of 8 years or more compared to those with a driving experience of one to seven years (59.7 vs. 40.3%).

Table 2 shows that older participants were 3 and 2.9 times more likely to have MetS than younger participants. While the significant association of MetS with age was unavailable when the data were adjusted for lifestyle practices (i.e., cigarette smoking, alcohol consumption, sleeping duration, physical activity level, and money spent on SF each day), it was available for age after we removed the confounding effects of the other sociodemographic variables explored in the current analysis.

When examining the components of MetS (Table 3), the overall mean values for WC, TG, HDL-C, SBP, DBP, and FBG were 99.1 (SD: 18.3), 1.3 (SD: 1.1), 1.1 (SD: 0.3), 133.4 (SD: 17.2), 84.8 (SD: 13.2), and 6.4 (SD: 3.5), respectively. We also observed that there were many participants with abnormal WC (59.5%), HDL-C (51.4%), and SBP (58.4%). However, there were few participants with abnormal TG (20.5%) and DBP (43.2%). The participants with MetS had significantly higher abnormal WC (64.5% vs. 35.5%), TG (81.6 vs. 18.4%), HDL-C (61.1 vs. 38.9%), SBP (50.9 vs. 49.1%),

TABLE 1 The distribution of sociodemographic characteristics of South African minibus taxi drivers by metabolic syndrome status.

| | *N* = 185 | IDF MetS | | *P* value |
|---|---|---|---|---|
| | | No (*n* = 108) | Yes (*n* = 77) | |
| **Age_(years)** | | | | |
| M ± SD | 40.0 ± 10.7 | 37.3 ± 10.2 | 43.7 ± 10.3 | <0.001 |
| **N(%)** | | | | |
| 20-39 | 102 (55.1) | 72 (66.7) | 30 (39.0) | |
| ≥40 | 83 (44.9) | 36 (33.3) | 47 (61.0) | <0.001 |
| **Ethnicity** | | | | |
| **N(%)** | | | | |
| Black | 146 (78.9) | 85 (78.7) | 61 (79.2) | |
| Non-Black | 39 (21.1) | 23 (21.3) | 16 (20.8) | 0.932 |
| **Level of Education *N* (%)** | | | | |
| No schooling/primary education | 58 (31.4) | 35 (32.4) | 23 (29.9) | |
| Some high school/high education | 127 (68.6) | 73 (67.6) | 54 (70.1) | 0.714 |
| **Marital status** | | | | |
| ***N* (%)** | | | | |
| Single/separated/divorced | 97 (52.4) | 60 (55.6) | 37 (48.1) | |
| Married/living as married | 88 (47.6) | 48 (44.4) | 40 (51.9) | 0.314 |
| **Driving experience (years)** | | | | |
| M ± SD | 9.1 ± 7.4 | 7.2 ± 6.1 | 11.7 ± 8.4 | <0.001 |
| **N(%)** | | | | |
| 1–7 | 103 (55.1) | 72 (66.7) | 31 (40.3) | |
| ≥8 | 82 (44.3) | 36 (33.3) | 45 (59.7) | <0.001 |

IDF, International Diabetes Federation; MetS, metabolic syndrome.

DBP (67.5 vs. 32.5%), and FBG (64.1 vs. 35.9%) compared to those without.

Seventy-seven (*n* = 77) study participants met the IDF diagnostic criteria for MetS (i.e., had a clustering of 3 or more metabolic disorders), of which 46 had three (3) risk factors, 25 had four (4) risk factors, and 6 had five (5) risk factors. The distribution is shown in Table 4.

Table 5 presents the lifestyle practices based on the outcomes of MetS. Overall, the participants smoked an average of almost 10 cigarettes (SD: 5.3) a day, slept an average of 6.1 h (SD: 1.1) each day, spent an average of ZARR 92.1 (exchange rate: ZARR 1 = United States Dollar [USD]$ 17.23) (SD: 36.7) on SF each day, and had an average PAL of 1.42 MET-minutes per week (SD: 0.14). While there were no significant differences regarding the average number of cigarettes smoked by the participants or the average amount of money spent on SF between those who had MetS and those without MetS.

In terms of participant lifestyle distribution based on the MetS status, while there were no significant differences between participants with and without MetS for lifestyle practices such as alcohol consumption and sleeping duration, there were significantly higher number of nonsmokers who were positive for MetS (those who gave an affirmative response for smoking) and those who were negative for MetS (those who gave a negative response for smoking). There were also significantly more participants with MetS who spent ZARR 100 or more than those who spent less than 100 ZAR (57.1% vs. 42.9%, p=0.022). Finally, there were significantly more sedentary participants with MetS compared to those with low and moderate PAL (79.2% vs. 14.3% and 6.5%).

According to Table 6, smokers, those who spent ZARR 100 or more and those who spent <1.4 MET-minute/week were 1.96, 2.0, and 13.6 times significantly more likely to suffer from MetS compared to those who did not smoke, those who spent less than ZARR 100, and those who spent 1.4 or more MET-minute/week. While the increased significant likelihood of MetS for sedentary activity remained, even after removing the confounding effects of sociodemographic characteristics and other lifestyle practices explored in the current study, the likelihood of smoking and the amount spent on SF disappeared. It is also important to note that removing the confounding effects of the other lifestyle facts of the participants resulted in an increased significant likelihood for developing MetS by 2.2 and 2.1 times for those who consumed alcohol and those who slept 7 h or more, respectively.

The frequency of SF consumption in relation to the likelihood of developing MetS and its components was also analyzed and is presented in Supplementary Table 1. Approximately 40.0% of the

TABLE 2 A binary logistic regression analysis to show the association between the sociodemographic characteristics and the MetS status of South African minibus taxi drivers.

| | IDF Metabolic syndrome | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Model 1 | | | Model 2 | | | Model 3 | | |
| | Crude | 95% CI | *P* value | AOR | 95% CI | *P* value | AOR | 95% CI | *P* value | AOR | 95% CI | *P* value |
| **Age (years)** | | | | | | | | | | | | |
| 20–39 | 1 | | | 1 | | | 1 | | | 1 | | |
| ≥40 | 3.133 | 1.706–5.756 | <0.001 | 0.541 | 0.217–1.351 | 0.188 | 0.589 | 0.225–1.539 | 0.280 | 2.955 | 1.2955–6.969 | 0.013 |
| **Ethnicity** | | | | | | | | | | | | |
| Black | 1 | | | 1 | | | 1 | | | 1 | | |
| Non-Black | 0.969 | 0.473–1.987 | 0.932 | 0.908 | 0.356–2.312 | 0.839 | 0.991 | 0.378–2.597 | 0.986 | 0.560 | 0.245–1.280 | 0.169 |
| **Level of Education** | | | | | | | | | | | | |
| No schooling/primary education | 1 | | | 1 | | | 1 | | | 1 | | |
| Some high school/high education | 1.126 | 0.598–2.120 | 0.714 | 2.880 | 1.212–6.847 | 0.017 | 2.676 | 1.103–6.506 | 0.030 | 2.004 | 0.940–4.273 | 0.072 |
| **Marital status** | | | | | | | | | | | | |
| Single/separated/divorced | 1 | | | 1 | | | 1 | | | 1 | | |
| Married/living as married | 1.351 | 0.752–2.429 | 0.314 | 0.557 | 0.254–1.219 | 0.143 | 0.639 | 0.282–1.450 | 0.284 | 0.893 | 0.449–1.778 | 0.748 |

OR, odds ratio; AOR, adjusted odds ratio. Model 1: adjusted for Cigarette smoking, Physical Activity Level and Money spent on Street Food each day; Model 2: adjusted for Cigarettes smoking, Alcohol drinking, sleeping duration, Physical Activity Level and Money spent on Street Food each day; Model 3: adjusted for age ethnicity, level of education, marital status and driving experience.

TABLE 3 The distribution of South African minibus taxi drivers by components of MetS.

| | Entire cohort (*n* = 185) | | IDF MetS | | | | *P* value "between groups" |
|---|---|---|---|---|---|---|---|
| | Mean ± SD | *n* (%) | No MetS (77) | | With MetS (108) | | |
| | | | Mean ± SD | *n* (%) | Mean ± SD | *n* (%) | |
| Waist circumference (cm) | 99.1 ± 18.3 | | 90.7 (14.5) | | 110.8(16.7) | | <0.001 |
| Normal <94 | | 75 (40.5) | | 69 (92.0) | | 6(8.0) | |
| Abnormal ≥94 | | 110 (59.5) | | 39 (35.5) | | 71(64.5) | |
| Triglycerides (mmol/l) | 1.3 ± 1.1 | | 1.0 (0.4) | | 1.9(1.5) | | <0.001 |
| Normal <1.7 | | 147 (79.5) | | 101 (68.7) | | 46(31.3) | |
| Abnormal ≥1.7 | | 38 (20.5) | | 7 (18.4) | | 31(81.6) | |
| HDL-C (mmol/l) | 1.1 ± 0.3 | | 1.2 (0.4) | | 1.0(0.3) | | <0.001 |
| Normal ≥1.0 | | 90 (48.6) | | 71 (78.9) | | 19(21.1) | |
| Abnormal <1.0 | | 95 (51.4) | | 37 (38.9) | | 58(61.1) | |
| Systolic blood pressure (mmHg) | 133.4 ± 17.2 | | 127 (13.3) | | 141(18.8) | | 0.002 |
| Normal <130 | | 77 (41.6) | | 55 (71.4) | | 22(28.6) | |
| Abnormal ≥130 | | 108 (58.4) | | 53 (49.1) | | 55(50.9) | |
| Diastolic blood pressure (mmHg) | 84.8 ± 13.2 | | 79 (9.1) | | 92.7(13.9) | | <0.001 |
| Normal <85 | | 105 (56.8) | | 82 (78.1) | | 23(21.8) | |
| Abnormal ≥85 | | 80 (43.2) | | 26 (32.5) | | 54(67.5) | |
| Fasting blood Glucose (mmol/l) | 6.4 ± 3.5 | | 5.3 (1.1) | | 7.9(4.8) | | <0.001 |
| Normal <5.5 | | 93 (50.3) | | 75 (80.6) | | 18(19.4) | |
| Abnormal ≥5.5 | | 92 (49.7) | | 33 (35.9) | | 59(64.1) | |

HDL-C, high density lipoprotein cholesterol; IDF, international diabetes federation; MetS, metabolic syndrome.

TABLE 4 The distribution of South African minibus taxi drivers by the clustering of MetS components.

| Number of metabolic disorders | *n* (%) |
|---|---|
| 0 | 22 (11.9) |
| 1 | 40 (21.6) |
| 2 | 46 (24.9) |
| 3 | 46 (24.9) |
| 4 | 25 (13.5) |
| 5 | 6 (3.2) |

Metabolic disorders (abnormal WC, TG, SBP, DBP, HDL-C and FBG).

entire population consumed processed meat (sausages, polony, and cold cuts Viennas, Frankfurters, Russians, and salami) at least 1–3 times a week, with a significantly higher proportion (44.4%) of them experiencing abnormal BP compared to those with normal BP (37.5%). Similar results were also observed for the participants who consumed takeaway foods. Moreover, a higher proportion of participants with MetS and hypertension consumed fried food and snacks (i.e., chips, vetkoek, fried chicken, fried fish) compared to those who did not consume these foods. The daily consumption of deep-fried foods was also associated with an abnormal WC.

As illustrated in Table 7, consuming processed meat daily increases the risk of abnormal HDL-C by 3.7 times, while avoiding processed meat reduces hypertension. Further, avoiding takeout reduced the likelihood of developing MetS by 68.2% and abnormal TG by 25%. Daily takeout meal consumption increased hypertension risk by 3.1 times, even after adjusting for age and sociodemographic charactristics. The daily consumption of fried meat and fish increased the likelihood of developing MetS, abnormal WC, and hypertension by 2.1, 2.2, and 2.3 times, respectively. The association remained unchanged, even after removing the confounding effects of age, ethnicity, money spent on buying these foods, sociodemographic characteristic, and unhealthy lifestyle practices.

Moreover, the consumption of these foods 1–3 times a week increased the likelihood of developing abnormal HDL-C by 2.5 times, and this interaction also remained unchanged, even after removing all the confounding effects. The daily consumption of fried snacks also increased the likelihood of developing MetS, abnormal WC, abnormal HDL-C, and hypertension by 3.8, 1.7, 2.3, and 1.9 times, respectively. The consumption of packaged snacks such as crisps and amazimba (Niknaks Maize Snack) every day also increased the likelihood of abnormal HDL-C by eight times. Moreover, consuming these snacks 1–3 times a week increased the likelihood of developing MetS by 4.1 times. These interactions remained unchanged even after removing

TABLE 5 The distribution of the South African minibus taxi drivers by their lifestyle risk factors (i.e., cigarettes smoking, alcohol consumption, physical activity level, sleep duration and money spent on street food each day) and MetS.

| | | IDF metabolic syndrome | | |
|---|---|---|---|---|
| | Entire cohort ($n$ = 185) | No ($n$ = 108) | Yes ($n$ = 77) | $P$ value |
| | $n$ (%) | $n$ (%) | $n$ (%) | $n$ (%) |
| Cigarettes smoking | | | | |
| Yes | 80 (43.2) | 54 (50.0) | 26 (33.8) | |
| No | 105 (56.8) | 54 (50.0) | 51 (66.2) | 0.028 |
| Average number of cigarettes smoked each day | | | | |
| M ± SD | 9.9 ± 5.3 | 9.3 ± 4.9 | 11.0 ± 5.9 | 0.179 |
| 1–5 | 24 (30.0) | 17 (31.5) | 7 (26.9) | 0.793 |
| 6-9 | 7 (8.8) | 4 (7.4) | 3 (11.5) | |
| ≥10 | 49 (61.3) | 33 (61.1) | 16 (61.5) | |
| Current alcohol drinking | | | | |
| Yes | 100 (54.1) | 55 (50.9) | 45 (58.4) | 0.312 |
| No | 85 (45.9) | 53 (49.1) | 32 (41.6) | |
| Frequency of alcoholic beverage consumption | | | | |
| Monthly or less | 52 (36.9) | 31 (36.9) | 24 (37.0) | 0.248 |
| 2–4 time a month | 51 (34.2) | 30 (35.7) | 21 (32.3) | |
| 2–3 times a week | 28 (18.8) | 12 (14.3) | 16 (24.6) | |
| 4 or more time a week | 15 (10.1) | 11 (13.1) | 4 (6.2) | |
| Number of alcoholic beverages consumed on a typical day | | | | |
| 1 or 2 | 9 (9.0) | 4 (7.3) | 5 (11.1) | 0.906 |
| 3 or 4 | 9 (9.0) | 4 (7.3) | 5 (11.1) | |
| 5 or 6 | 59 (59.0) | 34 (61.8) | 25 (55.6) | |
| 7,8 or 9 | 18 (18.0) | 10 (18.2) | 8 (17.8) | |
| 10 or more | 5 (5.0) | 2 (5.5) | 2 (4.4) | |
| Sleeping duration (hours) | | | | |
| M ± SD | 6.1 ± 1.1 | 6.1 ± 1.0 | 6.2 ± 1.2 | 0.624 |
| $n$ (%) | | | | |
| <6 | 112 (60.5) | 70 (64.8) | 42 (54.5) | |
| ≥7 | 73 (39.5) | 38 (35.2) | 35 (45.5) | 0.159 |
| Money spend on street food each day (ZAR) | | | | |
| M ± SD | 92.1 ± 36.7 | 88.6 ± 37.7 | 96.9 ± 34.9 | 0.056 |
| $N$ (%) | | | | |
| <R99.00 | 96 (52.7) | 63 (60.0) | 33 (42.9) | |
| ≥R100.00 | 86 (47.5) | 42 (40.0) | 44 (57.1) | 0.022 |
| Physical activity level (MET-minutes per week) | | | | |
| $N$ ± SD | 1.42 ± 0.14 | 1.35 ± 0.12 | 1.51 ± 0.10 | <0.001 |
| Sedentary PAL | | | | |
| <1.4 | 94 (50.8) | 33 (30.6) | 61 (79.2) | |
| Low PAL | | | | |
| 1.4-1.69 | 86 (46.5) | 75 (69.4) | 11 (14.3) | |
| Moderate PAL | | | | <0.001 |
| 1.70-1.99 | 5 (2.7) | - | 5 (6.5) | |
| Vigorous PAL | | | | |
| ≥2 | - | - | - | |

IDF, International Diabetes Federation; ZAR, South African Rand (exchange rate 17.23 United States Dollar); PAL, physical activity level.

**TABLE 6** Binary logistic regression analysis to show the association between the lifestyle factors and MetS status of the South African minibus taxi drivers.

| | IDF—metabolic syndrome | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Crude | | | Model 1 | | | Model 2 | | | Model 3 | | |
| | OR | 95% CI | *P* value | AOR | 95% CI | *P* value | AOR | 95% CI | *P* value | AOR | 95% CI | *P* value |
| **Current cigarettes smoking** | | | | | | | | | | | | |
| No | 1 | 1.072–3.590 | 0.029 | 1 | 0.301–1.063 | 0.077 | 1 | 0.318–1.142 | 0.120 | 1 | 0.270–1.208 | 0.143 |
| Yes | 1.962 | | | 0.566 | | | 0.602 | | | 0.571 | | |
| **Alcohol consumption** | | | | | | | | | | | | |
| No | 1 | | | 1 | | | 1 | | | 1 | | |
| Yes | 1.355 | 0.751–2.444 | 0.312 | 1.776 | 0.935–3.374 | 0.079 | 1.706 | 0.886–3.287 | 0.110 | 2.191 | 1.021–4.699 | 0.044 |
| **Sleeping duration** | | | | | | | | | | | | |
| <6 | 1 | | | 1 | | | 1 | | | 1 | | |
| ≥7 | 1.535 | 0.844–2.791 | 0.160 | 1.558 | 0.832–2.915 | 0.166 | 1.497 | 0.786–2.851 | 0.220 | 2.107 | 0.977–4.521 | 0.057 |
| **Money spends on street food each day (ZAR)** | | | | | | | | | | | | |
| <R99.00 | 1 | | | 1 | | | 1 | | | 1 | | |
| ≥R100.00 | 2.000 | 1.101–3.633 | 0.023 | 1.225 | 0.619–2.423 | 0.560 | 1.400 | 0.691–2.838 | 0.350 | 1.157 | 0.548–2.441 | 0.702 |
| **PAL (MET–minutes per week)** | | | | | | | | | | | | |
| Active (low, moderate and vigorous) PAL≥1.4 | 1 | 6.388–29.109 | <0.001 | 1 | 5.449–29.354 | <0.001 | 1 | 5.769–32.780 | <0.001 | 1 | 6.769–36.891 | <0.001 |
| Sedentary (<1.4) | 13.636 | | | 12.647 | | | 13.751 | | | 15.802 | | |

IDF, International Diabetes Federation; ZAR, South African Rand (exchange rate 17.23 United States Dollar); PAL, physical activity level; OR, odds ratio; AOR, adjusted odds ratio = Model 1: adjusted for age and driving experience; Model 2: adjusted for age, ethnicity, level of education, marital status and driving experience; Model 3: adjusted for tobacco smoking, alcohol consumption, sleeping duration, PAL and money spent on street food each day.



