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EDITED BY
Alejandro Lopez-Feldman,
University of Gothenburg, Sweden

REVIEWED BY
Lorenzo Caruso,
University of Ferrara, Italy
Samantha Elizabeth Robinson,
University of Arkansas, United States

*CORRESPONDENCE
Viliam Pichler
✉ pichler@tuzvo.sk;
✉ vilopichler@gmail.com

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Forests serve vulnerable groups in times of crises: improved mental health of older adults by individual forest walking during the COVID-19 pandemic

Kiki Ekiawan Lamatungga[1], Magdaléna Pichlerová[2], Júlia Halamová [3], Martin Kanovský[4], Dhanalakshmi Tamatam[1], Daniela Ježová[5] and Viliam Pichler[1]*

[1]Department of Natural Environment, Faculty of Forestry, Technical University in Zvolen, Zvolen, Slovakia, [2]Department of Landscape Planning and Design, Faculty of Ecology and Environmental Science, Technical University in Zvolen, Zvolen, Slovakia, [3]Faculty of Social and Economic Sciences, Institute of Applied Psychology, Comenius University in Bratislava, Bratislava, Slovakia, [4]Faculty of Social and Economic Sciences, Institute of Social Anthropology, Comenius University in Bratislava, Bratislava, Slovakia, [5]Institute of Experimental Endocrinology, Biomedical Research Center, Slovak Academy of Sciences, Bratislava, Slovakia

Understanding the effects of environment on the mental health of older adults is crucial in an aging society. Previous research concerning restorative benefits of forests almost entirely omitted older adults as the primary target group and typically involved group forest visits, which were largely restricted during the COVID-19 pandemic. Here we investigated the effects of individual walks on the mental health of adults aged 60 years or older ($N = 54$). A randomized parallel intervention study was conducted with one group walking in forests and the other in built-up city centres. Each participant completed eight individual 40-min walks during 1 month. Significant improvements in cognitive flexibility and heart rate variability (HRV) as an autonomic nervous system functioning indicator were established in the forest-walking group. The relationship between HRV and environment was modulated by ambient temperature. The study shows that access to forests during crises can support mental health of older adults as a vulnerable demographic.

KEYWORDS

forest walking, older adults, cognitive function, heart rate variability, ambient temperature, environmental modulation

1 Introduction

Exposure to nature and forests offers manifold restorative benefits for human mental health, including stress reduction, improved cognitive function, alleviation of depression, enhanced mood, and positive emotions (Hartig et al., 1996; Karjalainen et al., 2010; Jarosz, 2022; Pichlerová et al., 2023). Both health policymaking and forest management planning are expected to reflect the expanding knowledge about forest benefits for human health as one of the most important services provided by ecosystems (Vining and Tyler, 1999; Levy et al., 2012). To achieve this, more information on woodland experience and the exposure frequency and duration is needed to maximize benefits from time spent in forests and the management of forests according to people's specific needs (Milcu et al., 2013; Doimo et al., 2020). For example, the demand for additional ways of coping with health problems, e.g., nature-based health interventions in this study, is also driven by the issues with access to healthcare and the rising costs of medical treatments of older adults (De Beurs et al., 1999; Rowan et al., 2013). Currently representing 10% of the global population, this demographic is projected to increase to 16% over the next 30 years (United Nations, 2022). This trend creates complex predicaments due to the high prevalence of mental disorders in older adults (World Health Organization, 2017). While older people can withstand stress better than younger people owing to, e.g., life experience and quality of relationships (Vahia et al., 2020), the declines in cognitive functioning begin as early as the mid-40s (Hughes et al., 2018). The importance of investigating the effects of forests on mental health was highlighted by the COVID-19 pandemic that saw an overall increase in the number of nature and forest visits, except in older adults who constituted the most disadvantaged population segment due to restrictive measures (Pichlerová et al., 2021).

The theoretical framework encompassing forest ecosystem services (FES), public health, healthy aging, and environmental psychology links the beneficial forest features shaped by nature or forest management with attention restoration (Kaplan and Kaplan, 1989) and stress reduction (Ulrich, 1983; Ulrich et al., 1991). The relationship may be enhanced by relational restoration through supportive exchanges between people (Hartig, 2021), especially in older adults who often suffer from social isolation (Donovan and Blazer, 2020). Because nature's effects on health and well-being result from multiple additive nature–health pathways (Kuo, 2015), it is crucial that studies provide descriptions of forest environments to pinpoint and promote the beneficial forest features through practical forest land management (Yamada, 2006; Meneguzzo and Zabini, 2021; Clark et al., 2023). Moreover, the relationship between restoration and the exposure to nature and forests can be conditioned or modulated by various factors inherent to natural environments, including bad weather or potentially dangerous wildlife that may trigger anxiety or stress (Ulrich, 1983; Grassini et al., 2016). An individual's level of nature exposure can be assessed by the time spent in direct contact with nature and the amount of residential greenspace (Keniger et al., 2013), commonly assessed by the normalized difference vegetation index (NDVI), tree canopy coverage, and proximity to forests and parks.

Typical outcome measures for mental health characteristics used in nature intervention studies rely on instruments validated in many settings, such as Trail Making Test (Arbuthnott and Frank, 2000), combined with measures of autonomic nervous system function, for example heart rate (HR) and HR variability (HRV) (Kobayashi et al., 2018). TMT has two parts: TMT-A that accounts for rote memory, and TMT-B as an executive functioning index (Ciolek and Lee, 2020). It is scored by the time needed to draw a line connecting consecutive numbers (TMT-A), and numbers and letters in an alternating progressive sequence (TMT-B) (McMorris, 2016). The difference between TMT-B and TMT-A (TMT-B – A) is considered cognitive flexibility measure (Corrigan and Hinkeldey, 1987). HRV has been widely used as an indicator of autonomic nervous system functioning, especially stress (D'Angelo et al., 2023). It can be expressed by several parasympathetic tone indexes, e.g., the normalized root mean square of the successive difference of normal inter-beat intervals (RMSSD) (Daffre et al., 2022). RMSSD has been identified as a reliable metric of vagal activity (Cosmo et al., 2022) that tends to decrease with increased stress level and vice versa (Pietilä et al., 2018; Skov et al., 2022). HRV may be affected through medicaments used for hypertension treatment, especially β-blockers (Schroeder et al., 2003). Consumer wrist-worn fitness tracking devices with photoplethysmography (PPG) sensors have been increasingly used to measure HRV in outdoor environment research (Evenson and Spade, 2020; Natarajan et al., 2020). Binary classification of HRV changes (e.g., HRV increase detected versus not) is sometimes used in ecological momentary assessment research (Schwerdtfeger and Rominger, 2021).

Despite previous research on the health benefits of forest walking and viewing (Lanki et al., 2017; Stigsdotter et al., 2017; de Brito et al., 2020), there is a need for more studies in this area (Piva et al., 2022). A recent scoping review of the research on forest features and mental health or wellbeing (Clark et al., 2023) did not identify studies with a specific focus on elderly people as a vulnerable population segment. In addition to that, numerous interventions were implemented in groups, thus implying social interaction. The presented study aimed to address the knowledge gap through evaluating the effects of individual, one-month intervention on the autonomic nervous system and cognitive functions specifically in older adults (60+). Our goal was to determine and compare the restoration effects of eight one-hour walking and viewing visits to forest and urban environments, evenly distributed during 1 month with a frequency of two walks per week. The working hypotheses were: (1) Both forest and urban interventions reduce stress and improve cognitive function. (2) Forest walks reduce stress and improve cognitive flexibility more than urban walks. (3) Intervention effect size on cognitive function is greater than on stress reduction. (4) Interrelationship between stress reduction and environment is modulated by ambient temperature.

2 Materials and methods

The study was performed from the 1st to the 31st of October 2021, during a period without heatwaves or sub-zero daily temperatures. The selected time period was between two COVID-19 pandemic waves when the pandemic-related measures were eased, but social interaction had to be kept at a minimum.

2.1 Study participants

The study was conducted on a sample consisting of 54 older adults (60 years of age and older) living in the district of Zvolen, a town located in one of the urbanized and industrialized Slovak regions, with a population of 43 thousand citizens. The participants were recruited in collaboration with the municipal social and older adult welfare authorities from June to August 2021. To be enrolled in the study, participants had to meet the inclusion criteria: (1) age of 60+, (2) vaccinated from COVID-19, (3) being able to walk independently, and (4) willing to participate in a one-month intervention. The exclusion criteria were: (5) staying in institutional care, (6) prescribed antidepressant drugs. Seventy-four older adults took part on the orientation day, and 54 of them met the criteria. Study participants