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TABLE 7 The logistic regression analysis to show the association between the street foods consumed by the South African minibus taxi drivers and their MetS status.

| | MetS | | Abnormal WC | | Abnormal FBG | | Abnormal HDL–C | | Hypertension | | Abnormal triglyceride | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Frequency of food consumption | OR | 95% CI | OR | 95% CI | OR | 95% CI | OR | 95% CI | OR | 95% CI | OR | 95% CI |
| Processed meat (sausages, polony, and cold cuts Viennas, Frankfurters, Russians, salami) | | | | | | | | | | | | |
| None | 0.963 | 0.416–2.227 | 1.024 | 0.477–2.199 | 0.842 | 0.390–1.819 | 1.056 | 0.477–2.376 | 0.413* | 0.182–0.937 | 1.165 | 0.459–2.957 |
| Every day | 1.143 | 0.318–4.109 | 0.594$^{\$}$ | 0.208–1.702 | 0.605$^{\$}$ | 0.205–1.783 | 3.667$^{*\#\circ@\$\wedge}$ | 4.881–15.264 | 1.353 | 0.461–3.975 | 0.879 | 0.200–3.859 |
| 1–3 times last week | 0.830 | 0.366–1.882 | 1.007 | 0.481–2.107 | 0.756 | 0.357–1.599 | 0.850 | 0.388–1.860 | 0.831 | 0.390–1.768 | 0.563 | 0.210–1.506 |
| 4–6 times last week | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| Takeaway food (pizza, burgers, chicken and fish parcels) | | | | | | | | | | | | |
| None | 0.318* | 0.115–0.878 | 1.618 | 0.266–9.852 | 0.865 | 0.163–4.602 | 1.250 | 0.173–9.019 | 0.767 | 0.075–7.860 | 0.750$^{*\circ@\$}$ | 1.574–67.602 |
| Every day | 1.227 | 0.263–5.734 | 1.014 | 0.448–2.298 | 1.300 | 0.583–2.899 | 0.833 | 0.338–2.052 | 3.097$^{*\#\$}$ | 1.123–8.544 | 3.055 | 0.680–13.729 |
| 1–3 times last week | 0.738 | 0.275–1.981 | 0.518 | 0.177–1.514 | 1.615 | 0.538–4.853 | 0.917 | 0.276–3.040 | 1.533 | 0.402–5.841 | 1.853 | 0.277–12.389 |
| 4–6 times last week | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| Fried meat and fish dishes (chips, vetkoek, fried chicken, fried fish) | | | | | | | | | | | | |
| None | 1.778 | 0.236–13.405 | 1.200$^{\$}$ | 0.471–3.056 | 1.059 | 0.406–2.762 | 1.128 | 0.393–3.236 | 1.310 | 0.465–3.684 | 2.000 | 0.533–7.508 |
| Every day | 2.051$^{*\#\circ@\$\wedge}$ | 1.757–5.558 | 2.223$^{*\#\circ@\wedge}$ | 1.007–4.904 | 1.310 | 0.595–2.882 | 1.974 | 0.851–4.580 | 2.278* | 1.977–5.312 | 2.082 | 0.696–6.227 |
| 1–3 times last week | 1.697 | 0.447–6.439 | 1.079 | 0.850 | 1.116 | 0.501–2.486 | 2.538$^{*\#\circ@\$\wedge}$ | 1.089–5.918 | 0.776 | 0.314–1.916 | 1.358 | 0.437–4.228 |
| 4–6 times last week | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| Fried snacks (vetkoek, samoosas, doughnuts) | | | | | | | | | | | | |
| None | 1.786 | 0.550–5.802 | 0.457 | 0.191–1.096 | 1.315 | 0.551–3.138 | 1.875 | 0.678–5.182 | 0.483 | 0.180–1.301 | 0.520 | 0.139–1.945 |
| Every day | 3.772$^{*\circ@}$ | 1.479–9.616 | 1.760$^{\#\circ}$ | 0.693–4.470 | 1.004 | 0.431–2.342 | 2.333$^{*\#}$ | 2.880–6.188 | 2.194* | 1.927–5.191 | 1.354 | 0.459–3.998 |
| 1–3 times last week | 1.875 | 0.730–4.816 | 0.656 | 0.320–1.342 | 0.994 | 0.494–2.001 | 2.035 | 1.898–4.611 | 0.842 | 0.403–1.703 | 0.780 | 0.303–2.006 |
| 4–6 times last week | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| Packaged snacks (chips/crisps, mazimba) | | | | | | | | | | | | |
| None | 3.036 | 0.593–15.547 | 0.606 | 0.186–1.977 | 0.643 | 0.201–2.052 | 3.354 | 0.716–18.637 | 0.381 | 0.117–1.241 | 3.056 | 0.351–26.593 |
| every day | 3.125 | 0.474–20.583 | 0.273 | 0.063–1.178 | 1.111 | 0.262–4.719 | 8.000$^{*\#\circ@\$\wedge}$ | 1.215–52.693 | 0.889 | 0.216–3.662 | 3.300 | 0.294–37.103 |
| 1–3 times last week | 4.113$^{*\circ@\wedge}$ | 1.862–19.626 | 0.739 | 0.244–2.237 | 0.705 | 0.239–2.086 | 6.538$^{\$}$ | 1.373–31.132 | 0.660 | 0.226–1.926 | 3.075 | 0.379–24.933 |
| 4–6 times last week | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |
| Sugar Sweetened beverages (gas/fizzy cold drink and reconstituted) | | | | | | | | | | | | |
| None | 0.545 | 0.133–2.236 | 0.541 | 0.186–1.577 | 0.923 | 0.317–2.685 | 0.426 | 0.127–1.427 | 0.500 | 0.127–1.965 | 0.967 | 0.229–4.087 |
| Every day | 1.660* | 1.796–3.461 | 1.164 | 0.608–2.228 | 1.620 | 0.850–3.088 | 0.833 | 0.416–1.668 | 1.691 | 0.848–3.372 | 0.767 | 0.324–1.812 |
| 1–3 times last week | 1.889 | 0.772–4.619 | 0.854 | 0.383–1.904 | 0.997 | 0.444–2.235 | 1.193 | 0.502–2.833 | 1.442 | 0.610–3.409 | 1.364 | 0.507–3.669 |
| 4–6 times last week | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |

FF, food frequencies; OR: $^{*}p < 0.05$; $^{\#}$Model 1= AOR, $p < 0.05$ adjusted for age; $^{\circ}$Model 2 = AOR, $p < 0.05$ adjusted for eth[illegible]l 3 = AOR, $p < 0.05$ adjusted for money spent on street food each day; $^{\$}$Model 4 = AOR, p < 0,05 adjusted for all socio demographic status, $^{\wedge}$Model 5 = AOR, $p < 0.05$ adjusted for all lifestyle factors.

the confounding effects such as age, ethnicity, money spent on these foods, and sociodemographic status, and unhealthy lifestyle practices. The daily consumption of SSB increased the likelihood of developing MetS by 1.6 times. However, this interaction disappeared after removing the confounding effects such as age, ethnicity, money spent on these foods, sociodemographic characteristics, and unhealthy lifestyle practices.

## Discussion

The current study aimed to investigate the risk factors for MetS among the male minibus taxi drivers working in Cape Town and the surrounding areas. The majority of the taxi drivers had abnormal levels of WC, HDL-C, SBP, and FBG. Approximately 70% of the taxi drivers had clusters of three or more of these health issues. These results are corroborated by both national and international literature that show that individuals who are in the long-duration driving occupation, including taxi drivers, have a high likelihood of developing metabolic disorders compared to other professionals such as industrial and office workers (1–3, 27–30). In addition, these studies also identified age, driving duration, and driving experience as factors that accelerate the onset of these metabolic diseases (31–34). More importantly, Hildrum et al. (35) long argued that this condition strongly increases with age, regardless of any algorithm used to measure MetS. Indeed, in the current study, the mean age of the minibus taxi drivers was 40 years, with older participants having more driving experience compared to their younger counterparts. Even though the current analysis did not demonstrate a significant relationship between driving experience and MetS, it showed that old age increased the likelihood of developing MetS by up to 2.95 times.

Moreover, like in the current study, the majority of occupational drivers involved in other studies (28, 36) reported sleeping hours that are less than the recommended 6 h of sleep each day (37). This may be due to these drivers' long and irregular shift hours (28, 31). Unlike the aforementioned international researchers who reported sleep duration and its quality as the determinants of MetS, in the current study, the association between sleeping duration and MetS was significant. However, it is important to note that the majority of the minibus taxi drivers participating in the current research also reported long working hours such that their daily shifts started as early as 5 am most days and sometimes ended after 10 pm. They cite reasons such as the need to secure passengers who start work early and those who knock off late in the evenings from work because of their long working hours.

In the current study, despite no significant differences observed in the number of cigarettes smoked by those who had MetS and those without MetS, on average, the minibus taxi drivers smoked almost 10 cigarettes each day, and smoking increased their likelihood of developing MetS by up to two times. However, this interaction disappeared after we removed the confounding effects, such as sociodemography and other lifestyle practices investigated in the current study. Therefore, this suggests that factors such as age, ethnicity, the number of cigarettes smoked, and so on moderate propensity of smoking and the likelihood of developing MetS. Additionally, while some of the literature (32, 33) could not establish a relationship between smoking and the likelihood of developing MetS among occupational drivers, Appiah et al. (38) found that non-users of tobacco are less likely to suffer from MetS and its components. Mohebbi et al. (31) also showed that smokers are more likely to suffer from with MetS than nonsmokers. It is also important to explain the differences in the results regarding smokers between the current study and a recent study by Mabetwa et al. (32), which was also conducted for South African taxi drivers. Mabetwa et al.'s (32) study was conducted in the Gauteng province, while the current study was conducted in the Western Cape province. According to Statistics South Africa (39), Cape Town has the highest concentration of male smokers in South Africa. Additionally, it is commonly reported that smokers often smoke in public places, increasing the likelihood of exposure to secondhand smoke for nonsmokers. Therefore, we observed a high prevalence of MetS among nonsmokers in the current study. Moreover, it is important to highlight that the prevalence of smokers in the current study was higher than that of smokers reported in Mabetwa's study (43 vs. 30%).

In the current study, we also found results suggesting that minibus taxi drivers with a sedentary lifestyle had a 13-fold increased risk of developing MetS. This relationship remained strong even after removing the confounding effects such as sociodemography and other lifestyle factors investigated in the current study. This study indicates that physical activity has an independent and significant impact on metabolic health independently, regardless of other social determinants of health. These results are corroborated by substantiated evidence from international studies(40, 41) suggesting a significant negative correlation between physical activity and the likelihood of developing MetS among bus and taxi drivers. Moreover, Chen et al. (1) showed that sedentary occupations, including taxi driving, increase the risk of developing MetS. Several international studies have shown the dose–response relationship between physical activity and metabolic outcomes (13–18). According to Myers et al. (42), most active individuals generally have a low risk of developing metabolic diseases. Additionally, the aforementioned studies found that even meeting the minimal physical activity requirements outlined in the health guidelines (14) (i.e., at least 150 min per week of moderate-intensity activity or 75 min per week of vigorous activities) has significant benefits for reducing metabolic risk. However, we also have to acknowledge that, in our analysis, even though the participants who suffered from MetS had a higher PAL than those without MetS, their activity levels were still within the low PAL range (i.e., they were within the range of 1.4 and 1.7 Met-minutes per week). Thus, the average 1.51 MET-min per week dosage they obtained could not improve their metabolic health. We also must acknowledge that other studies could not find a significant association between physical activity and MetS (32, 38). The reason for this is currently unknown and needs further investigation.

Other interesting results from the current research were that the type and quality of food and beverages consumed by minibus taxi drivers impacted their metabolic health. For instance, when the confounding effects of other lifestyle factors were removed from the current study, alcohol consumption increased the risk of MetS by up to two times. Even though we did not measure the exact amount of alcohol consumed by the minibus taxi drivers participating in our research, the majority reported that they consumed alcoholic beverages that ranged from 5 to 9 standard drinks most days. This is a cause for concern given that studies by Hernández-Rubio et al. (43) and Fan et al. (44) found that heavy drinking is independently associated with reduced kidney function and metabolic risk factors such as impaired fasting glucose/diabetes mellitus, abdominal obesity, arterial stiffness and plaque buildup, hypertension, and dyslipidemia. In the current analysis, we also found that the consumption of takeaway foods, fried foods, and snacks such as crisps and SSB sold by the SF vendors increased the likelihood of developing MetS, abnormal HDL-C, TG, and hypertension. We also found that avoiding takeaway and fried foods decreased the likelihood of MetS.

International research by Kim and Je (45) corroborates our finding in that individuals with MetS generally consume large quantities of processed meat (such as sausages, polony, and cold cuts such as Viennas, Frankfurters, Russians, and salami). Furthermore, the aforementioned study also found that participants in the highest category of total meat, red meat, and processed meat consumption had an increased risk of developing MetS by approximately 14, 33, and 35%, respectively, compared to those in the lowest consumption category of these foods. A meta-analysis of studies (46, 47) revealed a strong correlation between the consumption of red meat and the likelihood of developing MetS after excluding studies from Asia. For instance, Pan et al. (48) found that even a slight increase in the daily consumption of red and processed meat had a 14% and 32% increase in the likelihood of type 2 diabetes mellitus, respectively. Abete et al. (49) also found high rates of mortality due to metabolic disorders in populations with high consumption of processed meat.

Some potential mechanisms have been explained to indicate the association between processed meat consumption and the likelihood of developing MetS. Among these are the findings that total and saturated fat contained in processed meat increase the risk of MetS through increased body fat centralization, hyperinsulinemia, and hyperglycemia, which are important components of MetS (50). According to Abete et al. (49), the aforementioned mechanism is mediated by nitrosamines. This chemical is toxic to pancreatic cells formed from the nitrates used as preservatives in processed meat. Additionally, these compounds cause insulin resistance.

Moreover, Marku et al. (51) argue that because iron is a strong pro-oxidant, it causes oxidative stress, which can harm tissues such as pancreatic beta cells. Furthermore, the aforementioned researchers argue that high iron levels may inhibit glucose metabolism and reduce pancreatic insulin synthesis and secretion. Based on the literature, we must also acknowledge that high levels of inflammatory mediators, such as C-reactive protein, in people who consume a high amount of red and processed meat could be another reason for the increased risk of MetS. Because C-reactive proteins also increase blood pressure (52), this could explain the association we found in the current research between the consumption of processed meat and hypertension. Griep et al. (53) reported similar results that suggest high consumption of processed meat is positively associated with the risk of hypertension. Another possible explanation for our findings may be those given by Micha et al. (54), who suggest that the high sodium content of processed meat results in elevated blood pressure.

Our current study further found the association between MetS risk and high consumption of fried food bought from street vendors and consumed on-site (i.e., fries/chips, vetkoek, fried chicken, and fried fish, to be specific). Our results were unsurprising given that the food sold on South African streets, including at the transport interchange areas where we recruited our participants, is not healthy. Additionally, Mchiza et al. (8) and Flores et al. (55) showed that, besides fruits and vegetables, most of the SF sold by vendors are not healthy as they are deep-fried, which is associated with cardiovascular risks. However, we must acknowledge that not all researchers have found associations between fried food and the risk of MetS. For instance, upon investigating a Mediterranean cohort of young Asian adults, Sayon-Orea et al. (56) and Kang and Kim (57) found no association between MetS and the frequency of consuming fried foods. The differences between the results of our study and those of the aforementioned Asian studies could be based on the type of food groups included in the current study and the two Asian studies; among the four groups of fried food included in the Asian studies were fried vegetables, fried fish, and fried seaweed. Therefore, we must always be cognizant of the literature that associates plant foods and fish with preventing metabolic diseases (58, 59). In the current study, on the other hand, the four groups of fried food were deep-fried potato chips (or French fries), vetkoek (a cake of deep-fried dough that is stuffed inside), fried chicken, and fried fish. In this case, fried vegetables and seaweeds impact health differently than fried potatoes and fried starch. Finally, the frying mechanisms in these studies were also different. In Asia, pan frying is mostly preferred, while deep frying is favored in South Africa, and these cooking methods have also been shown to impact health differently (60, 61).

This study's results found a statistically significant association between fast-food consumption and MetS risk. These results are consistent with those of Bahadoran et al. (62), where they showed evidence that regular fast-food consumption has a detrimental effect on general health and can increase the risk of obesity, insulin resistance, and other metabolic abnormalities. Several mechanisms have been proposed to explain the negative effects fast foods have on health outcomes. One such mechanism is that fast foods are energy-dense, thus modulating the weight gain process (63). Indeed, Mchiza et al. (8) showed that most fast foods sold in the streets of South Africa are energy dense and have an energy density that is almost two times the recommended energy for a healthy meal. Moreover, the mean total energy of these meals is estimated to be approximately 158–163 kcal per 100 g of food, with the total fat percent of beef hamburgers, chips, chicken hamburgers, and hot dogs being reported to be about $35.8 \pm 10.7$, $35.8 \pm 8.7$, $23.0 \pm 5.1$, and $34.0 \pm 13.5\%$, respectively, with most of this fat being saturated fat (64).

The current study also showed that consuming packaged snacks (chips/crisps and mazimba) 1–3 times a day was associated with an increased risk of developing MetS. In agreement with this study's results, a significant relationship was also shown between dyslipidemia and the frequency of consumption of hydrogenated fat, fast foods, cheese puffs, and crisps in both urban and rural areas of Iran (65).

The current analysis also showed that the consumption of SSBs increased the risk of MetS by up to 1.8 times. Consistent with this study's are a few international studies (66, 67) that reported that SSB intake has significant effects on MetS risk. Moreover, a study conducted on 596 young adult South Africans by Seloka et al. (68) also showed that high consumption of SSBs increases the risk of high FBG in men. This is not a surprise since Deshpande et al. (67) have long shown that sweetened beverages disrupt the hormones involved in regulating energy balance and the satiety center within the human limbic system, which may lead to overeating and result in an increase in positive energy balance in the body. Therefore, the results are body weight gain and an increase in WC. It is also important to note that the SSBs that were included in our study consisted of cold drinks and reconstituted gas/fizzy drinks. Overconsumption of fructose and sucrose from these SSBs has been shown to stimulate and initiate lipid production in the liver, resulting in higher serum triglyceride and cholesterol levels, visceral fat accumulation, and plaque buildup (69). Moreover, glucose in SSBs has a higher glycaemic index, which can cause high blood glucose spikes and may lead to glucose intolerance, insulin resistance, and an increase in inflammatory biomarkers (70).

Finally, in the current study, we found that avoiding the consumption of fresh fruits increased the likelihood of developing abnormal HDL-C. Although we could not specify the type, color, and amount of fruit we referred to in our research, we could attribute these significant interactions to the fiber and antioxidants that fresh fruit and vegetables have, which are compounds that have been shown to mitigate metabolic risks (71). Although several epidemiological studies have evaluated the association between fruit and vegetable consumption and the risk of MetS, the results remain controversial. For instance, some studies have emphasized fruits' and vegetables' roles in mitigating metabolic disease risk or eliminating the disease entirely (72–74), while others have shown the opposite or no association at all with disease downregulation (75). However, a meta-analysis of international studies by Tian et al. (76) cleared up the controversy by showing that, when data from these studies were combined, high fruit and vegetable consumers were 13% and 24% less likely to have MetS, respectively. This meta-analysis of 78 studies further investigated the relationship between the consumption of fruits, vegetables, and MetS risk. When these researchers stratified these interactions by continent, the inverse association of fruit and vegetable consumption was observed to be OR: 0·86 (0·77, 0·96) and OR: 0·86 (0·80, 0·92), respectively, with the risk of MetS remaining significant in Asia. Based on these results, they concluded that people should consume more fruits and vegetables to reduce the risk of metabolic diseases. However, we should be cognizant of the amount, type, and quality of fruit and vegetables that bring about this kind of health benefit. Studies by Nguyen et al. (77) and Sharma et al. (78) suggest that plant foods high in fiber, such as brown and white rice, have greater metabolic health benefits. Numerous substantiated pieces of evidence suggest that the consumption of good fatty acids can prevent MetS risk and its components (79–83). Sekgala et al. (81), in their recent research, eloquently indicated that substituting SFA for PUFA significantly decreases the likelihood of elevated BP by 7%.

To end the aforementioned arguments, it is also important to highlight that, unlike many studies conducted in South African populations with financial constraints, the current study was based on a population that could afford to procure food. Hence, the majority spent more than ZARR 100 on buying SF. A hundred ZAR and more a day is way above the recommended amount (ZARR 40 per day) per person recommended as enough budget to spend on healthy food each day. Abraham et al. (84) have long suggested that, on average, for an adult South African man, a healthier diet costs ZARR 17.3 (which is about USD$ 1) per day. In the current research, the minibus taxi drivers who spent more than ZARR 100 on SF had two times greater risk of MetS than their counterparts who spent ZARR 99 or less. This adverse outcome of MetS could be attributed to the unhealthy food options readily available near transportation hubs. While this relationship was lifestyle and sociodemography dependent, the amount spent on SF was not found to be the mediator/moderator of the type of foods purchased and consumed by the minibus taxi drivers included in the current study.

## Limitation

Despite the notable and important results of the current study outlined above, there are a number of limitations to this study that need to be considered. First, the study was cross-sectional. Hence, causal inferences cannot be drawn from this study's results. Second, the results of the current study focused only on South African male taxi drivers. Therefore, they can only be generalized to occupational drivers in the long-duration driving business but not to the general population. Finally, even though most of the major confounders have been taken into account in most of the studies, there is still a chance of unmeasured and residual confounding factors impacting in the current study. The confounders that were taken into account in the current study were also different from those in the other international studies that have been used to corroborate/contrast this study's results. Hence, notable differences were observed.

## Conclusion

In the current study, we have shown the significant determinants of MetS and its components among South African minibus taxi drivers who presented with abnormal levels of WC, HDL-C, SBP, and FBG, of whom 70% were diagnosed to have MetS according to the IDF diagnostic criteria. Among these important determinants of MetS, we showed that sociodemographic factors such as age and high experience in taxi driving are significantly associated with MetS risk and its components. Moreover, lifestyle factors such as fewer sleeping hours, smoking many cigarettes each day, alcohol and SSB consumption, spending a lot of money on SF, and being sedentary impacted the minibus taxi drivers' metabolic health. More importantly, the consumption of fried food, processed foods, and commercially packaged snacks like crisps, obtained as takeaways, increased the likelihood of minibus taxi drivers developing MetS and its components. However, avoiding the consumption of takeaway and fried foods reduces the risk of MetS. Finally, avoiding the consumption of fruit increased MetS risk. These results have significant public health implications, as policymakers need to adopt evidence-based strategies to encourage a healthy lifestyle among South African men, especially minibus taxi drivers.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

## Ethics statement

The studies involving human participants were reviewed and approved by Ms. Patricia Josias Research Ethics Committee Officer University of the Western Cape. The patients/participants provided their written informed consent to participate in this study.

## Author contributions

MS and ZM: conceptualization and funding acquisition. MS: formal data analysis, methodology, and writing–original draft. ZM and MO: supervision, writing, review, and editing. BM: biochemical analysis. All authors contributed to the article and approved its submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2023.1112975/full#supplementary-material

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# Facilitators and barriers associated with breastfeeding among mothers attending primary healthcare facilities in Mpumalanga, South Africa

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**Introduction:** Despite the health benefits of breastfeeding for both the mother and the child, early cessation of breastfeeding remains a public health problem in South Africa, attributed to contextual barriers and facilitators. Within the context of Mpumalanga province, which is characterized by low breastfeeding rates and high infant mortality rates in children under 5 years, we explored the facilitators and barriers to breastfeeding among mothers attending the three primary health facilities in Ermelo.

**Methods:** Using a semi-structured interview guide suggested by the socio-ecological model, three focus group discussions and 12 in-depth interviews were conducted among mothers selected using a purposive sampling. Transcripts from audiotaped and transcribed verbatim interviews were assessed through thematic analysis using NVivo version 10.

**Results:** Mothers were aged between 18 and 42 years and from poor sociodemographic backgrounds. At the individual level, mothers valued breastfeeding facilitated by their commitment, maintaining it, eating healthy foods, and having sufficient breast milk. However, returning to work, insufficient breast milk, misconceptions about breastfeeding, and interference with social life were the barriers for mothers to breastfeed continuously. At the interpersonal level, the family was identified as the main form of support to breastfeeding mothers; however, family interference was also identified as a barrier. At the community level, mothers shared some family beliefs and practices but were still split between societal and cultural norms and traditional beliefs as facilitators or barriers to breastfeeding. At the organizational level, most mothers valued the support provided by healthcare workers on childcare and techniques for breastfeeding at the health facilities. They did however articulate concerns on the miscommunication some healthcare workers offered regarding breastfeeding, which negatively influenced their infant feeding practices.

**Discussion:** Intervention efforts should focus on behaviour change to educate and equip mothers to overcome the barriers that are within their control. Such interventions should further focus on family-centered education and strengthening the proficiency of healthcare workers on advising breastfeeding mothers.

KEYWORDS

**breastfeeding, facilitators, barriers, qualitative research, primary health facilities, South Africa**

## Introduction

Breastfeeding is a behavior that relates to the relationship between the mother and the child (1). The World Health Organization recommends early initiation of breastfeeding, exclusive breastfeeding, and timely introduction of complementary feeding and continued breastfeeding for up to 2 years or beyond (2). In sub-Saharan Africa (SSA), South Asia, and parts of Latin America, the rate of breastfeeding has been estimated at 12 months, on average, with suboptimal exclusive breastfeeding among infants younger than 6 months in sub-Saharan Africa (3). Countries in East and South Africa have lower rates of continued breastfeeding, on average, but higher rates of exclusive breastfeeding than West Africa (4). Initiation and continuation of breastfeeding are closely related to the sociodemographic status of the mother (5–7), while successful breastfeeding is influenced by the mother's subjective norms regarding infant feeding, together with previous breastfeeding experience, her age, knowledge, attitudes, beliefs, and expectations (1, 8). The literature documents many advantages of breastfeeding for infants and their mothers (9, 10), including health, nutritional, and psychological benefits (3, 10). However, shorter breastfeeding duration predisposes infants to poor child survival and the risk of infectious and chronic diseases, including diarrhea and respiratory tract infections (3, 11), and mothers, to increased risk of breast and ovarian cancer, type 2 diabetes, and hypertension (12).

Breastfeeding can be negatively (i.e., barriers) or positively (facilitators) influenced at various levels from individual, interpersonal, community, and organizational to policy levels (13). In the sequence of these levels, low self-efficacy, lack of partner support, community stigma, hospital formula samples, and lack of protective laws hinder (i.e., negative) breastfeeding (14–16). On the contrary, the positive elements of the aforementioned levels can facilitate breastfeeding (8, 17–19). Documented influences on breastfeeding around cultural traits may be harmful, harmless, or beneficial to the optimal breastfeeding practices (20) and implicated in the early cessation of breastfeeding (21–23). Early cessation of breastfeeding has been attributed to the lack of support from family members or healthcare workers (HCWs), peer pressure, mothers' body image, the role of women in the reproduction process, and pressure to use artificial feeding (17, 24, 25). Precisely, culture affects the role of women regarding breastfeeding and may create doubts about the mother's natural ability to feed the baby, resulting in early cessation of breastfeeding (15).

In South Africa, research on breastfeeding practices has reported that 75–95% of mothers initiate breastfeeding within an hour after birth (75–95%) (18), with suboptimal rates of exclusive breastfeeding reported (19), especially among vulnerable populations, including those living in poor conditions (26). Significant disparities exist within breastfeeding across income, the mother's educational status, and race (27). A breastfeeding paradox in some contexts shows that infants from low-income households are the least likely to receive optimal breastfeeding and most likely to be food-insecure (28). Early cessation of breastfeeding and mixed feeding are common among South African mothers, including the addition of other liquids and complementary feeds in the first 6 months of a child's life being a norm (28, 29). Among children aged 0–5 months, 25.2% were not breastfed at all, 11.4% were fed breast milk and other milk, and 17.6% were given complementary feeds (30). On a broader picture, socio-cultural beliefs, illiteracy of mothers, home delivery, cracked nipples, milk insufficiency, and breast engorgement of mothers were found to be major barriers and factors that influence breastfeeding practice in terms of initiation, exclusivity, and duration in SSA, especially in West Africa (31).

The key facilitators of breastfeeding, especially exclusive breastfeeding, are summarized as breastfeeding knowledge, high levels of self-confidence, the presence of a spouse/partner who assists with chores, family support, and nurses who provided breastfeeding information (32, 33), but barriers to breastfeeding are enormous (34–36). From the few provinces in South Africa, such as Kwa-Zulu Natal, North West, and Western Cape, barriers to breastfeeding have been reported as misconceptions about breastfeeding, lack of knowledge, desire for social acceptance, pressure to maintain an ideal body shape, fuelled negative attitudes, insufficient milk, and reduced breast milk production (34–36). In their systematic review, Sokan-Adeaga and colleagues (31) have identified high socioeconomic status, delivery at the health facility, knowledge of mothers, and expensive infant formula as major facilitators prevalent in SSA, mostly citing Nigeria and Ghana. Studies in Kenya from different contexts in Nairobi (37), Nyando (38), and Offa (39) have identified the following various factors as potential determinants of breastfeeding, especially exclusive breastfeeding: socioeconomic, demographic, maternal, socio-cultural, social, and psychosocial support factors.

Despite the importance of breastfeeding to the health of mother and child, early cessation of breastfeeding remains a societal concern, attributed to contextual/environmental barriers and facilitators. Facilitators and barriers to breastfeeding are well-established in other provinces in South Africa (34–36), but data on the totality of breastfeeding pressing issues are scarce in most regions in Mpumalanga province according to Nieuwoudt and colleagues (40). In addition, previous studies addressing the challenges associated with breastfeeding have been mostly quantitative, with only a few using a qualitative approach, including in South Africa (30, 41). Therefore, within the context of Mpumalanga province, characterized by low breastfeeding rates (42, 43) and high infant mortality rates in children under 5 years (44), we explored the facilitators and barriers to breastfeeding by interviewing using a qualitative approach among mothers attending the primary health facilities in Ermelo. Improving nutrition and preventing child mortality are United Nations' goals to be met by 2023, and South Africa has a golden opportunity to scale up breastfeeding through multisectoral approaches, investment, and systemic change (4, 45, 46).

## Materials and methods

### Study design and theory

This study used a qualitative descriptive design to explore contextual facilitators and barriers to breastfeeding among mothers in primary health facilities in Mpumalanga, South Africa. The study was conducted between May 2019 and October 2019 and adhered to the Consolidated Criteria for Reporting Qualitative Research (COREQ), a 32-item checklist for interviews and focus groups (47). A socio-ecological model (SEM) was used to describe the facilitators and barriers to breastfeeding among mothers (48).

Using this framework, research has shown that individual factors (i.e., low self-efficacy), interpersonal (i.e., lack of partner support), community (i.e., community stigma), organizational (i.e., hospital formula samples), and policy (mainly lack of protective laws) hinder breastfeeding (48). On the contrary, the positive side of the aforementioned barriers facilitates breastfeeding on each level, such as high self-efficacy (individual), supportive family and friends (interpersonal), access to community resources (community), in-hospital education (organizational), and workplace protections (policy) (48). Furthermore, there are individuals within a breastfeeding women's microsystem that can influence each level of the SEM, such as family and/or friends, childcare providers, and HCWs (48).

## Study setting and population

The study was conducted in a small town, located in the Mpumalanga province of South Africa called Ermelo, in the Msukaligwa local municipality of Gert Sibande district. At the time of data collection, this area had three primary health facilities and a regional hospital providing healthcare services to the majority of the residents. Data were collected in all three primary health facilities. The population of Ermelo is estimated to be 96,219, close to 60% of the total Msukaligwa population of 164,608, with most being Black people and mainly speaking isiZulu.

Purposive sampling was used to select mothers of children under the age of 2 years from an approximated number of mothers (i.e., 30 to 50/week) attending childcare services at the primary health facilities. With the help of nurses, mothers were recruited by the principal researcher while waiting to be attended to and were informed about the purpose of the study. Participants who showed interest and met the inclusion criteria were invited to participate in the study. During recruitment in the health facilities, information leaflets written in isiZulu to explain the overall aim, objectives, and procedures were distributed to the mothers, while further details were explained by the researcher and the research assistants. Mothers were eligible to participate in the study if they were at least 18 years old and able to provide written informed consent, had a child aged under 2 years, and had ever breastfed, or were breastfeeding at the time of the study. Mothers were recruited while in the queues for child services, and those who met the inclusion criteria were identified and approached with the help of the nursing staff at the respective facilities. The researcher and the research assistant explained the purpose of the study in detail and those who volunteered to participate were requested to meet the researcher to arrange their participation in focus group discussions (FGDs) or individual in-depth interviews (IDIs).

## Data collection

A semi-structured interview guide, informed by SEM, was developed by the research team focusing on mothers' views in relation to the various levels (individual, interpersonal, community, and organizational [i.e., HCWs]) that might have facilitated or hindered breastfeeding (48). The interview guide was developed in English and translated into isiZulu. The guide consisted of open-ended questions that addressed issues about the facilitators and barriers to breastfeeding. The questions were modified as the data collection proceeded, and during interviews, follow-up questions and predefined probes were asked in response to the responses given by the mothers. During interviews, follow-up questions and probes were asked to seek clarity or further explore responses given by the mothers. The study used a combination of IDIs and FGDs to produce in-depth views of mothers on the facilitators and barriers to breastfeeding.

The sample size consisted of 30 mothers of whom 18 participated in three FGDs consisting of six members per group, and 12 participated in IDIs, and the sample size was determined by data saturation. Data saturation implies that no new information could be obtained during interviews on a question level, and entirely from the tool collectively to replicate the study, and when further coding was no longer feasible, as we kept getting repeat/identical information (49, 50). The literature acknowledges three to six FGDs and 10 to 15 IDIs suitable for achieving data saturation on a studied phenomenon (51–53). Prior to conducting and audiotaping interviews, consent to audiotape the discussion was obtained from the mothers, and pseudonyms were used for each participant. Each IDI lasted between 30 and 35 min, while FGDs took ∼1 h. Both FGDs and IDIs were conducted in a private room in the facilities at separate times during the days of data collection without interfering with the daily running of the facilities, with a moderator and a note taker. Sociodemographic data on personal and household information, as well as the obstetric history, were taken at the end of each FGD and IDI using an adapted short demographic tool (54–57). The IDIs preceded the FGDs to avoid the influence of FGDs on individual interviews and helped the moderator to draw focus on possible discussion in FGDs (50). Triangulation, peer debriefing sessions, and the use of a local language during interviews were used to ensure trustworthiness, including taking field and interview notes. After the interviews, mothers were given refreshments.

## Data management and analysis

Using Braun's steps for thematic analysis (58), transcripts were read by the researchers to familiarize and immerse themselves with the data, which was followed by generating initial codes from the data using manual coding. Data were analyzed using NVivo 10 (59). All transcripts were transcribed verbatim by an experienced transcriptionist, translated into English, and later reviewed by the principal researcher to ensure accuracy and that there was no loss of meaning. Authors familiarized and immersed themselves with the depth and breadth of the content. The codebook was developed by reviewing the themes, refining them, and naming them. A rigorous process was ensured to define and reach a consensus on the emerging themes and subthemes. The themes were given definitions that determined the essence of what each theme was about and determined what aspect of the data each theme captured. Bracketing was maintained throughout the data analysis to reduce inherent biases. Once the codebook had been developed, consensus about the themes was reached. The findings are presented in themes and quotations that reflect the facilitators and barriers to breastfeeding among mothers. Data showing the process, records, and findings were kept as an audit trail (50).

## Ethical considerations

The permission to conduct the study was granted by the Sefako Makgatho Health Sciences University Research and Ethics Committee (SMUREC) (SMUREC/H/23/2019: PG), which also granted ethical approval. Further permissions to conduct the study were obtained from the Mpumalanga Province Department of Health (Reference number MP_201905_004), South Africa, and from the managers of the three primary healthcare facilities. All mothers gave consent to participate in the study.

# Results and findings

## The characteristics of mothers and children

Table 1 shows the characteristics of mothers and their children. The mean age of mothers was 27 ± 6 years, ranging from 18 to 42 years, while the mean age of children was 9 ± 7 months, with 70% of them under 1 year. Most of the mothers were single, unemployed, had no tertiary education, and were from households with a monthly income of below R5,000/month (≈$282,20). Poor obstetric history was observed in terms of unplanned pregnancy, late or no attendance of antenatal care, cesarean mode of delivery, and living with HIV. The mothers included in this study gave birth to boys, born last, and all of them were HIV-negative.

TABLE 1 Characteristics of the mothers and children.

| Variables | Categories | n | % |
|---|---|---|---|
| Age | ≤30 years | 21 | 70 |
| | >30 years | 9 | 30 |
| Marital status | Single | 25 | 83 |
| | Married | 2 | 7 |
| | Cohabiting | 3 | 10 |
| Education | Primary | 10 | 33 |
| | Secondary | 1 | 3 |
| | Completed matric | 17 | 57 |
| | Tertiary | 2 | 7 |
| Employment status | Employed | 8 | 27 |
| | Unemployed | 22 | 73 |
| Household income/month | <R5000 (<$282,20) | 29 | 97 |
| | >R5000 (>$282,20) | 1 | 3 |
| Maternal HIV status | Positive | 12 | 40 |
| | Negative | 18 | 60 |
| Pregnancy planned | No | 20 | 67 |
| | Yes | 10 | 33 |
| Number of pregnancies | 1 | 6 | 20 |
| | 2 | 9 | 30 |
| | ≥3 | 15 | 50 |
| Parity | 1 | 8 | 27 |
| | 2 | 8 | 27 |
| | ≥3 | 14 | 46 |
| Attended ANC | No | 4 | 13 |
| | Yes | 26 | 87 |
| Time attended ANC | ≤3 months | 14 | 47 |
| | >3 months | 13 | 4 |
| | Never attended | 4 | 13 |
| Delivery mode | Normal | 21 | 70 |
| | Cesarean | 9 | 30 |
| Child sex | Boy | 20 | 67 |
| | Girl | 10 | 33 |
| Child age | <1 year | 21 | 70 |
| | >1 year | 9 | 30 |
| Childbirth order | Last | 23 | 77 |
| | Only | 7 | 23 |
| Child HIV status | Negative | 30 | 100 |
| | Positive | 0 | 0 |

## Emergent themes

In Figure 1, the themes were identified at four levels of SEM, which are individual, interpersonal, community, and organization, related to facilitators and barriers to breastfeeding identified from the interviews. Individual factors facilitating breastfeeding were commitment to breastfeeding, maintaining breastfeeding, eating healthy foods, and production of sufficient breast milk, while the barriers were returning to work, insufficient breast milk, misconceptions about breastfeeding, and interference with social life. Interpersonal factors were characterized by family support to breastfeed (facilitator) and family interference to breastfeed (barrier), while community factors included the mother's adopted societal cultural beliefs and practices (facilitator), cultural and societal norms, and traditional beliefs (community). The organizational factors took into consideration the interaction of healthcare workers with mothers while at the facilities, as well as HCWs support to breastfeed (facilitator), and HCWs miscommunication about breastfeeding (barrier).

### First level—Individual factors

In the context of this study, facilitators of breastfeeding reflect on the responses that mention factors that enhanced breastfeeding, while the barriers to breastfeeding reflect on the responses that mention any situation that makes breastfeeding practice difficult.

On an individual level, commitment to breastfeeding, maintaining breastfeeding, eating healthy foods, and the production of sufficient breast milk were categorized to show the high self-efficacy of a mother regarding breastfeeding.

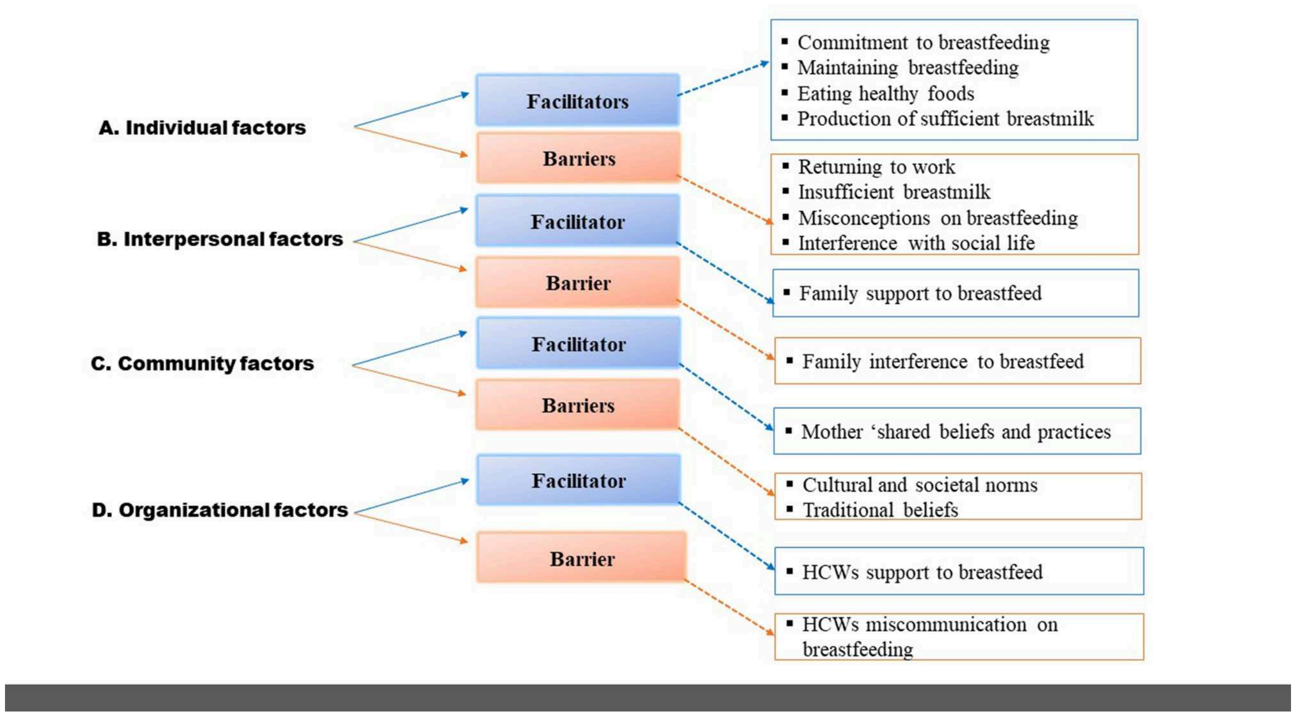


FIGURE 1
Emergent themes from IDIs and FGDs.