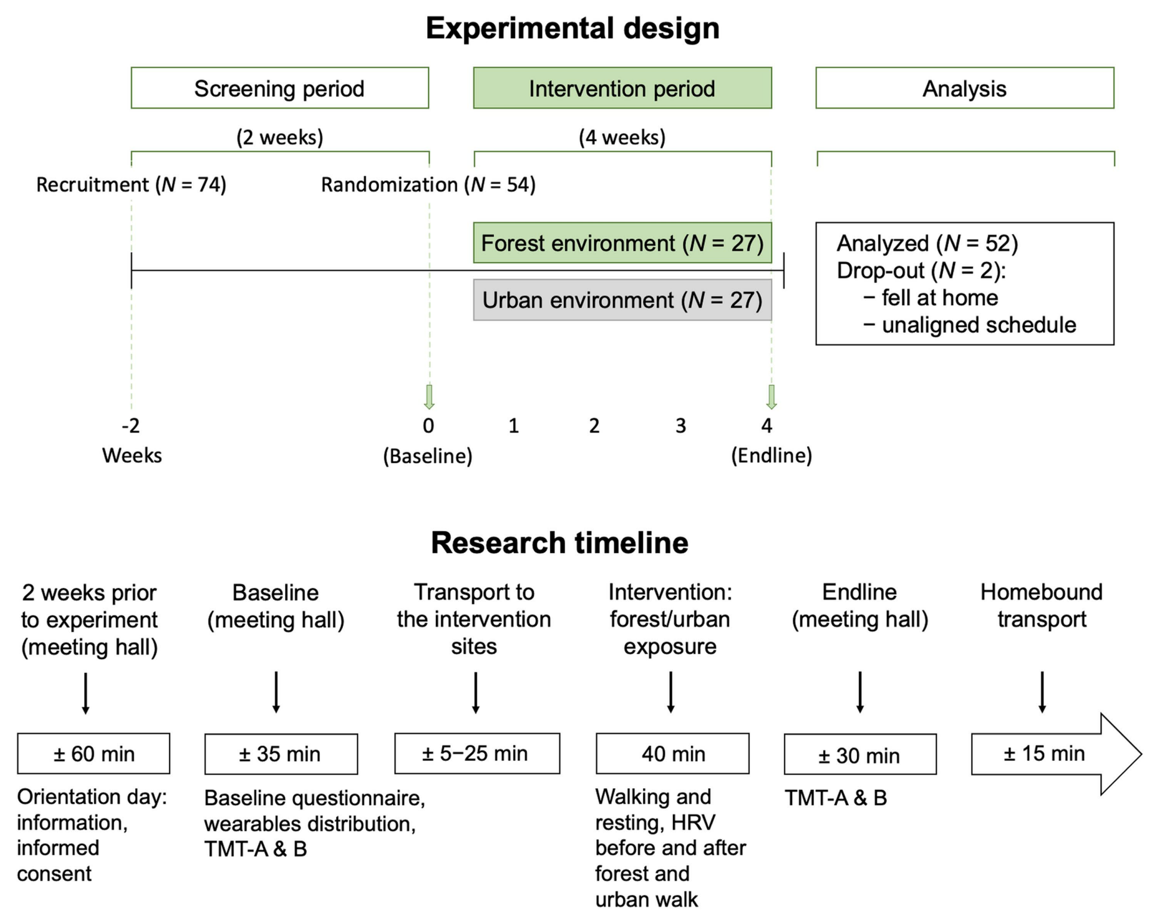

FIGURE 1
Design and research timeline of the randomized parallel intervention.

were randomly assigned into the forest (intervention) and urban (active control) groups with a ratio of 1:1 through the web-based research randomizer.[1] Most of the participants characteristics (age, BMI, marital status, education, tobacco/smoking status, number of chronic illnesses, occupation, household income) were relatively similar in both groups. There were 5 and 9 participants either on β-blockers or on undeclared medication for hypertension treatment in the forest and urban groups, respectively. The remaining subjects declared either non-β-blocker medications or no prescriptions for hypertension. Among environmental features (tree canopy coverage, distance to parks and forests), the residential areas of the urban group members were characterized by higher NDVI ($p < 0.01$). The detailed characteristics of 54 participants (randomly assigned to the forest and urban groups) and their residential environments are shown in Supplementary Table S1; Supplementary Figure S1. An administrator with professional experience in communication was appointed to maintain telephone contact with the participants and provide organizational instructions. Eight field assistants provided guidance to the participants in the intervention localities and collected their HRV data.

2.2 Study design and procedure

The study was based on a randomized, parallel intervention design (Figure 1). Before starting the intervention, all subjects signed the informed consent form. Blinding from the specific research questions was conducted for participants and the research assistants. Four to 2 days prior to the intervention, the baseline data were collected and measurements were taken. The participants filled out the baseline questionnaire and afterward, research assistants administered TMT to each individual. Finally, the participants were provided with and instructed to use Garmin Venu Sq, consumer wrist-worn fitness tracking devices using photoplethysmography sensors, for 24 h a day during the whole intervention period.