Some mothers reported that it was their choice to breastfeed (i.e., commitment), while others expressed breast milk for baby feeding in their absence and continued to breastfeed under the circumstances (i.e., maintaining breastfeeding). The commitment to breastfeeding was also observed through eating healthy foods to promote the production of sufficient breast milk (i.e., facilitators).

- Commitment to breastfeeding—refers to the dedication and sacrifices mothers made to ensure that they continued to breastfeed. From the perspective of some mothers, breastfeeding is a commitment, to the point that one mother mentioned that she made a choice prior to delivery that she will breastfeed, while one had to stop working to engage in breastfeeding. For instance, mothers said:

> *"I have made peace before the child was born that I must breastfeed the child" (IDI, Participant 12).*
>
> *"With this child that I recently gave birth to, I can say that because I was breastfeeding the child exclusively, I had to stay with her so that when she needed the breast she could feed, I even had to stop working" (IDI, Participant 3).*

- Maintaining breastfeeding—refers to responses that mention efforts to continue breastfeeding despite any circumstances. Mothers talked about the significance of continuing to breastfeed, to the point of producing milk for a child to feed in their absence while they were visiting town or frequenting between home and the workplace:

> *"When I had to go to town and had to leave the child, I had to express milk a leave it behind" (IDI, Participant 12).*
>
> *"I once tried to give the child formula milk just after I returned from the hospital. Now I am not giving it, I was doing it so that when I return to work then the child will feed on the formula. But then now when I go to work, I leave him breastfed, and I can come back again at 10 am, then again at 1pm because I am working close to home"* (FGD 3, Participant 3).

- Eating healthy foods—reflects on responses that mention certain foods significantly linked to producing sufficient breast milk. Mothers explained how they consumed some foods that are known to boost breast milk production, like salted ground nuts, soft porridge, water and tea, and maize-based foods. Mothers said:

> *"…one must eat healthy food so that you have enough breastmilk…, like soft porridge, drink water and tea, eat the food that is maize based" (IDI, Participant 6).*
>
> *"When I gave birth to my baby I had little milk, so my friends and family had to bring me those salted ground nuts, then I could see that after eating them my breastmilk started leaking, even when I was just sitting, it was a proof that ground nuts were working, in <30 mins the milk was already there…, just like a miracle" (IDI, participant 10).*

Individual barriers to breastfeeding typically involved returning to work, insufficient breast milk, misconceptions about breastfeeding, and interference with social life. Having to return to work was the most concerning thing for mothers because it led to early cessation of breastfeeding. This was also due to insufficient breast milk, which some mothers referred to as white water, while others felt that a child cannot survive only on breast milk. Hence, mothers introduced foods, and some used milk formulas. There were misconceptions about breastfeeding from mothers, some claiming that breast milk causes constipation, while others considered breastfeeding practice necessary for mothers living with HIV and associated with the stigma, which was concerning. More interesting is the fact that breastfeeding was hindering them to socialize or look slim. One mother mentioned the disturbance of having to take a child with her if she/he is breastfeeding to visit her partner for sexual relations and wanting to lose weight.

- Returning to work—any response indicating a return to work that hindered or led to the cessation of breastfeeding. Mothers expressed having to return to work, which made breastfeeding practice difficult. They said:

> *"Yes, I have breastfed both children, but I have[sic] stopped when they were 4 months because of work, working overtime, and shift" (IDI, Participant 5).*
>
> *"Six months is too long, especially to[sic] those working mothers like me. It does not happen that they give you 6 months' maternity leave. Maybe they give you 3 months. Now, it is better to breastfeed for 3 months or maybe 2 months. Then, on the 2 month, you start to try to mix feeding so that a baby can be able to....by the time you go back to work she already knows how to eat yes[sic]" (*FGD 2, Participant 3).

- Insufficient breast milk—in this context, insufficient breast milk refers to the description of the inadequacy of breast milk to satisfy the child. Some mothers went on to explain how breast milk is not enough, and as a result that led them to stop breastfeeding. Mothers said:

> *"Breastmilk is water and water does not satisfy..., it is just that it is colored, and is milk. Alone it will never satisfy the baby. You will always need to also feed the child solid food on a side"* (FGD 1, Participant 2).
>
> *"Breastmilk alone is not good because the child does not get full sometime. The child does not get well satisfied. Breastmilk is like a letdown fluid to give the child after you have given solid food" (IDI, participant 1).*

- Misconception about breastfeeding—refers to responses that describe a lack of understanding of breastfeeding. Mothers articulated misconceived ideas on breastfeeding practice to the point of associating breastfeeding with a child suffering from constipation, justifying that the introduction of solid foods assists in resolving the constipation problem. Mothers also misconceived that breast milk is not enough to fill the child, hence they believe that is the reason why a child is crying. As a result, complementary and mixed feeding at an early age, such as at 2 months, was the way to go. According to some mothers, this would lead to the child sleeping. Most concerning is that some mothers considered breastfeeding practice necessary for mothers living with HIV and associated with the stigma. Furthermore, some mothers' views indicated that breastfeeding leads to excessive weight loss to the point where they felt uncomfortable because they started to look sickish. For instance, mothers said:

> "My child *took time to pass stools because she was constipated when she was feeding only on the breastmilk, and that would happen for maybe 2 days. There would still be no passing of stools, then I could see that she does not get satisfied then I decided to give her food" (*FGD 3, Participant 1).
>
> "*Breastfeeding practice is different between those who have HIV and those who do not have it. Those who are not sick, we breastfeed until the child is 2 years old and those who are sick, they say they must breastfeed for 6 months then only after that they can start giving the child food[sic]."* (FGD 2, Participant 5).

- Interference with social life—reflects on responses that explain disturbances in their life regarding socializing, sexual relations, and weight loss. The viewpoints of mothers on breastfeeding interfering with their social life were more concerning to the point that one mother mentioned that she does not want to be left behind due to breastfeeding. As a result, she opted for formula. More interesting is the fact that one mother mentioned the disturbance of having to take a child with her if she is breastfeeding to visit her partner for sexual relations and wanting to lose weight. In addition, some mothers indicated that breastfeeding was interfering with their plan to lose weight because breastfeeding prevents them from dieting or consuming weight loss drinks and causes them to eat a lot.

> *"What I have noticed from young mothers is that they don't[sic] want to breast feed because, they say a child that is breast feeding makes it difficult for you to socialize. It is difficult to be left behind, so they opt for formula so that when they want to go, they can do so with ease" (*FGD 3, Participant 4).
>
> *"The child cries when you go away, you are no longer able to leave the child just for a little while, even when you want to visit the father for sexual relations. At least you must always go with child[sic] because the child is breastfeeding" (*FGD 2, Participant 6).
>
> *"I can't even be on a diet, and now December is so close. So as for me of[sic] really, I can't even...like I am saying now that I can't even be on a diet, particularly because of the child, I can't just drink things for weight loss while I am breastfeeding you see. So, some of the things [weight loss] would want me to wait this 6 month[sic] to finish breastfeeding you see" (*FGD 2, Participant 6).

## Second level—Interpersonal factors

At the interpersonal level, the family was identified as support for breastfeeding, especially from their mothers and grandmother; however, family interference was also identified as a barrier.

- Family support for breastfeeding—refers to any mention of the support mothers received for breastfeeding. Mothers mentioned that the support they received from family members, especially from their mothers and grandmothers, for caring for the child, enabling them to breastfeed and to rest, and they said:

> *"I had support from my grandmother on breastfeeding the child and that whenever the baby wakes up, I must breastfeed, and also that I must feed frequently so that the child can grow" (IDI, Participant 7).*
>
> *"Let's say that maybe the child did not sleep at night my mother would take the child and look after the child so that I can be able to sleep for a while during the day" (IDI, Participant 8).*

- Family interference—refers to responses that mention obstacles to breastfeeding caused by family members' involvement. Further barriers included family interference, in which grandmothers and mothers suggested that mothers must feed their children with solid foods. Similarly, mothers introduced solids foods, purity, and formula while breastfeeding, because they felt that milk was not enough.

> *"Because some of us are staying with grannies, they don't understand the situation of not giving the child food before 6 months. They always say fundza [feed] the baby. Then I would feed the baby solids and give the breast too" (*FGD 2, Participant 2).
>
> *"At home, my mother decided that it was better that I give my child food so that we can see whether he is crying or if the baby wanted food" (*FGD 3, Participant 5).

## Third level—Community factors

At the community level, mothers shared some personal beliefs and norms they have adopted from family beliefs and practices but were still divided between societal and cultural norms and traditional beliefs as facilitators or barriers to breastfeeding. The belief systems of individuals, families, and society significantly influence the decision-making of mothers regarding infant feeding practices.

### Mothers' shared beliefs and practices

For example, some of the mothers reported breastfeeding choice as personal but adopted the practice from their mothers who breastfed them and their siblings. Infant feeding beliefs and practices of mothers were shared from the cultural norms and traditions of elders. Mothers said:

> *"I think it is a personal decision to decide whether it is good to give breast milk only or if you want to give both."* (*IDI, Participant 11).*
>
> *"I think it's a belief thing..., older people believe in cultural practices...[sic], it is a belief thing, because they believe that when you breastfeed and give solids food at the same time, the child would be well, healthy, and grow well" (*FGD 3, Participant 6).

### Cultural and societal norms

Mothers' narratives indicated that while some of them had their own individual beliefs and attitudes about breastfeeding, there were active cultural norms and traditional beliefs, which influenced them to breastfeed and/or to opt for formula feeding or mix feed. As indicated, some of the mothers who initiated breastfeeding did so because of the family culture of breastfeeding, especially from a family perspective. Mothers said:

> *"As for me, yes, I choose to breastfeed because my mother breastfed me, so I just want to follow the way of the breast and breastfeed my child" (IDI, Participant 10).*

### Traditional beliefs influencing breastfeeding

Mothers in this study reported traditional practices that affect their efforts to breastfeed, even exclusively breastfeeding their infants. In most African societies, performing traditional rituals on babies to protect them from evil spirits is a norm. The mothers reported that their babies were given traditional medicines: [imbiza] and other concoctions for the treatment of ibala [maroon birthmark at the back of the head and neck], as well as colic and inyoni [described as loose stools similar to diarrhea]. Mothers said:

> *"Just after I was discharged from the hospital maybe after 2 weeks of discharge when the child cried too much and would not stop crying, I took the child to the healer who made a cut [razor cuts on ibala, birth mark] and then gave me imbiza [traditional medicine] for the child to drink" (IDI, Participant 9).*
>
> *"When the child is passing out loose stools, they call it inyoni, so they make razor cut around the umbilicus and put the traditional medicine and also the child is given traditional medicine to drink" (*FGD 2, Participant 3).

Some mothers did not believe in giving their babies traditional medicines for the treatment of colic. They reported the use of over-the-counter medications, such as Lennon Products for infantile colic, to heal a child. Mothers said:

> *"I don't give anything traditional; I give only Western medicine for such things, as in case[sic], the child might absorb the bad spirits, I use the Western ones like stapes drupels you see" (IDI, Participant 6).*
>
> *"As for us at home, we don't use cultural medicine, so actually when you get a baby, you must just breastfeed, otherwise you just buy medicines like Phillips Gripe water, if the baby is having a troubled tummy, Bascopan, you give those" (FGD 1, Participant 4).*

## Fourth level—Organizational factors

At the organizational level, most mothers valued the support provided at the health facilities by healthcare workers for childcare and breastfeeding techniques, but still articulated concerns about healthcare workers' miscommunication about breastfeeding, which influenced their feeding practices negatively.

### HCWs support for breastfeeding

Mothers described breastfeeding support by mentioning how they had received support from the HCWs regarding initiating breastfeeding after giving birth, especially on breastfeeding techniques and advice on breast milk production. Some mothers went on to discuss receiving continued support for breastfeeding while they were at the primary healthcare facilities, and they said:

> *"Nurses show you how to hold the breast when breastfeeding. let us say, like with me, I would see some mothers doing this (a mother is holding the breast at the nipple with two fingers). They say it is called scissor[sic], so I also did that when I breastfed and then the nurses showed me how to do it right so that when the child is breastfeeding, you do not end up closing the nose with your breast and said doing the scissor is not right and should not be used, that is all" (IDI, Participant 8).*
>
> *"...Like me I once asked a nurse at the clinic about the breastmilk that in my view was not enough, that it would quickly finish when the child feeds on the breast. The nurse told me what to drink to make breastmilk increase" (IDI, Participant 2).*

### Miscommunication on breastfeeding by HCWs

The theme include any articulation that lacked understanding or caused contradiction regarding breastfeeding messages HCWs. Mothers articulated the miscommunication they had received from HCWs on breastfeeding, explaining the concerns about the comments made by HCWs during clinic visits for childcare services, which influenced their feeding practices negatively. Some mothers said:

> "*Isn't it, like for instance when you bring the baby at[sic] the clinic for weight monitoring, you find that nurses complain about the baby's weight and they ask you if you are feeding the baby well or what, meaning breastfeeding at that time. So, then you start to think on your own that there is something missing, even though they will never tell you that this baby needs some solids too" (*FGD 1, Participant 4).
>
> "*When I was discharged from the hospital after childbirth, my child weighed 3.06 kg, but when I brought him for weight monitoring and immunization as a newborn, he had lost weight to 2.8 kg[sic]. Mm, when the nurse was busy putting the baby on the scale, she asked me questions, but this child's weight at birth is written here in the Road to Health Birth card what[sic] made him lose weight. Then when I got home, I started feeding him*" (FGD 1, Participant 6).

## Discussion

This qualitative study was undertaken to explore contextual facilitators and barriers to breastfeeding among mothers attending primary health facilities in Mpumalanga, South Africa. The study utilized the SEM approach and interviewed breastfeeding mothers to understand, mostly, their microsystem of breastfeeding facilitators and barriers (60, 61). This study further identified factors that should be considered to improve continuous breastfeeding, including exclusive breastfeeding, like other research areas of improvement (13, 41). Mothers lived in poor socioeconomic households and most were unmarried, unemployed, received minimal income, and had low tertiary education, while poor obstetric history was characterized by unplanned pregnancy, late or zero attendance at antenatal care, cesarean mode of delivery, and mothers living with HIV, similar to other studies (62, 63). Socioeconomic status is one of the most important factors associated with health and medical outcomes of women of reproductive age, and lower status is associated with poor breastfeeding (64, 65). In addition, women with lower socioeconomic status are less likely to receive prenatal care, which is associated with poor obstetric outcomes (64–66). Early cessation of breastfeeding, including low exclusive breastfeeding, and an early introduction of solid foods observed in this study are consistent with other studies in South Africa (63, 67, 68) and other African countries (69–71).

Several ways of ensuring breastfeeding were identified from mothers' interviews. For example, at the individual level, mothers saw breastfeeding as valuable, and for that reason, they endeavored to breastfeed by being committed, maintaining breastfeeding, eating healthy foods, and ensuring that there was enough breast milk. Having the desire to breastfeed was observed among mothers who mostly considered breastfeeding as valuable. Personal decisions influenced mothers' commitment to breastfeeding as they explained that it took a firm resolve to breastfeed, and few of them exclusively breastfeed their babies, as was the case in studies conducted in Malawi (71) and South Africa (30). Mothers had to produce breast milk frequently between home and the workplace to maintain breastfeeding. Maintaining breastfeeding is strongly influenced by contextual factors and maternal sociodemographic characteristics, as well as factors related to prenatal care, delivery, and the postpartum period (72). In addition, mothers believed that eating healthy foods, such as salted ground nuts, soft porridge, water and tea, and maize-based foods, enabled breastfeeding by producing sufficient breast milk, supported by other research showing that adequate maternal nutrition plays a role in facilitating breastfeeding (70, 73, 74). It is, therefore, important to have nutritionists based at health facilities, especially in rural areas, to provide advice to mothers on the specific type of food to eat in order to produce breast milk (41).

However, this study identified barriers to breastfeeding, such as returning to work, insufficient breast milk, misconceptions about breastfeeding, and interference with social life. Mothers who were employed in this study, mentioned work-related issues hindering breastfeeding, such as working overtime and shifts (i.e., workloads), as well as the inability to get maternity leave and working at a place that does not have space to accommodate babies, as reported previously (73, 75–77). Provision should be made for mothers to take their children to work or there should be flexible working terms for breastfeeding mothers, such as working from home if there is a need (41). They also communicated a state of despair and concern when the child was crying, not being able to sleep, and not satisfied with breast milk, which suggested that breast milk is not enough, similar previous reports (35, 42). The quality of breast milk was a concerning issue for mothers, who stated that milk is white water and not sufficient to fill the child's stomach, as reported previously (35, 69). This underscores the relevance of counseling and education to identify the cause of the insufficient flow of breast milk to help mothers in managing breastfeeding challenges, as suggested (41).

Further misconceptions about breastfeeding insinuated poor awareness and lack of understanding of breastfeeding among mothers, consistent with other reports (73, 78). The misconceived association of breastfeeding with a child being constipated was disturbing, including mothers claiming that breastfeeding is relevant for mothers living with HIV and leads to excessive weight loss. Most interesting viewpoints is that breastfeeding interferes with their social life, depriving them of time to socialize, visiting their partners for sexual relations, hindering weight loss, and causing them to overeat. These factors, reported prevoiusly (79, 80), could only mean that mothers saw breastfeeding as a tiring process, and these could be one of the reasons that led to the early cessation of breastfeeding (69). The implication is that if these misconceptions are not addressed, mothers may stop breastfeeding (41), which is harmful to their health and the health of their child. Therefore, programs that encourage mothers to breastfeed must consider addressing issues like these misconceptions.

Although family support was the most identified form of support at the interpersonal level in this study, the family remained the largest barrier to breastfeeding. Mothers articulated the role that grandmothers and mothers played regarding breastfeeding and childcare. According to the literature, family members such as mothers, grandmothers, and mothers-in-law, play essential roles in promoting breastfeeding (70, 81, 82). This was reported in studies in SSA, such as in Mozambique (81), Tanzania (82), Zimbabwe (70), and Nigeria (76), supporting the positive role of mothers and mothers-in-law in encouraging breastfeeding mothers (70, 76, 82). In contrast, researchers have reported that breastfeeding mothers are not able to reject messages opposing breastfeeding from family, which ultimately affects their infant feeding practices by responding to family pressure (30). Therefore, family-centered breastfeeding education support is crucial because the inclusion of significant others and extended family members in prenatal breastfeeding education has been associated with longer breastfeeding durations (16).

At the community level, mothers in this study shared some family beliefs and practices consistent with other studies (46, 83), which have reported the important role of the social and cultural contexts of women in breastfeeding. However, mothers were still split between societal and cultural norms and traditional beliefs as facilitators or barriers to breastfeeding. Predominantly, mothers and grandmothers of the breastfeeding mother are the custodians of these norms, beliefs, and systems, which interfere with breastfeeding because mothers often feel obligated to these cultural prescriptions (70, 84). The use of herbal concoctions as medicines, which is apparent in many African populations (85), was reported to treat infantile colic and prevent bad spirits among children in this study, as in other studies (30, 70), which has adverse effects and is toxic for infants (84, 86). Conforming to cultural norms and traditional beliefs contradicts the guidance of HCWs informed by scientific evidence on breastfeeding.

Finally, at the organizational level, the focus was more on the role HCWs at the health facilities play in breastfeeding immediately after childbirth. It emerged that HCWs' breastfeeding was valued by mothers, especially in terms of breastfeeding techniques and advice on breast milk production relating to diet and childcare. However, HCWs miscommunication on breastfeeding was identified as a barrier, as in studies conducted in Zimbabwe (69, 70) and other local studies (30, 34–36). When mothers visited the facilities for childcare services, the comments made by HCWs misconstrued breastfeeding practice, negatively affecting their feeding practices. There is still confusion about breastfeeding in the context of HIV in South Africa, with some HCWs encouraging the use of formula and others breast milk (87). Some HCWs have been reported to provide breastfeeding mothers with advice that is not supportive of breastfeeding, especially exclusive breastfeeding (30). Desiring to breastfeed, valuing breastfeeding, and having supportive health facilities are associated with high breastfeeding initiation rates (34). Therefore, mothers always value HCWs' practical support (88) to continuously ensure that breastfeeding services are tailored to mothers with special needs, including those who are living with HIV and from poor socio-economic backgrounds. In addition, good communication between mothers and HCWs is critical for building mothers' confidence, promoting bonding, and the participation of mothers in the care of their babies. This might have long-term benefits for the health and wellbeing of the mother and her baby (89), while misleading information from health facilities can be detrimental.

## Limitations and strengths of the study

Although all three primary facilities operating at Emerlo were used, one of the weaknesses of this study is that it was limited to only one area, the Msukaligwa local municipality of Gert Sibande district, Mpumalanga Province. The second limitation in terms of social desirability bias is acknowledged in this study given the possibility that some mothers might have withheld information, despite using a moderator who understood the field of infant feeding and constantly reminded them about the issues of confidentiality while using probes for mothers to be open regarding their breastfeeding practices and conducting interviews in their local language, isiZulu. Third, although data collection ended when data saturation was reached, the use of 12 IDIs and three FGDs might be viewed as small. Three to six FGDs are typically sufficient to achieve data saturation (57, 59), while 10 to 15 IDIs are suitable for addressing the phenomenon being studied (58). Therefore, an integration of FGDs and IDIs enriched the conceptualization and interpretation of the phenomenon studied and enhanced the trustworthiness of the findings as mothers gave in-depth and detailed information. Fourth, not allowing the expression of the frequency of the themes or ranking them in order according to their level of importance is also acknowledged as a limitation. All the emergent themes of the study are considered important regarding breastfeeding.

# Conclusion

This study suggests that there are individual, interpersonal, community, and organizational factors that influence breastfeeding among mothers in Ermelo, South Africa. These factors are shaped by the experiences of mothers, their interaction with family members, the community environment, and HCWs. At the individual level, breastfeeding is a valued behavior, and mothers were committed to breastfeeding and maintaining breastfeeding, including eating healthy foods and ensuring the production of breast milk. However, mothers were hindered by returning to work, insufficient breast milk, misconceptions about breastfeeding, and interference with social life. At the interpersonal level, the family was identified as the greatest form of support for breastfeeding. However, family interference was also identified as a barrier. At the community level, mothers shared some family beliefs and practices but they were still divided between societal and cultural norms and traditional beliefs as facilitators or barriers to breastfeeding. At the organizational level, the support of the HCWs was most valued by mothers; nonetheless, HCWs' miscommunication on breastfeeding negatively influenced their feeding practices. Intervention efforts should focus on behavior change to educate and equip mothers to overcome the barriers that are within their control. Such interventions should further focus on family-centered education and strengthening the proficiency of healthcare workers in advising breastfeeding mothers.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by Sefako Makgatho Health Sciences University Research and Ethics Committee (SMUREC/H/23/2019: PG) and received permission from the Mpumalanga Province Department of Health, South Africa (Reference Number: MP_201905_004), and from the managers of the three primary health care facilities. The patients/participants provided their written informed consent to participate in this study.

## Author contributions

ES contributed to the research concept, developed the proposal, data collection, project administration, data transcription and translation, data analysis, and the first draft of the manuscript. PM contributed to the research concept, development of the proposal, supervision, data analysis, the first draft of the manuscript, and reviewed and approved the final manuscript. KM contributed to the first draft of the manuscript, data analysis, and reviewed and approved the final manuscript. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



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# Factors associated with medication interruption among outpatients with severe mental illness exposed to COVID-19

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Many patients with severe mental illness (SMI) relapsed and deteriorated during the COVID-19 pandemic, as they experienced medication interruption. This study aimed to investigate factors affecting medication interruption in patients with SMI during the COVID-19 pandemic. A total of 2,077 patients with SMI participated in an online survey on medication interruption during the COVID-19 outbreak. The questionnaire comprised six parts: basic demographic information, COVID-19 exposure, state of disease, medication compliance before COVID-19, medication interruption during COVID-19, and the specific impact and needs. A total of 2,017 valid questionnaires were collected. Nearly 50% of patients with SMI have been affected to varying degrees of life expectancy and treatment. Among them, 74 patients stopped taking medicines for more than 14days without a prescription. Logistic regression analysis showed that cohabitant exposure [OR=26.629; 95% CI (3.293–215.323), $p$=0.002], medication partial compliance and non-compliance pre-COVID-19 [OR=11.109; 95% CI (6.093–20.251), $p$<0.001; OR=20.115; 95% CI (10.490–38.571), $p$<0.001], and disease status [OR=0.326; 95% CI (0.188–0.564), $p$<0.001] were related to medication interruption. More than 50% of the patients wanted help in taking medications, follow-up, and receiving more financial support and protective materials. We found that the daily lives of patients with SMI were much more susceptible to impact during the pandemic. Patients with a history of partial or non-medication compliance before COVID-19 and an unstable disease state are more easily affected by pandemics and epidemics and need extra attention should similar large-scale outbreaks occur in the future.

KEYWORDS

**COVID-19, severe mental illness, schizophrenia, medication compliance, medication interruption**

## 1. Introduction

Almost 3 years have passed since the first confirmed case of coronavirus disease 2019 (COVID-19) was reported in Wuhan, China. Scientists now have a deeper understanding of COVID-19, including the natural origin of its causative agent (severe acute respiratory syndrome coronavirus 2: SARS-CoV-2) and mode of transmission (human-to-human transmission, etc.), and have developed several vaccines (1–4). As a result of concerted global efforts, the COVID-19 pandemic has been controlled in many parts of the world. This outstanding achievement is largely due to the strict, large-scale prevention and control mechanisms adopted by governments, such as the immediate implementation of lockdown measures, enforced home isolation and quarantine measures, wearing masks, and social (physical) distancing (5, 6).

However, these procedures have had a negative impact on psychological wellbeing, causing profound changes in health behaviors, including decreased daily physical activity and increased rates of anxiety, depression, irritability, and insomnia (7). Further findings suggest that people with pre-existing mental health disorders are more likely to develop adverse mental health effects, with their symptoms increasing during the pandemic (8). In addition, basic healthcare services that are important for maintaining and stabilizing clinical symptoms and ensuring long-term prognosis for chronic diseases such as severe mental illness (SMI), including routine physical examinations and regular follow-ups, were disrupted during the pandemic due to an unbalanced distribution of medical resources (9). Thus, patients with chronic diseases such as SMI may be the most vulnerable to the COVID-19 pandemic (10). It is generally accepted that medication maintenance is one of the most important ways to prevent relapse and rehospitalization for chronic diseases. It has been estimated that non-compliance leads to an approximately 40% chance of relapse in schizophrenia (11). Even short periods (2 weeks or less) of medication interruption can nearly double the risk of psychotic exacerbation and hospitalization (11, 12). In such cases, good medication compliance is particularly important for maintaining the patient's condition and preventing relapse. For example, studies have found that although the frequency of seizures increased slightly during the pandemic, patients with epilepsy were more motivated and informed about drug compliance and had no impact on stigma (13).

Apart from consistent medication compliance, a 12-month follow-up study on substance use disorder (SUD) and major depressive disorder (MDD) found that general health for asymptomatic SUD and MDD, and physical functioning for SUD were two predictors of relapses (14). Furthermore, social support, another important factor in rehabilitation and prognosis, has been explored in several studies. However, its role may vary across different psychiatric diagnoses. A 1-year follow-up study found that social support was the only factor that predicted the presence of relapses in SUD with schizophrenia but not in SMI patients with major depressive disorder (15).

In China, SMI is the general term for a group of disorders, such as schizophrenia, schizoaffective disorder, paranoid psychosis, bipolar disorder, mental disorders caused by epilepsy, and intellectual disability (16, 17). In clinical practice, we have encountered patients with SMI who experienced medication interruption during COVID-19, which led to their relapse and varying degrees of deterioration in their illnesses. Patients with SMI often have obvious mental symptoms at the onset of the disease, such as hallucinations, delusions, serious thought disorders, and behavioral disorders. They lose self-awareness through the disease, and consequently, control over their behavior, endangering personal and public safety (18). Furthermore, caregivers, peers, and healthcare workers bear an additional burden, increasing the risk of infection in this special situation (9). However, there has been no investigation of the factors associated with medical interruption in patients with SMI during the COVID-19 pandemic.

Therefore, this study aimed to identify such patients' medical interruption status and influencing factors during the COVID-19 pandemic. Furthermore, the study explores the unique needs of such patients in order to provide them with more targeted help. We hope that our work provides a theoretical basis for ensuring the stability of patients' clinical symptoms in cases where similar outbreaks occur in the future.

## 2. Methods and analysis

### 2.1. Participants

Patients with SMI were recruited from four districts in Chengdu, Sichuan Province, China, where the pandemic occurred. All participants and legal guardians were aware of the contents of the informed consent form and willing to cooperate with the investigation. Verbal informed consent was obtained from all participants prior to enrolment. Combined with other studies on patients with mild cognitive impairment or involuntary mental illness, they require careful evaluation of decision-making ability before treatment and research (19–21). However, due to the strict, large-scale prevention and control mechanisms adopted by the Chinese government, the assessment of decision-making ability and on-site data collection of patients with severe mental illness have been seriously affected. Furthermore, patients with severe mental illness are vulnerable groups; most cannot agree to treatment and research, and they are determined to have limited to no capacity for civil conduct according to the Civil Code of the People's Republic of China.[1] Therefore, we sent the assessment questionnaires *via* the internet, to patients' caregivers and legal guardians to assess their conditions. This was mainly to prevent the spread of COVID-19; caregivers and legal guardians were contacted because they have been involved in patients' everyday care and are most familiar with their medicines and treatment. This study was approved by the ethics committee on Biomedical Research of West China Hospital and conducted in accordance with the Declaration of Helsinki.

### 2.2. Inclusion criteria

All patients met the diagnostic criteria for SMI according to the International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10) and were under community management by an administrator. Patients that had full capacity for civil conduct, as assessed by the Judicial Expertise Center, completed their own informed consent with their legal guardians. Patients with SMI had to take prescribed medicines regularly before COVID-19. Administrators have medical records of all patients in their jurisdictions.

1 http://www.npc.gov.cn/npc/c30834/202006/75ba6483b8344591abd07917e1d25cc8.shtml

## 2.3. Exclusion criteria

Patients with SMI or their legal guardians who were unable or unwilling to provide consent and those with no telephone or who were unable to operate the phone to cooperate with the investigation were excluded. Patients without legal guardians were not included in this study. If the patient's condition had reached clinical remission and they had completely stopped taking medicine under the guidance of a doctor before the pandemic, they were also excluded.

## 2.4. Procedure

With reference to the management of patients with SMI and the on-site survey, questionnaires were compiled by five senior psychiatrists with professional qualifications. The questionnaires were further revised through a pre-survey and used for the interviews. To facilitate data collection and ensure data integrity, we conducted a survey *via* the Wenjuanxing platform[2], which sounded a warning when there were unanswered questions at the time of submission. The questionnaire included six parts (31 items).

1. *Basic demographic information:* age (below 30 years, between 30 and 50 years, and older than 50 years), sex (male or female), education level (lower than senior high school, senior high school, college, or undergraduate), living status (not alone, living alone), marital status (single, married, divorced, or widowed), monthly family income, reimbursement ratio of drug insurance (none, partial, complete), working status (working or unemployed), and family relationships (poor, good).
2. *COVID-19 exposure* (yes or no).
3. *The state of disease* (diagnosis, medical history, disease state, social function assessment, insight, drug knowledge, side effect assessment, etc.)
4. *Medication compliance pre-COVID-19* (Complete compliance, partial compliance, and non-compliance).
5. *Medication interruption*, specifically examining the impact of the pandemic (e.g., medication type, days of interruption, and follow-up).
6. *The specific impact and needs of Patients with SMI during COVID-19*: Inconvenience in taking medicine, inconvenience in patient's follow-up to hospital, inconvenience in doctor's return visit, and so on.

The study was conducted in Chengdu, China, between 3 September and 7 October 2020, during a relatively stable phase of the pandemic.

## 2.5. Definitions and standards

To ensure data consistency, we set the following evaluation criteria according to previous literature:

1. *Medication interruption:* Any treatment gap of at least 14 days without prescription during COVID-19, including antipsychotics, antidepressants, and mood stabilizers (22).
2. *COVID-19 exposure:* The patient had a history of travel in epidemic areas, there was a confirmed patient in the residential community, or the patient's cohabitant had a history of exposure to COVID-19 or was diagnosed with COVID-19.
3. *Evaluation of sojourn history:* Living or traveling in communities where confirmed cases or asymptomatic infected persons have been reported in China or having a travel history of visiting countries or regions with epidemic diseases within 14 days before the onset of illness.
4. *Living community exposure:* People in their community who had been diagnosed with COVID-19 in the preceding 2 weeks.
5. *Cohabitant's exposure:* The patient's cohabitant had a history of contact with COVID-19 or was diagnosed with COVID-19.
6. *Retrospective evaluation of medication compliance pre-COVID-19:* Complete compliance meant that the patient completely obeyed medical advice and insisted on taking medication; partial compliance referred to situations in which patients did not take medication according to medical advice consistently and took less, missed, took more, or failed to take medication on time. Non-compliance refers to cases in which patients fail to take medicines according to medical advice and often refuse to obey or stop taking medicines.
7. *Evaluation of social function:* Self-care ability, housework, productive labor and work, learning ability, social interpersonal communication, and so on. According to the patient's actual situation, this was divided into three categories: completely, partly, and not at all.
8. *Apropos work status:* Working status described people who had been able to work for most of the preceding year and had a fixed income; otherwise, they were regarded as unemployed.
9. *Disease state*: The general state of diseases during COVID-19 was divided into stable and unstable, according to whether the disease state fluctuated. Insight refers to the patient's cognitive ability in their own psychological state, which is divided into no insight, partial insight, or full insight.
10. *Regarding drug knowledge evaluation:* According to the patient's understanding of the importance of drug maintenance therapy, the effect of drug treatment, common side effects, and precautions for administration, drug knowledge evaluation was divided into three situations: good, general, and poor.
11. *Regarding the evaluation of drug side effects:* The patients' main complaints were divided into two types: yes or no.
12. *Drug type evaluation:* This refers to the number of different drugs taken by patients simultaneously.
13. *Regarding the evaluation of outpatient follow-up to the hospital:* Regular follow-ups referred to follow-ups according to the medical arrangement or self-arrangement; intermittent follow-ups referred to patients arranging irregular follow-ups according to the changes in their illness, although not according to the time agreed by their doctors. No follow-up meant that there was neither a doctor's appointment nor any self-arranged follow-up.
14. *Family support status:* Good support referred to family income that could completely meet patients' medication expenses. This generally described family income that could partially meet

2 https://www.wjx.cn/

their medication expenses, and which did not cause great hardship to the family. Poor support meant that the family income could not meet medication expenses, resulting in great hardship for the family.

15. *Family relationship:* A good relationship referred to a comfortable and happy relationship with the family, where the patient felt respected and supported by family members. A poor relationship meant that the patient's family was not harmonious, and showed little concern, respect, or understanding toward the patient.

### 2.6. Quality control

To familiarize administrators with the use of the questionnaires and to unify the evaluation criteria based on the definitions and standards described earlier, we conducted centralized training for all administrators who participated in the survey. We asked administrators to check the questionnaire surveys individually and verify them with caregivers and legal guardians. The Wenjuanxing platform had a warning system that ensured that the participants completed all survey questions. Each person could answer the questionnaire only once to ensure the authenticity and reliability of the questionnaire data. Data were entered by one person and verified by a second person. Any discrepancies in the data were verified by a third reviewer.

### 2.7. Statistical analysis

All statistical analyses were performed using SPSS 22.0. The significance level was set at $\alpha = 0.05$, and all the tests were two-tailed. Categorical data are presented as n (%). Chi-square tests were used to identify potential predictive and associated factors. Logistic regression analysis was performed based on the inclusion criteria and variables, and the associations between risk factors and outcomes were presented as odds ratios (ORs) and 95% confidence intervals (CIs).

## 3. Results

### 3.1. General demographic information

There were 2,077 patients with SMI in four districts of Chengdu, China. Three patients were excluded as they refused to participate in the study. Fifty-five older adults who lived alone without legal guardians were also excluded because they either did not have a mobile phone or could not operate one. Most patients and legal guardians were willing to participate in the survey, which may be based on long-term contact and good relationships between community managers and patients or guardians. Two patients with SMI who were in stable condition and did not take medicine according to their doctor's advice were excluded.

In total, 2,017 valid questionnaires were collected (Table 1). The respondents included 1,156 (57.3%) women and 861 (42.7%) men; 16.6% of the participants were under 30 years of age, 48.9% were between 30 and 50 years old, and 34.5% were 50 years old or above. Most patients were diagnosed with schizophrenia ($n = 1{,}502$, 74.5%), whereas the rest had bipolar disorder ($n = 181$, 9.0%), paranoid psychosis ($n = 28$, 1.4%), intellectual disability ($n = 107$, 5.3%), mental disorders caused by epilepsy ($n = 129$, 6.4%), and schizoaffective disorder ($n = 70$, 3.4%).

The education level of most patients ($n = 1{,}460$, 72.4%) was lower than that of senior high school students, and most were unemployed ($n = 1{,}496$, 74.2%). Half of the participants were married ($n = 1{,}134$, 56.2%), and most were not living alone ($n = 1{,}902$, 94.3%). Most participants had an average monthly household income of 4,999 Chinese Yuan (CNY) ($n = 1{,}448$, 71.8%) and a good familial relationship ($n = 1{,}853$, 91.9%). In addition, more than 810 (40.2%) patients were diagnosed more than 10 years ago. A total of 1,416 (70.2%) patients were taking two to five medications. A total of 48 (2.4%) were exposed to COVID-19. Of these, nine (0.4%) had a history of travel in epidemic areas (e.g., Wuhan), 36 (1.8%) lived in COVID-19-infected communities, and five (0.2%) had a history of contact with COVID-19 (Table 1).

### 3.2. COVID-19's impact on daily life and treatment among patients with SMI

We found that the daily lives of 1,121 (55.1%) patients were affected by COVID-19 at different levels, with 127 (6.3%) patients being seriously affected (Table 2). Compared to the other five severe mental diseases, patients with mental illness caused by epilepsy (less than 50%) were least affected by the pandemic. However, there was no statistical difference in the overall mean of the six groups of data, 99% CI (0.236–0.259), $p = 0.247$, by the chi-square test performed using the Monte Carlo method. In terms of treatment, 936 patients (46.6%) were affected. Among them, 56 (2.8%) were seriously affected, as assessed by the subjective feelings of patients' families. However, the number of patients affected by COVID-19 was less than 50%. There was no statistical difference in the overall mean of the six groups of data, 99% CI (0.568–0.594), $p = 0.581$.

### 3.3. Specific impact and needs of patients with SMI during COVID-19

To help patients with SMI more effectively, we summarized the specific impacts and needs that emerged during the COVID-19 pandemic; it affected more than 50% of patients, resulting in difficulties in obtaining medications and follow-ups. More than 50% of the patients wanted to receive more financial support, protective materials, help in taking medicine, and more follow-up visits by their doctor (Table 3).