Participants were asked to complete two interventions per week, i.e., a total of eight visits to intervention sites during 4 weeks. The intervention times were randomly assigned to each participant. The intervention schedule was provided to each participant at the beginning of each week via telephone call. One day before each intervention, the concerned participant was reminded by phone to be ready for individual transport to one of the research sites. After being picked up from their home address by a dedicated driver and arriving individually at the assigned intervention site, each participant was met by a site assistant who repeated the walking instructions. The use of cell phones, eating, and casual conversation were not allowed.

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[1] www.randomizer.org

Drinking water was permitted. The assistants navigated the participants by walking approximately 10 m in front of them without interaction during the intervention lasting approximately 40 min, of which 25–30 min were spent walking at a pace of about 3 km per hour, and around 10 min viewing the environment from a portable chair or bench. The assistants initiated HRV measurement every pre-post walk and recorded the values or any observations regarding participants' feelings, e.g., anxiety. At the end, the participants were driven back to their homes. Each day, 15 to 18 participants were individually mobilized to the sites from 9:00 a.m. until 4:00 p.m. The wearable devices were collected after 2 weeks for data download and cleaning. The intervention was thereby divided into two 14-day sub-periods that facilitated further statistical analyses. The TMT test was administered again at the end of the whole intervention period (endline).

2.3 Intervention sites

There were three urban and three forest intervention localities, and each participant completed a minimum of two interventions in each of them according to their assignment to the urban or forest group. Multiple locations were selected to avoid boredom and fatigue. At the end, the aggregated means of the separate effects of the forest and urban environments were used. The localities were selected based on topographic data and field reconnaissance to ensure comfortable walkability on relatively even surfaces (trails, pavement) with a max. 3° inclination to avoid physical exertion and acceptable driving times from participants' addresses, similar for both urban and forest localities and groups (5–25 min). The study was conducted in the Central Slovakia. For urban sites, two major towns (Banská Bystrica, Zvolen) were selected. Two main walking spots were established in Zvolen and one in Banská Bystrica (Figure 2). The forest sites featured species and structural diversity: Mláčik (48.664°N, 19.026°E) – a non-managed, mixed fir-beech-spruce old-growth forest; Stráže (48.579° N, 19.095°E) – a beech-oak-hornbeam forest subject to shelterwood management; and Sliač (48.611°N, 19.160°E) – a mixed pine-hornbeam-spruce forest surrounding a spa complex (Figure 3). The walking pathways in each site were around 1 km in length. The average air temperatures for October 2021 were obtained from the main weather station of the Slovak Hydrometeorological Institute, Bratislava, in Sliač, and several nearby stations operated by the National Forestry Centre, Zvolen, and the Technical University in Zvolen. The air temperatures at the five intervention localities were 12.1°C (Sliač), 11.0°C (Stráže), 9.5°C (Mláčik), 12.0°C (Banská Bystrica), and 12.5°C (Zvolen). The average minimum temperature between 9:00 a.m. and 4:00 p.m. in Sliač declined from 9.2°C during the first period (walks 1–4) to 6.4°C during the second period (walks 5–8) of the intervention.

2.4 Measured variables

The main outcome variables in the presented study were cognitive flexibility and HRV.

2.4.1 Cognitive function

The Trail Making Test (parts TMT-A and TMT-B) was administered to assess cognitive performance of older adults before and after the intervention. We used the validated Slovak TMT version that was earlier used to establish normative data for the adult Slovak population (Mális̆ová et al., 2021). The cutoff time of 300 s was applied to discontinue the test administration (Bowie and Harvey, 2006; National Institute of Health, 2013) and the respective cases were not used in further analysis. The TMT-B – A values were calculated as differences between TMT-B and TMT-A scores, both at baseline and endline. Similar to numerous other cognitive function tests, the scores are affected by the repeated administration up to 1 year after the initial exposure (Basso et al., 1999).