### 3.4. Risk factors related to medication interruption

Seventy-four (4%) patients stopped taking medicines for more than 14 days without a prescription. The results of the bivariate analysis (Table 1) showed that, among all factors, medication interruption was related to the following 16 factors with statistical significance (all *p*-values less than 0.05): living conditions ($\chi^2 = 5.964$), family

TABLE 1 Bivariate association between medication interruption and related factors.

| Variables | | *N*(%) | No medication interruption | Medication interruption | $\chi^2$ | *p*-value |
|---|---|---|---|---|---|---|
| Sex (*n* = 2,017) | Female | 1,156(57.3) | 1,117(57.5) | 39(52.7) | | |
| | Male | 861(42.7) | 826(42.5) | 35(47.3) | 0.667 | 0.414 |
| Age, years (*n* = 2,017) | <30 | 334(16.6) | 321(16.5) | 13(17.6) | | |
| | 30–50 | 987(48.9) | 954(49.1) | 33(44.6) | | |
| | >50 | 696(34.5) | 668(34.4) | 28(37.8) | 0.590 | 0.745 |
| Education level (*n* = 2,017) | <Senior high school | 1,460(72.4) | 1,409(72.5) | 51(68.9) | | |
| | Senior high school | 306(15.2) | 291(15.0) | 15(20.3) | | |
| | College or undergraduate | 251(12.4) | 243(12.5) | 8(10.8) | 1.609 | 0.447 |
| Marital status (*n* = 2,017) | Single | 615(30.5) | 591(30.4) | 24(32.4) | | |
| | Married | 1,134(56.2) | 1,091(56.2) | 43(58.1) | | |
| | Divorced or widowed | 268(13.3) | 261(13.4) | 7(9.5) | 0.991 | 0.609 |
| Living status (*n* = 2,017) | Not alone | 1902(94.3) | 1837(94.5) | 65(87.8) | | |
| | Alone | 115(5.7) | 106(5.5) | 9(12.2) | 5.964 | 0.015 |
| Monthly household income (*n* = 2,017) | <5,000 | 1,448(71.8) | 1,388(71.4) | 60(81.1) | | |
| | 5,000–10,000 | 393(19.5) | 381(19.6) | 13(17.6) | | |
| | >10,000 | 175(8.7) | 174(9.9) | 1(1.4) | 5.826 | 0.054 |
| Family relationships (*n* = 2,017) | Poor | 164(8.1) | 149(7.7) | 15(20.3) | | |
| | Good | 1853(91.9) | 1794(92.3) | 59(79.7) | 15.155 | 0.000 |
| Working (*n* = 2,017) | Working | 521(25.8) | 503(25.9) | 18(24.3) | | |
| | Unemployed | 1,496(74.2) | 1,440(74.1) | 56(75.7) | 0.091 | 0.763 |
| Reimbursement ratio of drug insurance (*n* = 2,017) | None | 210(10.4) | 199(10.2) | 11(14.9) | | |
| | Partial | 1,631(80.9) | 1,572(80.9) | 59(79.7) | | |
| | Total | 176(8.7) | 172(8.9) | 4(5.4) | 2.446 | 0.294 |
| Epidemic exposure (*n* = 2,017) | No | 1969(97.6) | 1898(97.7) | 71(95.9) | | |
| | Yes | 48(2.4) | 45(2.3) | 3(4.1) | 0.927 | 0.336 |
| Sojourn history (*n* = 2,017) | No | 2008(99.6) | 1935(99.6) | 73(98.6) | | |
| | Yes | 9(0.4) | 8(0.4) | 1(1.4) | 1.417 | 0.234 |
| Living community exposure (*n* = 2,017) | No | 1981(98.2) | 1908(98.2) | 73(98.6) | | |
| | Yes | 36(1.8) | 35(1.8) | 1(1.4) | 0.082 | 0.774 |
| Cohabitant's exposure (*n* = 2,017) | No | 2012(99.8) | 1940(99.8) | 72(97.3) | | |
| | Yes | 5(0.2) | 3(0.2) | 2(2.7) | 18.720 | 0.000 |
| Diagnosis (*n* = 2,017) | Schizophrenia | 1,502(74.5) | 1,448(74.5) | 54(73.0) | | |
| | Bipolar disorder | 181(9.0) | 172(8.9) | 9(12.2) | | |
| | Paranoid psychosis | 28(1.4) | 26(1.3) | 2(2.7) | | |
| | Intellectual disability | 107(5.3) | 105(5.4) | 2(2.7) | | |
| | Mental disorders caused by epilepsy | 129(6.4) | 128(6.6) | 1(1.4) | | |
| | Schizoaffective disorder | 70(3.4) | 64(3.3) | 6(8.1) | 10.647 | 0.059 |
| Medical history (Year) (*n* = 2,017) | <1 | 76(3.8) | 69(3.6) | 7(9.5) | | |
| | 1–5 | 527(26.1) | 508(26.1) | 19(25.7) | | |
| | 5–10 | 604(29.9) | 588(30.3) | 16(21.6) | | |
| | >10 | 810(40.2) | 778(40.0) | 32(43.2) | 8.569 | 0.036 |

*(Continued)*

TABLE 1 (Continued)

| Variables | | *N*(%) | No medication interruption | Medication interruption | $\chi^2$ | *p*-value |
|---|---|---|---|---|---|---|
| Disease state (*n* = 2,017) | Unstable | 246(12.2) | 220(11.3) | 26(35.1) | | |
| | Stable | 1771(87.8) | 1723(88.7) | 48(64.9) | 37.745 | 0.000 |
| Side-effects assessment | No | 1762(84.8) | 1,664(85.6) | 47(63.5) | | |
| (*n* = 2,017) | Yes | 306(15.2) | 279(14.4) | 27(36.5) | 27.120 | 0.000 |
| Kind of drugs (*n* = 2,017) | 1 | 588(29.2) | 555(28.6) | 33(44.6) | | |
| | 2–5 | 1,416(70.2) | 1,375(70.8) | 41(55.4) | | |
| | >5 | 13(0.6) | 13(0.7) | 0(0.0) | 9.175 | 0.010 |
| Medication compliance pre-COVID-19 (*n* = 2,017) | Complete compliance | 1837(91.1) | 1804(92.8) | 33(44.6) | | |
| | Partial compliance | 114(5.7) | 93(4.8) | 21(28.4) | | |
| | Non-compliance | 66(3.3) | 46(2.4) | 20(27.0) | 220.896 | 0.000 |
| Personal self-care ability (*n* = 2,017) | Completely | 1,199(59.4) | 1,159(59.7) | 40(54.1) | | |
| | Partly | 773(38.3) | 744(38.3) | 29(39.2) | | |
| | Not at all | 45(2.2) | 40(2.1) | 5(6.8) | 7.443 | 0.024 |
| Housework (*n* = 2,017) | Completely | 1,025(50.8) | 993(51.1) | 32(43.2) | | |
| | Partly | 917(45.4) | 879(45.2) | 37(50.0) | | |
| | Not at all | 76(3.8) | 71(3.7) | 5(6.8) | 3.044 | 0.218 |
| Productive labor and work (*n* = 2,017) | Completely | 807(40.0) | 787(40.5) | 20(27.0) | | |
| | Partly | 1,049(52.0) | 1,008(51.9) | 41(55.4) | | |
| | Not at all | 161(8.0) | 148(7.6) | 13(17.6) | 12.249 | 0.002 |
| Learning ability (*n* = 2,017) | Completely | 684(33.9) | 666(34.3) | 18(24.3) | | |
| | Partly | 1,182(58.6) | 1,138(58.6) | 44(59.5) | | |
| | Not at all | 151(7.5) | 139(7.2) | 12(16.2) | 9.912 | 0.007 |
| Social interpersonal communication (*n* = 2,017) | Completely | 702(34.8) | 682(35.1) | 20(27.0) | | |
| | Partly | 1,160(57.5) | 1,119(57.6) | 41(55.4) | | |
| | Not at all | 155(7.7) | 142(7.3) | 13(17.6) | 11.158 | 0.004 |
| Insight level (*n* = 2,017) | Full insight | 1,272(63.1) | 1,237(63.7) | 35(47.3) | | |
| | Partial insight | 701(34.8) | 671(34.5) | 30(40.5) | | |
| | No insight | 44(2.2) | 35(1.8) | 9(12.2) | 38.846 | 0.000 |
| Drug knowledge (*n* = 2,017) | Good | 618(30.6) | 605(31.1) | 13(17.6) | | |
| | Moderate | 1,188(58.9) | 1,144(58.9) | 44(59.5) | | |
| | Poor | 211(10.5) | 194(10.0) | 17(23.0) | 15.784 | 0.000 |
| Family support status (*n* = 2,017) | Poor | 104(5.2) | 98(5.0) | 6(8.1) | | |
| | average | 712(35.3) | 678(34.9) | 34(45.9) | | |
| | Good | 1,201(59.5) | 1,167(60.1) | 34(45.9) | 6.150 | 0.046 |
| Follow-up (*n* = 2,017) | Regular follow-up | 1,089(54.0) | 1,064(54.8) | 25(33.8) | | |
| | Intermittent follow-up | 705(35.0) | 680(35.0) | 25(33.8) | | |
| | No follow-up | 223(11.1) | 199(10.2) | 24(32.4) | 24.529 | 0.000 |

A chi-square test with Fisher's exact probability method was used.

relationships ($\chi^2 = 15.155$), cohabitant exposure ($\chi^2 = 18.720$), medical history ($\chi^2 = 8.569$), disease state ($\chi^2 = 37.745$), side effects evaluation ($\chi^2 = 27.120$), several different categories of medication ($\chi^2 = 9.175$), medication compliance pre-COVID-19 ($\chi^2 = 220.896$), personal self-care ability ($\chi^2 = 7.443$), productive labor and work ($\chi^2 = 12.249$), learning ability ($\chi^2 = 9.912$), social interpersonal communication ($\chi^2 = 11.158$), insight level ($\chi^2 = 38.846$), drug knowledge ($\chi^2 = 15.784$), family support ($\chi^2 = 6.150$), and follow-up ($\chi^2 = 24.529$). To further clarify the relationship between the above factors and medication interruption, we performed a logistic regression analysis (Table 4). Medication interruption was set as the dependent variable, while these 16 factors were set as independent variables. By consulting experts and existing literature, we also included factors such as sex, age, education level, and residence as independent variables. The results showed that

TABLE 2 Impact of COVID-19 on severe mental illness patients.

| Item | | Schizophrenia *n* (%) | Bipolar disorder *n* (%) | Paranoid psychosis *n* (%) | Intellectual disability *n* (%) | MD caused by epilepsy *n* (%) | Schizoaffective disorder *n* (%) | *N* (%) | *p*-value |
|---|---|---|---|---|---|---|---|---|---|
| The impact of COVID-19 on daily life | No obvious impact | 664 (44.2) | 80 (44.2) | 13 (46.4) | 50 (46.7) | 69 (53.5) | 29 (41.4) | 905 (44.9) | |
| | General impact | 738 (49.1) | 88 (48.6) | 14 (50) | 56 (52.3) | 55 (42.6) | 34 (48.6) | 985 (48.8) | |
| | Seriously impact | 100 (6.7) | 13 (7.2) | 1 (3.6) | 1 (0.9) | 5 (3.9) | 7 (10) | 127 (6.3) | 0.261 |
| The impact of COVID-19 on treatment | No obvious impact | 787 (52.4) | 104 (57.5) | 16 (57.1) | 58 (54.2) | 76 (58.9) | 37 (52.9) | 1,078 (53.4) | |
| | General impact | 669 (44.5) | 72 (39.8) | 12 (42.9) | 49 (45.8) | 49 (38.0) | 32 (45.7) | 883 (43.8) | |
| | Seriously impact | 46 (3.1) | 5 (2.8) | 0 (0.0) | 0 (0.0) | 4 (3.1) | 1 (1.4) | 56 (2.8) | 0.588 |

MD, mental disorders. The chi-squared test was performed using the Monte Carlo method.

TABLE 3 Specific impacts and needs related to COVID-19.

| Item | | *N* | % | Item | | *N* | % |
|---|---|---|---|---|---|---|---|
| Specific impacts of COVID-19 on medical behavior | Inconvenience in taking medicine | 1,290 | 60.7 | Specific needs in COVID-19 | Convenience in taking medicine | 1,334 | 66.1 |
| | Inconvenience in patient's follow-up to hospital | 727 | 36.0 | | Convenience in follow-up to hospital | 580 | 28.8 |
| | Inconvenience in doctor's return visit | 1,081 | 50.8 | | Doctor's return visit | 1,146 | 56.8 |
| | | | | | Financial support | 1,037 | 51.4 |
| | | | | | Convenience in using mental health services | 650 | 32.2 |
| | | | | | Using sufficient protection against COVID-19 | 1,055 | 52.3 |

cohabitant exposure [OR = 26.629; 95% CI (3.293–215.323), $p = 0.002$], medication partial compliance pre-COVID-19 [OR = 11.109; 95% CI (6.093–20.251), $p < 0.001$], medication non-compliance pre-COVID-19 [OR = 20.115; 95% CI (10.490–38.571), $p < 0.001$], and disease status [OR = 0.326; 95% CI (0.188–0.564), $p < 0.001$] were closely related to medication interruption.

# 4. Discussion

In recent years, SMI has attracted increasing attention; it has become an important public health issue and a prominent social problem. As with other chronic diseases, positive health outcomes such as non-relapse or non-rehospitalization are heavily reliant on patterns of compliance with medicine, a relaxed environment, and appropriate psychological intervention (9). With the outbreak of COVID-19, countries have launched prevention and control mechanisms that can limit the spread of the epidemic; however, these have several side effects (6, 23). Among these, relapse and deterioration of SMI due to medication interruption during COVID-19 have elicited widespread concern.

We found that the daily life of more than 50% of patients with SMI was affected at different levels. Our results were higher than those reported in other studies; one study of Portuguese adults found that periods of social isolation resulted in altered eating habits, such as eating more (45.2%) or in larger quantities (31.6%) (24). A nationwide survey in the United States found that 27% of parents reported that their mental health deteriorated, while 14% reported that their children's behavioral health deteriorated (25). However, a study on healthy Chinese adults who had been isolated at home for an average of 77 days found that more than 50% of respondents indicated that they spent less time on daily physical activity and more time on sedentary behaviors than before the lockdown, and 23% had changed their diet (6). Although we did not investigate the days of patients' social isolation, we suggest that this difference may be due to the different durations of social isolation. Maintaining a consistent daily routine is important for patients with SMI to maintain good sleep and emotional stability. However, their daily lives are much more susceptible to change than that of a normal person, which is another important factor leading to treatment interruption or discontinuation. Therefore, when encountering similar situations in the future, we should pay more attention to those patients with SMI who have been severely affected by the government's isolation policy and attempt to ensure that their normal routine is not compromised.

In addition, the treatment of nearly 50% of patients with SMI was affected. Among them, the condition of 246 (12.2%) patients fluctuated during the COVID-19 outbreak and 74 patients (4%) had a history of medication interruption. The rate of treatment discontinuation or interruption in 1 year was found to be between 40 and 75%, presenting a major obstacle to the effective treatment of schizophrenia (12, 26).

TABLE 4 Logistic regression analysis of factors associated with drug withdrawal.

| Item | *B* | Sb | Wald | *p* | OR | 95%CI |
|---|---|---|---|---|---|---|
| Cohabitants exposure | 3.282 | 1.066 | 9.472 | 0.002 | 26.629 | (3.293–215.323) |
| Medication partial compliance pre-COVID-19 | 2.408 | 0.306 | 61.755 | 0.001 | 11.109 | (6.093–20.251) |
| Medication non-compliance pre-COVID-19 | 3.001 | 0.332 | 81.655 | 0.001 | 20.115 | (10.490–38.571) |
| Stable disease state | −1.112 | 0.280 | 16.031 | 0.001 | 0.326 | (0.188–0.564) |

OR, odds ratio.

The medication interruption rate of community-managed patients with SMI was much lower, which showed that community management could significantly improve medication compliance of patients with schizophrenia. This reminds us that strengthening the community management of patients with SMI may be an effective way to reduce and prevent the interruption of treatment. In addition, clinical practice should factor in the effects of the pandemic when evaluating compliance with drug treatment and the causes of disease fluctuation.

Binary logistic regression analysis indicated that medication interruption was related to cohabitant exposure, partial medication compliance before COVID-19, medication non-compliance before COVID-19, and disease status. It is well known that cohabitants often supervise and manage the drug treatment and follow-up of patients with SMI. According to the requirements of the pandemic prevention and control management policy in China[3], when a cohabitant has been diagnosed with COVID-19, all patients should be transferred to their designated medical institutions for treatment and isolated medical observation within 2 h of the discovery. Cases that recovered after discharge should continue to be isolated for 14 days. Cohabitants (SMI patients) with confirmed COVID-19 patient were also considered to be in close contact with the novel coronavirus and underwent intensive isolated medical observation for 14 days. During this period, patients are often unable to regularly receive the necessary drugs. Therefore, we suggest that routine health surveys be conducted for infected family members and cohabitants to prevent similar situations from occurring again during the pandemic. For patients with SMI with one or more of the following conditions, including residents' exposure, partial medication compliance, non-compliance, and unstable disease state, more attention should be paid to prevent medication interruption in the future when similar situations occur.

The literature indicates that non-suicidal self-injury is a strong predictor of future suicide attempts and behaviors (27, 28). This conceptual framework may also hold for medication interruptions. It is well known that medication non-compliance or partial compliance is the most important modifiable risk factor for relapse and rehospitalization in patients with schizophrenia (11, 29). Our results further showed that partial medication compliance pre-COVID-19 and non-compliance pre-COVID-19 may be related to medication interruption during the pandemic. Furthermore, a stable disease state was the only confirmed protective factor against medication interruption during the COVID-19 outbreak, which means that the more stable the patient, the lower the risk of medication interruption. Therefore, extra attention should be given to patients with an unstable disease state and a history of partial medication compliance or non-compliance before the pandemic.

3 http://www.gov.cn/fuwu/zt/yqfwzq/yqfkblt.htm

This study had some limitations. First, drug types/differences could account for the variation in medication adherence across patients with various SMI. However, we did not factor this into our model (30). Second, owing to the requirements of pandemic prevention and control, we were limited to seeking anonymous responses to questionnaires online, which was the safest data collection option. In addition, the nature of the measures was such that they were based on retrospective recall, with most items being a single categorical variable rather than a psychometrically validated instrument. Furthermore, the current level of the participants' functioning given their diagnoses is unclear, especially considering that some were described as having intellectual disabilities. Thus, the reliability of the data was unclear. Further research is required to confirm these findings.

## 5. Conclusion

This study demonstrates that, compared to healthy people, the daily life of patients with SMI was much more susceptible to the impact of the pandemic. Exposure to cohabitants and poor drug treatment compliance were closely related to medication interruption. Therefore, more attention should be paid to patients with SMIs in similar situations. This study provides empirical support for ensuring the stability of clinical symptoms of patients with SMI that should occur during similar epidemics or pandemics in the future.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by Ethics approval was granted by the ethics committee of the West China Hospital of Sichuan University [reference number 2020 (200)]. Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

## Author contributions

ZD received the funding and designed the study. JJ analyzed the data together with YJ. JJ drafted the manuscript. All authors were involved in this study, and have read and approved the final version of the manuscript.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as potential conflicts of interest.

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# Abrupt peaks in perceived risk of occasional drug use after changing the question order in a repeated self-administered survey

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**Background:** Question-order changes in repeated surveys can distort comparisons. We want to describe the evolution of drug risk perceptions among Spanish adolescents and assessing whether the 2006 peaks in perceived risk of occasional drug use can be explained by question-order changes.

**Methods:** The subjects were secondary students from a biennial national survey during 2000–2012. A one-off intervention was applied in 2006, replacing the two-adjacent items on perceived risk of occasional and regular use of each drug by non-adjacent items. Annual prevalence of high-risk perception were obtained for occasional and regular use of cannabis, heroin, cocaine and ecstasy. Subsequently, the 2006 percent level change (PC) in such were estimated prevalence using segmented Poisson regression, adjusting for various student and parent covariates.

**Results:** The 2006 PC in prevalence of high-risk perception of occasional drug use ranged from +63% (heroin) to +83% (ecstasy). These PCs were very high in all considered subgroups. However, the 2006 PC in prevalence of high-risk perception of regular drug use ranged from 1% (heroin) to 12% (cannabis). The evolution of preventive interventions does not suggest alternative causal hypotheses for 2006 peaks other than question-order changes.

**Conclusion:** Within the cognitive heuristics framework, the 2006 spikes in perceived risk of occasional drug use were most likely due to a release of the anchor exerted by perceived risk of regular drug use over that of occasional use triggered by 2006 question-order changes. In repeated surveys it is inexcusable to pre-test the effect of any change in questionnaire format.

KEYWORDS

**question-order, drug use, risk perception, natural experiment, cognitive heuristics, anchoring**

## Introduction

Repeated surveys are often used to make cross-period or cross-site comparisons of health-related phenomena in both patients and population, in order to improve decision-making on health interventions. These surveys are prone to information bias that can severely limit such comparisons, due to various factors, including differences or changes in measurement instruments, particularly questionnaires. When designing survey questionnaires, most researchers know that they must keep the same question wording in different or successive measurements, but they often forget that changes in the format, ordering or clustering of the questions can strongly affect their interpretation and response (1–4). Changing, deleting or adding a previous question item could greatly alter the answers to the next one, even if its wording is entirely kept (5–12), particularly when questionnaires include multiple question items on similar topics with identical response categories –question grids- (13). In some self-administered question grids, a subsequent question may also affect the preceding one, because the respondent may receive both simultaneously (14, 15). These context or question-order effects can appear when recalling witnessed events, behaviors, tasks performance or people (7, 11, 16). However, they are especially conspicuous for subjective phenomena such as perceptions, beliefs, values, preferences, attitudes or future intentions, since they are usually subject to greater uncertainty in response selection (6, 8–10, 15, 17–19). Susceptibility to order effects depends on numerous factors, including the nature and difficulty of the self-reported subject, specific questionnaire format, and respondent factors such as sex, age, education level, or direct experience on the subject (20–23). It is generally believed that the greater is the respondent's direct experience or personal involvement in the self-reported issue and their cognitive abilities, the less prone they would be to question-order effects. However, previous evidence on the influence of these factors is often inconsistent (23).

Among the subjective phenomena prone to question order effects are people's risk perceptions on health-related issues, which are relevant in predicting future decisions and actions of people regarding such issues and implementing strategies to control and reduce the associated health and social harm. Thus, question-order effects have been identified when measuring risk perceptions on diseases/causes of death (cancer, COVID-19, homicide), psychiatric patients, environmental hazards (nuclear power, second-hand smoke, air pollution, food preservatives, electromagnetic radiations, traffic accidents) and health-related behaviors (tobacco, alcohol or drug use) (24–32).

Perceived risk of illicit drug use by adolescents is routinely monitored in many countries (33–35), most of these data employed on secondary analysis on risk prevention (36). ESTUDES is a biennial school survey on drugs aimed at secondary school students conducted in all Spain since 1994, which uses a self-administered paper-and-pencil questionnaire, including questions on subjective judgments on risk of occasional and regular use of different illicit drugs (37). In 2006, the ordering and clustering of the questions on perceived risk of occasional and regular drug use was changed. In statistical analyses, sudden increases in risk perception of occasional use of all considered drugs were found in 2006, which were suspected to be artifacts due to the aforementioned reordering of questionnaire items, so in 2008 and later editions it was decided to restore the initial questionnaire format. The study objective is to describe the evolution over time of the perceived risk of occasional and regular use of illicit drugs among Spanish adolescents stratified according to respondent's sociodemographic factors, and to assess whether the 2006 peaks in perceived risk of occasional drug use can be explained by question-order changes.

## Materials and methods

### Study population

Secondary school students aged 14–18 years who participated in the seven editions of ESTUDES biennial survey during 2000–2012. A national representative sample was selected in each edition through a two-stage cluster sampling procedure (school and classroom) (37). The total sample size was 188,921 students, ranging from 20,450 to 32,234 in the different editions.

### Study design and variables

The study is conceived as a large-scale unplanned single-group experiment, in which a one-off intervention that had not been applied between 2000 and 2004 was applied in 2006 to the entire study population and ceased to be applied in subsequent years, being analyzed the changes in a target and a control outcome over time. The intervention consisted of changing the ordering of questions on drug risk perception (question-order changes), although in fact it also implies a change in their clustering. Specifically, drug risk perception had been assessed until 2006 by an adjacent item-pair model, in which the pair of questions assessing the risk perception of occasional and regular use of a given drug were consecutively presented one after the other without any intermediate question. However, the questionnaire changed in 2006 towards a non-adjacent item-pair model, in which the pair of questions mentioned for a given drug were not consecutively presented, but in two large different blocks or grids, the first referring to occasional use of all drugs and the second to regular use (Table 1).

The outcomes were the perceived risk of using occasionally (monthly or less frequently) and regularly (weekly or more frequently) four illicit drugs, specifically cannabis, heroin, cocaine and ecstasy. To assess the risk perception of drug use, the respondents had to indicate the problems (health or otherwise) that entails each of the considered drug use behaviors using an ordinal scale of four responses (no problem, few, quite a few and many) (Table 1). Except for the question-order changes, there were no other changes in questions about outcomes in the analyzed ESTUDES editions, although the questions on cocaine referred simply to "cocaine" until the 2004 edition and "cocaine powder" in the 2006 and later editions (37). For stratification or adjustment the following individual covariates were considered:

Abbreviations: aPR, adjusted prevalence ratio; ESTUDES, Survey on Drug Use in Secondary Education in Spain [Encuesta sobre Uso de drogas en Enseñanzas Secundarias en España]; 95% CI, 95% confidence interval; PC, relative percent change.

**TABLE 1 Questionnaire models on perceived risk of drug use included in ESTUDES survey (Spain, 2000–2012).**

| A. Adjacent item-pairs model[1] (ESTUDES Surveys before and after 2006) | | | | | |
|---|---|---|---|---|---|
| Grid 1. What do you think about the problems (health or otherwise) that the occasional and regular use of each drug entails. | | | | | |
| | Response options | | | | |
| | No problem | Few problems | Quite a few | Many | Do not know |
| Using tranquillizers/sleeping pills occasionally | | | | | |
| Using tranquillizers/sleeping pills regularly | | | | | |
| *Smoking hash/marijuana occasionally* | | | | | |
| *Smoking hash/marijuana regularly* | | | | | |
| Smoking cocaine base or crack occasionally | | | | | |
| Smoking cocaine base or crack regularly | | | | | |
| *Using cocaine occasionally* | | | | | |
| *Using cocaine regularly* | | | | | |
| Using GHB or liquid ecstasy occasionally | | | | | |
| Using GHB or liquid ecstasy regularly | | | | | |
| *Using ecstasy occasionally* | | | | | |
| *Using ecstasy regularly* | | | | | |
| Using speed or amphetamines occasionally | | | | | |
| Using speed or amphetamines regularly | | | | | |
| Using LSD or magic mushrooms occasionally | | | | | |
| Using LSD or magic mushrooms regularly | | | | | |
| *Using heroin occasionally* | | | | | |
| *Using heroin regularly* | | | | | |
| B. Non-adjacent item-pair model[2] (2006 ESTUDES Survey) | | | | | |
| Grid 1. What do you think about the problems (health or otherwise) that the occasional use of each drug entails. | | | | | |
| | Response options | | | | |
| | No problem | Few problems | Quite a few | Many | Do not know |
| Using tranquillizers/sleeping pills occasionally | | | | | |
| *Smoking hash/marijuana occasionally* | | | | | |
| Smoking cocaine base or crack occasionally | | | | | |
| *Using cocaine powder occasionally* | | | | | |

*(Continued)*

TABLE 1 (Continued)

| B. Non-adjacent item-pair model[2] (2006 ESTUDES Survey) | | | | | |
|---|---|---|---|---|---|
| Grid 1. What do you think about the problems (health or otherwise) that the occasional use of each drug entails. | | | | | |
| | Response options | | | | |
| | No problem | Few problems | Quite a few | Many | Do not know |
| Using GHB or liquid ecstasy occasionally | | | | | |
| *Using ecstasy occasionally* | | | | | |
| Using speed or amphetamines occasionally | | | | | |
| Using LSD or magic mushrooms occasionally | | | | | |
| *Using heroin occasionally* | | | | | |
| Injecting drugs occasionally | | | | | |
| Grid 2. What do you think about the problems (health or otherwise) that the regular use of each drug entails. | | | | | |
| | Response options | | | | |
| | No problem | Few problems | Quite a few | Many | Do not know |
| Using tranquillizers/sleeping pills regularly | | | | | |
| *Smoking hash/marijuana regularly* | | | | | |
| Smoking cocaine base or crack regularly | | | | | |
| *Using cocaine powder regularly* | | | | | |
| Using GHB or liquid ecstasy regularly | | | | | |
| *Using ecstasy regularly* | | | | | |
| Using speed or amphetamines regularly | | | | | |
| Using LSD or magic mushrooms regularly | | | | | |
| *Using heroin regularly* | | | | | |
| Injecting drugs regularly | | | | | |

[1]It refers to the fact that the questions on risk perception of occasional and regular use of the same drug are presented consecutively one after the other, without any intermediate question. [2]It refers to the fact that the pair of questions on risk perception of occasional and regular use of the same drug are not presented consecutively one after the other, but in two large different blocks or grids, the first referring to occasional use of all drugs and the second to regular use. Occasionally refers to monthly or less frequently. Regularly refers to weekly or more frequently. *Items in italics* were those analyzed. The questionnaire also included questions on the perceived risk of using other specified substances such as alcohol or tobacco. LSD, GHB, crack, amphetamines and injecting drugs were included for the first time in 2006. Full questionnaires in Spanish are available for consulting in PNSD website (37).

sex, age, education level, ever had to repeat an annual course, parents' education level, parents' employment status, frequency of going out for fun in the evenings as indicator of leisure habits, and use of each considered drug. The education level and course repetition were considered as indicators of academic performance to achieve cognitive skills, and age was used as a proxy of expertise (knowledge on the self-reported subject), since it is assumed that older students have received more information on drug risks (prevention programs, courses, etc.) and have greater capacity to integrate that information. In addition to the ESTUDES variables, data on annual indicators of preventive interventions were obtained from activity reports of the National Plan on Drugs (38), in order to assess if the 2006 changes in outcomes could depend on greater magnitude of such interventions. These indicators include number of schools involved in drug prevention programs, secondary students coverage of such programs, spending index on drug prevention per secondary student and implementation of national preventive campaigns in the media. School drug prevention programs are structured interventions including scheduled sessions (>5) to be developed in the classroom by teachers, or by external prevention experts, often with application manuals, aiming at the development of student's skills and competencies for life and to avoid drug use. Occasional preventive activities such as talks, distribution of written materials,

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workshops, awareness days, contests or exhibitions are excluded. The coverage of secondary students by school drug prevention programs is the percentage of total secondary students in Spain (including vocational training) who participated in those programs. The spending index on drug prevention programs per secondary student was calculated by dividing the inflation-adjusted national budget for drug use prevention by the number of secondary students registered in Spain and expressing the result in relation to the year 2000 whose spending per student was assigned the value of 100. The aforementioned budget is the sum of the budgets of the central and regional governments and with it, school and non-school drug prevention interventions are financed. The national preventive campaigns in the media were aimed at informing and sensitizing the Spanish population, especially adolescents aged 12–18 years and their parents or guardians, about the risks of drug use.

## Data analysis

After a descriptive analysis, the prevalences of high-risk perception of occasional and regular use of cannabis, heroin, cocaine and ecstasy for each edition of ESTUDES during 2000–2012 were obtained. We considered "high-risk" perception regarding the use of a given drug when the respondent believed that such behavior could cause many problems. Next, two multivariate approaches were used to assess the magnitude of the 2006 change in high-risk perception of drug use compared to previous and subsequent years. The first approach was to estimate the annual Adjusted Prevalence Ratios (aPRs) of high-risk perception and its 95% confidence intervals (95% CIs) from Poisson regression models with robust variance (39) using the year 2000 as a reference. Adjustment covariates were referred to the students (sex, age, indicators of academic performance, leisure habits, and use or not of assessed drugs) or their parents (parents' education level, parents' employment status). The second approach was to use an interrupted time series design, which was analyzed with segmented Poisson regression. This design allowed adjustment for the covariates just mentioned plus the underlying time trend (40, 41). As the intervention seems to cause a temporary change (2006) in the outcome level immediately after the intervention, which disappears in the following years, we have adopted the impact model called "temporary level change" (41). This model can be formalized as $Y_t = \beta_0 + \beta_1 T_t + \beta_2 X_t + \beta_k X_k + \varepsilon$, where $Y_t$ is the log of annual prevalence, $T_t$ a continuous covariate whose value is the number of years elapsed since 2000, $X_t$ a binary predictor for the intervention (questionnaire change) with a value of 1 in 2006 and 0 other years, $X_k$ a vector for the adjustment covariates other than time, and ε the error term. In this model $\beta_0$ represents the intercept or baseline prevalence level, $\beta_1$ the change in outcome for each unit increase in sequential calendar year (underlying linear time trend for 2000–2012), $\beta_2$ the immediate level change in outcome following the intervention, and $\beta_k$ the coefficients of different adjustment covariates. To facilitate the interpretation, we transformed the $\beta_2$ regression coefficients to relative percent changes (PCs) as 100 ($e^{\beta}$–1). The 95% CI of PCs were estimated as 100 ($e^{\beta \pm 1.96SE}$–1), where SE is the standard error of β. Analyses were performed using Stata V.14.0 (Stata Corporation, College Station, Texas, USA).

# Results

General characteristics of study participants are shown in Table 2.

## Evolution of prevalence of high-risk perception of drug use during study period

The evolution of the prevalence of high-risk perception of drug use was very different for occasional and regular use (Figure 1). For occasional use the prevalence followed a relatively stable trend during pre-intervention period (2000–2004), it increased sharply in the intervention year (2006), doubling their figures, and decreased again in post-intervention period (2008–2012), although maintaining a slightly higher level than in 2000–2004. Thus, the prevalence of high-risk perception was 17–21% in 2000–2004, 42% in 2006 and 26–33% in 2008–2012 for cannabis use, 37–40, 75% and 51–58%, respectively, for heroin use, 30–33, 70% and 44–51% for cocaine use, and 26–31, 72% and 48–55% for ecstasy use. Abrupt spikes in prevalence of high-risk perception of regular drug use during 2006 were not observed. Thus, such prevalences in 2000–2012 ranged 51–65% (cannabis), 84–91% (heroin), 83–87% (cocaine), and 77–88% (ecstasy).

## Impact assessment of 2006 questionnaire change on risk perception of drug use

Like crude prevalences, the aPRs from Poisson regression models showed a very different evolution for occasional and regular drug use (Table 3). Regarding occasional use, the aPR values, using as a reference the prevalence in the year 2000, ranged 0.9–1.2 in pre-intervention years, increased sharply up to 2.0–2.8 in 2006, and decreased again in post-intervention years, staying at a higher level than in 2000–2006 (1.2–2.1). However, the aPRs for regular drug use showed little heterogeneity over time, ranging from 0.9–1.2 during the entire period 2000–2012.

Results from Poisson segmented regression models indicate an upward underlying linear trend in prevalence of high-risk perception of occasional drug use in 2000–2012 with annual PCs of 5, 4, 5, and 7% for cannabis, heroin, cocaine and ecstasy, respectively. Furthermore, there was an immediate relative level change in such prevalence during 2006 of 77, 63, 79, and 83%, respectively (Table 4). However, the 2006 level changes in prevalence of high-risk perception of regular use of cannabis, heroin, cocaine and ecstasy and their corresponding 95% CI were, respectively, 12% (10, 13%), 1% (0, 2%), 3% (2, 4%), and 6% (5, 7%).

## Stratified analysis of impact assessment of 2006 questionnaire change

Focusing on the results of segmented Poisson regression models, a large 2006 immediate percent level increase in prevalence of high-risk perception of occasional drug use was observed in all subgroups of sex,

TABLE 2 General characteristics of participants in ESTUDES survey by calendar-year (%) (Spain, 2000–2012).

| | Year | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2000 | 2002 | 2004 | 2006 | 2008 | 2010 | 2012 |
| Sample size (n) | 20,450 | 26,576 | 25,521 | 26,454 | 30,183 | 32,234 | 27,503 |
| Female (%) | 49.1 | 51.8 | 50.4 | 52.4 | 50.5 | 51.7 | 49.5 |
| Age (%) | | | | | | | |
| 14–15 years | 40.0 | 42.6 | 40.2 | 44.4 | 43.9 | 44.1 | 34.3 |
| 16 years | 28.5 | 25.4 | 32.4 | 25.7 | 26.7 | 27.9 | 24.0 |
| 17–18 years | 31.5 | 32.1 | 27.5 | 29.9 | 29.5 | 28.0 | 41.7 |
| Education level (%) | | | | | | | |
| Secondary, 1st stage | 50.4 | 53.9 | 54.1 | 56.5 | 51.9 | 56.3 | 47.5 |
| Secondary, 2nd stage | 38.3 | 34.2 | 33.0 | 36.0 | 34.3 | 36.0 | 36.0 |
| Vocational education | 11.4 | 11.9 | 12.9 | 7.5 | 13.8 | 7.8 | 16.6 |
| Ever had to repeat an annual course (%) | 35.7 | 35.3 | 34.9 | 33.2 | 36.8 | 32.9 | 32.4 |
| Parents' education level completed | | | | | | | |
| At least one parent university education | 21.5 | 24.9 | 27.0 | 26.0 | 25.2 | 28.8 | 28.5 |
| At least one parent secondary education | 12.9 | 13.1 | 13.4 | 16.2 | 15.5 | 19.6 | 20.1 |
| Both parents < secondary education | 40.7 | 37.9 | 36.4 | 36.0 | 35.3 | 31.5 | 32.9 |
| Unknown | 24.9 | 24.1 | 23.2 | 21.8 | 24.1 | 20.2 | 18.4 |
| Parents' employment status | | | | | | | |
| Both parents employed | 47.5 | 52.0 | 54.9 | 53.2 | 53.3 | 51.1 | 46.8 |
| One parent employed | 46.5 | 42.9 | 40.5 | 40.1 | 39.5 | 38.7 | 40.0 |
| Both parents unemployed or unknown | 6.0 | 5.2 | 4.5 | 6.7 | 7.2 | 10.3 | 13.2 |
| Going out for fun in the evenings ≥ weekly | 59.7 | 54.1 | 56.7 | 52.8 | 56.1 | 48.6 | 47.3 |
| Drug use in last 30 days | | | | | | | |
| Cannabis | 20.7 | 22.5 | 25.0 | 20.1 | 19.8 | 17.2 | 16.1 |
| Heroin | 0.3 | 0.2 | 0.4 | 0.5 | 0.5 | 0.5 | 0.6 |
| Cocaine | 2.5 | 3.2 | 3.8 | 2.0 | 1.6 | 1.2 | 1.1 |
| Ecstasy | 2.4 | 1.9 | 1.5 | 1.4 | 1.0 | 0.9 | 1.2 |

The methods and results of the ESTUDES surveys during the study period can be consulted on the website of the Spanish National Plan on Drugs (37).

age and academic performance and in both users and non-users of each assessed drug, except in heroin users where only a very slight non-statistically significant increase was observed. These increases were higher in women than men, although the differences were not statistically significant for cannabis. Likewise, the increases were generally greater in students with higher educational level or higher academic performance (as students in the second stage of secondary education or students who had not repeated any complete annual course), except for heroin. Regarding age, no consistent results were observed for the different drugs. Thus, the magnitude of the immediate level increase increased with age for cannabis, decreased with age for heroin, and varied little for cocaine and ecstasy (Table 4).

## Evolution of preventive drug use interventions in Spain during study period

The evolution of four indicators of drug prevention interventions aimed at secondary students is shown in Table 5.

Three of those indicators (number of schools involved in drug prevention programs, coverage of secondary students by these programs, and spending index on drug prevention per secondary student) followed a similar evolution, with a significant increase between 2000 and 2006, a relative stabilization between that year and 2010 and a subsequent rapid decrease. For example, the coverage of the school drug prevention programs went from

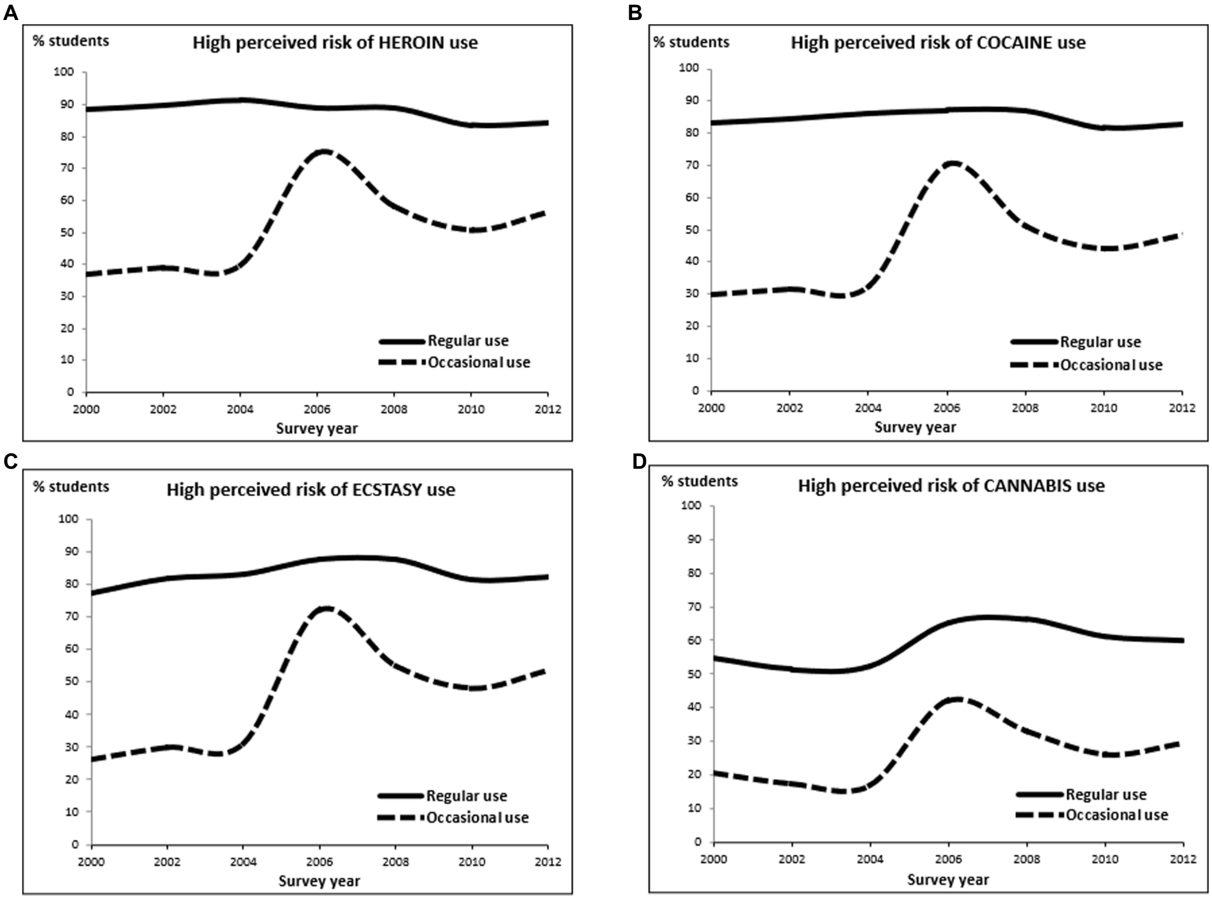


FIGURE 1
Evolution of the prevalence of high perceived risk of regular or occasional use of heroin **(A)**, cocaine **(B)**, ecstasy **(C)**, and cannabis **(D)** by survey year among secondary students aged 14–18 (%). Spain, 2000–2012. High perceived risk: the student thought that a drug use behavior (for example, using heroin regularly) could cause many problems (in health or other aspects). Regular use: using a drug weekly or more frequently. Occasional use: using a drug monthly or less frequently. The lines are shown smoothed.

**TABLE 3 Adjusted-prevalence ratio of high-risk perception[1] of drug use by specific drug use behavior and calendar-year [95% confidence intervals] among secondary students aged 14–18years (Spain, 2000–2012).**

| | Occasional use | | | | Regular use | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Cannabis | Heroin | Cocaine | Ecstasy | Cannabis | Heroin | Cocaine | Ecstasy |
| 2000 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| 2002 | 0.9 [0.8–0.9] | 1.1 [1.0–1.1] | 1.0 [1.0–1.1] | 1.1 [1.1–1.2] | 0.9 [0.9–1.0] | 1.0 [1.0–1.0] | 1.0 [1.0–1.0] | 1.0 [1.0–1.1] |
| 2004 | 0.9 [0.8–0.9] | 1.1 [1.1–1.1] | 1.1 [1.1–1.2] | 1.2 [1.1–1.2] | 1.0 [1.0–1.0] | 1.0 [1.0–1.0] | 1.0 [1.0–1.1] | 1.1 [1.1–1.1] |
| 2006 | 2.0 [1.9–2.1] | 2.1 [2.0–2.1] | 2.4 [2.3–2.4] | 2.8 [2.7–2.9] | 1.2 [1.2–1.2] | 1.0 [1.0–1.0] | 1.0 [1.0–1.1] | 1.1 [1.1–1.1] |
| 2008 | 1.6 [1.5–1.6] | 1.6 [1.5–1.6] | 1.7 [1.7–1.8] | 2.1 [2.0–2.2] | 1.2 [1.2–1.2] | 1.0 [1.0–1.0] | 1.0 [1.0–1.1] | 1.1 [1.1–1.1] |
| 2010 | 1.2 [1.2–1.3] | 1.4 [1.4–1.4] | 1.5 [1.4–1.5] | 1.8 [1.8–1.9] | 1.1 [1.1–1.1] | 0.9 [0.9–1.0] | 1.0 [1.0–1.0] | 1.0 [1.0–1.1] |
| 2012 | 1.4 [1.4–1.5] | 1.5 [1.5–1.6] | 1.6 [1.6–1.7] | 2.0 [2.0–2.1] | 1.1 [1.1–1.1] | 1.0 [0.9–1.0] | 1.0 [1.0–1.0] | 1.1 [1.1–1.1] |

[1]They were obtained from Poisson-regression models using 2000 as reference. Results were adjusted by sex, age, indicators of academic performance, leisure habits, use of assessed drugs, parents' education level and parents' employment status.

20.7% in 2000 to 55.6% in 2006, 58.7% in 2008, 54.1% in 2010, and 40.5% in 2012. There were annual campaigns in the general media aimed at drug prevention in 2000–2007, but they disappeared in 2008–2012. The maximum relative interannual increases in such indicators were found in 2002 for the coverage of school drug prevention programs (38.0%), in 2003 for the number of schools involved in drug prevention programs (48.8%), and in 2002 for the spending index on drug prevention per secondary student (62.9%). The 2006 relative annual increase of the different interventions ranged from 12.1% for the spending index on drug

TABLE 4 2006 percent level change in prevalence of high-risk perception of occasional drug use[1] [95% confidence interval] by subgroups of secondary students aged 14–18 years (Spain, 2000–2012).

| | Cannabis | Heroin | Cocaine | Ecstasy |
|---|---|---|---|---|
| Total | 77 [73–81] | 63 [61–65] | 79 [77–82] | 83 [80–86] |
| Sex | | | | |
| Men | 74 [68–80] | 50 [50–56] | 72 [68–76] | 74 [71–78] |
| Women | 79 [74–85] | 72 [69–76] | 86 [83–90] | 91 [87–95] |
| Age | | | | |
| 14–15 | 72 [67–77] | 69 [66–73] | 80 [76–83] | 80 [76–83] |
| 16 | 79 [70–88] | 64 [60–69] | 82 [76–87] | 88 [83–94] |
| 17–18 | 85 [75–95] | 53 [49–56] | 76 [71–81] | 82 [77–88] |
| Education level[2] | | | | |
| Secondary, 1st stage | 71 [67–76] | 65 [62–68] | 77 [74–80] | 78 [75–81] |
| Secondary, 2nd stage | 93 [84–103] | 65 [62–69] | 86 [81–91] | 94 [89–99] |
| Annual course repetition | | | | |
| Yes | 70 [62–77] | 48 [45–52] | 69 [64–73] | 72 [68–77] |
| No | 80 [75–85] | 70 [68–73] | 84 [81–88] | 88 [85–91] |
| Use of specific drug assessed in last 30 days[3] | | | | |
| Yes | 189 [159–223] | 11 [−30–77] | 164 [114–227] | 134 [80–205] |
| No | 71 [67–75] | 63 [61–65] | 78 [76–81] | 82 [80–85] |

[1]Obtained from segmented Poisson regression by building an impact model which specified a temporary level change during 2006 adjusted by underlying time trend during the entire period 2000–2012 and indicators of academic performance, leisure habits, use of assessed drugs, parents' education level and parents' employment status, except stratification variable. [2]Indicators for vocational training students were not obtained due to the small sample size in this subgroup and its heterogeneous characteristics. [3]Referred to the use of the specific drug of which risk perception is assessed.

prevention per secondary student to 31.3% for the coverage of the school drug prevention programs. The absolute maximums of these indicators were in 2008, 2010, and 2006, respectively. Moreover, parents' and teachers' involvement in drug prevention increased in 2006–2010 (data not shown in Table 5).

# Discussion

In 2006, after a question-order change in ESTUDES survey, there was a sudden and large increase in risk perception of occasional use of cannabis, heroin, cocaine and ecstasy among Spanish adolescents, which largely disappeared in 2008 after restoring the initial questionnaire format. Thus, the relative percent changes in prevalence of high-risk perception immediately after the 2006 intervention ranged from +63% (heroin) to +83% (ecstasy). These increases occurred in all sociodemographic subgroups analyzed. However, the 2006 increases in perceived risk of regular use of these drugs were very small, with relative percentage changes in prevalence of high-risk perception ranging from +1% (heroin) to +12% (cannabis). After assessing the evolution of preventive interventions, no sudden increases in magnitude of these interventions were identified in 2006, which does not suggest alternative causal hypotheses for 2006 peaks in perceived risk of occasional drug use other than 2006 question-order changes.

## Question-order changes as the main cause of the 2006 peaks in drug risk perception

It is highly likely that the 2006 peaks in the risk perception of occasional drug use was mainly due to question-order changes for several reasons. First, it was a peak of great magnitude, located only in 2006 and that disappeared after restoring the initial questionnaire format. Second, the Poisson regression model that identified the peak was adjusted for several individual time-varying covariates to avoid confounding. Third, the segmented Poisson regression model to measure the 2006 immediate relative change in prevalence level of high-risk perception was further adjusted for the underlying linear time trend during 2000–2012, which implies some control for unmeasured individual time-varying confounders that change slowly over time (42). Fourth, the peak was identified in all sociodemographic subgroups analyzed, including those of sex, age, education level and academic performance, both in drug and non-drug users (except heroin users). Fifth, the peak was almost non-existent for the perceived risk of regular drug use, considered the control outcome or negative control. Sixth, in 2006 there were no abrupt increases in magnitude of preventive drug use interventions. Thus, although 2006 had the largest budget for drug prevention during the analyzed period, no prevention indicator had in 2006 its highest annual percent increase. Furthermore, the 2006 annual percent increases in prevention indicators ranged 12–31% compared to 63–83% in the outcome. Although local and regional preventive drug interventions are difficult to measure, the occurrence of sudden

TABLE 5 Evolution of indicators on drug prevention interventions implemented by the public administration in Spain, 2000–2012.

| Year | Schools involved in drug prevention programs[1] (N° schools in 2000=100) | Coverage of secondary students by school drug prevention programs[2] (%) | Spending index on drug prevention per secondary student[3] (2000 spending=100) | National preventive campaigns in the media[4] |
|---|---|---|---|---|
| 2000 | 100 | 20.7 | 100 | Yes |
| 2001 | 129 | 18.9 | 92 | Yes |
| 2002 | 129 | 26.1 | 149 | Yes |
| 2003 | 192 | 33.3 | 166 | Yes |
| 2004 | 184 | 38.6 | 200 | Yes |
| 2005 | 201[5] | 42.4 | 201 | Yes |
| 2006 | 230 | 55.6 | 226 | Yes |
| 2007 | 149 | 42.9 | 223 | Yes |
| 2008 | 221 | 58.7 | 225 | No |
| 2009 | 209 | 50.7 | 208 | No |
| 2010 | 251 | 54.1 | 204 | No |
| 2011 | 166 | 45.7 | 170 | No |
| 2012 | 178 | 40.5 | 115 | No |

[1]Referred to schools with structured drug prevention programs aimed at secondary students (including vocational training). Such programs are those with scheduled sessions (>5) to be developed in the classroom by teachers, or by external prevention experts, often with application manuals, and aimed at the development of skills and competencies for life or to avoid drug use. Occasional preventive activities such as talks, distribution of written materials, workshops, awareness days, contests or exhibitions are not considered. [2]This refers to the percentage of total students enrolled in secondary education in Spain (including vocational training) who participated in structured drug prevention programs. [3]It was calculated by dividing the inflation-adjusted national budget for drug use prevention by the number of secondary students registered in Spain and expressing the result in relation to the year 2000 whose spending per student was assigned the value of 100. The aforementioned budget is the sum of the budgets of the central and regional governments and with it, school and non-school drug prevention interventions are financed. [4]The national preventive campaigns in the media were aimed at informing and sensitizing the Spanish population, especially adolescents aged 12–18 and their parents or guardians, about the risks of drug use. [5]This data was estimated. Data source: Data were extracted from activity reports of National Plan on Drugs.

large-scale synchronized increases in such interventions in 2006 are highly unlikely, mainly due to their partial dependence on the national budget. Finally, among adolescents an inverse relationship between drug risk perception and drug use is usually observed (43–47). However, in 2006–2010 in Spain the apparent huge decreases in perceived risk of cannabis, cocaine and ecstasy were accompanied by decreases in annual and monthly prevalences of use of these drugs (37), suggesting that decreases in perceived risk were not real. Taken together, the evidence suggests a causal relationship between the 2006 questionnaire change (intervention) and the sudden increases in perceived risk of occasional drug use (outcome).

## Interpreting the 2006 spike in drug risk perception as an anchor release effect

Although there are several explanations on the mechanism of the question-order effects, perhaps the most accepted rely on cognitive heuristics (13, 23). The mental processes of answering questionnaires usually has various steps (question understanding, retrieving relevant factual data from memory, integrating it into a judgment and answer selection) (1, 48). However, when there is considerable uncertainty, as often happens with subjective phenomena such as health-related risk perceptions, especially under conditions of fatigue or disinterest, respondents often resort to heuristics or mental shortcuts to answer by reducing the cognitive burden. One of the best known is the anchoring-and-adjustment heuristic, which involves initially focusing on an anchor or reference point, which is usually the phenomenon better known, easily recalled from memory, or more salient, and then adjusting the selected answer from the anchor (49–54). This heuristic aligns well with the evidence that human judgements are generally comparative (55), and its effects are extremely ubiquitous across topics, subgroups, and settings. Specifically, in a question grid including several items on a similar topic with a similar response scale, sometimes the response to an adjacent item, which is easier to elaborate, is used by respondents as a self-generated anchor to adjust the response to another item either by reducing the difference between both responses (assimilation) or expanding it (contrast) (51, 56).

The adolescents' judgments on risk of a given drug are subject to great difficulty and uncertainty because most of them could not base such judgments on personal experience since they are non-users or very sporadic users. Consequently, they would resort to anchoring heuristics, integrating the most easily available external information, which usually refers to regular drug use, since it is a very notorious and quite frequently associated behavior with social or health problems, and subsequently adjusting the response on the risk of occasional use from that reference. As indicated, the 2006 questionnaire change consisted of asking on perceived risk of occasional and regular use of a given drug using two non-adjacent items located in different blocks (non-adjacent item-pair model) instead of two adjacent or consecutive items as in 2000–2004 and 2008–2012 (adjacent item-pairs model). The findings show a 2006 peak in perceived risk for occasional drug use but not for regular use. This suggests that in the adjacent item-pairs model, operative in years other than 2006, the risk perception of regular drug use would act as an anchor item (57), so that adolescents would adjust the response to the immediately preceding item on the risk of occasional use, trying to considerably reduce the risk attributed to regular use (contrast effect) (58). However, in the non-adjacent item-pair model, operative in 2006, the anchor of regular use disappears since this item is far away in another question grid, so the perceived risk of occasional drug use shoots up. In short, the 2006 peak in perceived risk of occasional drug use was most likely due to a release from the anchor exerted by the perceived risk of regular drug use. Such release would have been triggered by the 2006 change in question-order.

As indicated, some respondent factors such as sex, age, education level, or direct experience on the subject (20–23) can modify susceptibility to question-order effects. The higher 2006 peaks in risk perception of occasional drug use among women than men found in our research are consistent with previous findings (20) and with an increased women's susceptibility to anchoring heuristics (59). Regarding age, our results referring to question-order effects in perceived risk of occasional drug use are mixed, since they show a greater effect among older and younger adolescents, respectively, for cannabis and heroin, and almost no effect for cocaine and ecstasy. However, there is some previous finding indicating that younger adolescents are more strongly influenced by questionnaire format and context than older adolescents (22). Finally, the higher peaks in adolescents with higher than lower educational level or academic performance are difficult to interpret. Thus, although it is usually thought that the greater the cognitive ability of the respondent and their direct involvement or experience in a self-reported issue, the less propensity they will have for question order effects, the truth is that the previous evidence in this regard is usually inconsistent (23). Similarly, it would be expected that the higher the educational level and academic performance of an adolescent, the greater their knowledge on drug effects and greater cognitive ability to develop independent responses without resorting to anchors. However, the evidence on susceptibility to anchoring effect according to education or intelligence level is also inconsistent (4, 21, 60–63). The key to the inconsistencies may be that, although the anchoring heuristic can generate bias, it is also a cognitive resource which in situations of great uncertainty and time constraints helps build responses and judgments (64). Lacking conclusive evidence or social consensus on the risk of occasional use of drugs such as cannabis or ecstasy, the adolescents' judgments on this involve great uncertainty and cognitive burden. Thus, it may be even more rational and valid to adjust the response from reliable anchors than to elaborate it ex novo relying on one's own beliefs or those of peers.

## Limitations

Given that this study is based on a natural experiment, its main limitation is the potential influence of uncontrolled factors changing between 2006 survey and the others. Notwithstanding, even if it cannot be completely ruled out, the role of potential unknown events (social, political, communicative, etc.) occurring in 2006 is quite unlikely. A detailed search has been made and no one relevant has been found. Other changes in survey methodology (i.e., sampling, fieldwork or database preparation) which could explain the results have not been identified either. In this sense, it is a guarantee that there have not been 2006 abrupt changes in other sociodemographic indicators, drug use, opinion and perceptions from the survey.

On the other hand, dissimilar results observed by drug and sociodemographic subgroup could be argued as a limitation. In fact, these findings do not match with previous knowledge concerning individual susceptibility to cognitive heuristics. However, this background is moderately inconsistent, and this study was not focused on analyzing individual differences. In general terms, the anchoring effect release in 2006 was observed among all drugs and subgroups, and just the magnitude of this fact changed from some groups to others.

## Conclusions

The findings suggest that when assessing the magnitude of a subjective health-related phenomenon subject to considerable uncertainty (i.e., the perceived risk of occasional and regular drug use) using two or more consecutive or adjacent items, responses may strongly depend on question ordering. Consequently, in repeated or panel health surveys, some seemingly "cosmetic" changes in ordering or clustering of questions, particularly the insertion of intermediate items, may cause unexpected anomalies or artifacts that severely limit comparisons. The standardization over time, space, groups and individuals of data collection methods or instruments, including questionnaires, is essential to achieve valid estimates of any health measure, particularly subjective ones, and to be able to make valid comparisons based on them. Questionnaire changes should be minimized and if unavoidable they should be carefully pretested through a cognitive interview and piloted before launching (65, 66). Likewise, researchers and decision makers in the health field must be aware that the comparison of findings from two questionnaires with items with the same wording but different ordering or clustering may be affected by question-order biases that invalidate such a comparison. Another important corollary is that the transfer of evidence from self-reported surveys to policies must be very careful and prudent, since the results are highly dependent on the characteristics of the data collection instrument. For this reason, it is also convenient to triangulate the results of these surveys with other sources or methods, such as qualitative techniques.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

## Author contributions

CP-R analyzed the data and wrote the manuscript. JoP and GB originated and designed the study and coordinated the writing of the article. JH, JuP, MD, and MB contributed to the analysis of the data and to the drafting of the manuscript. JG collaborated in the bibliographic search and in the debugging of the database. ER contributed to the interpretation of the results and to the drafting of the manuscript. All authors have contributed to the work, agree to the order in which they are listed, have read and reviwed the final manuscript and approved the final version and its submission.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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