2.4.2 Heart rate variability

The HRV was measured through Garmin Venu Sq, a consumer wrist-worn tracking device equipped with a PPG sensor (Garmin

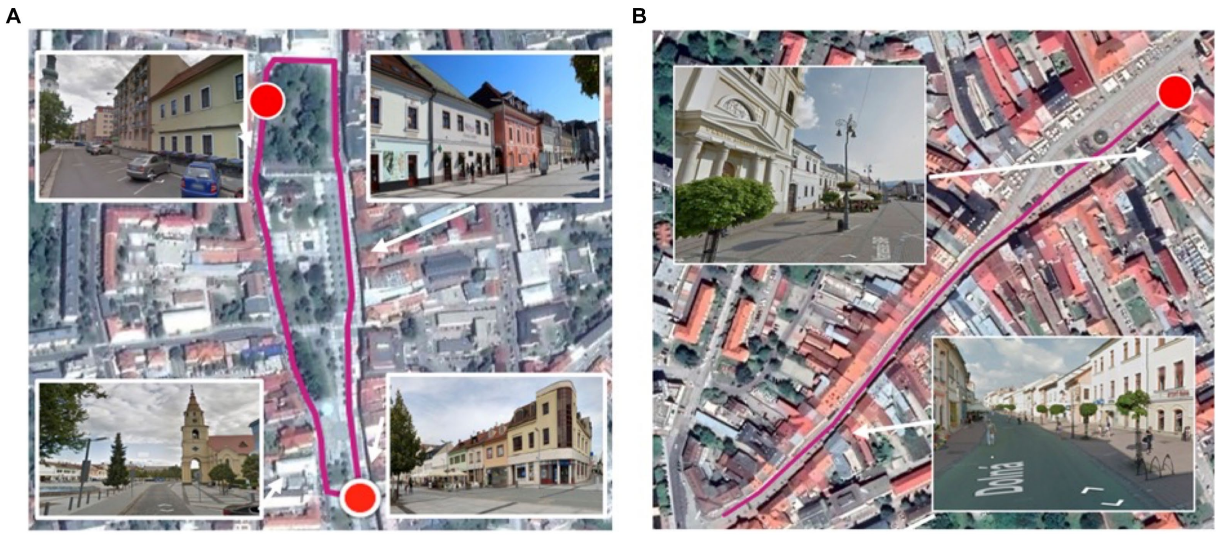

FIGURE 2
Walking routes in the urban sites: **(A)** Zvolen; **(B)** Banská Bystrica.

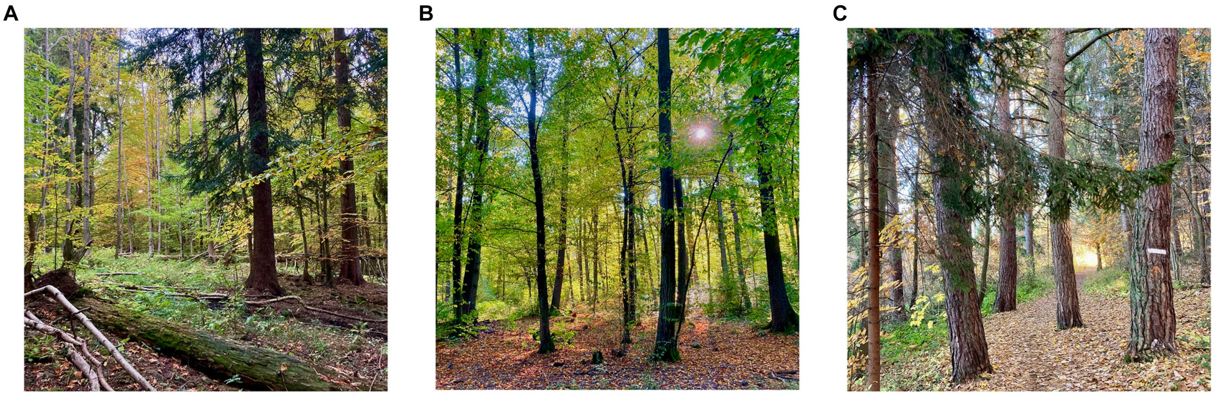

FIGURE 3
The interiors of the three forest intervention localities: **(A)** Mláčik, a fir-beech-spruce old-growth forest; **(B)** Stráže, a beech-hornbeam forest; **(C)** Sliač, a mixed pine-hornbeam-spruce forest. The pictures were taken in October 2021, when the experiment was conducted.

Elevate; Garmin, 2020), during 3 min windows before and after each of the eight interventions. It was measured at rest 5 min after the arrival at the sites and 5 min after the slow walking. The HRV (RMSSD) was extracted through Test HRV, v. 1.3.1, a custom Garmin Connect IQ application (Retty, 2022). The post-to pre-walk HRV difference (Δ HRV) was analyzed as an interval variable and a nominal variable in the binarized form (Δ HRV > 0, Δ HRV ≤ 0). HRV values from walks during which a participant reported strong anxiety or acute stress due to biophobia were not included in the analysis. The main analysis of HRV change scores only included respondents who declared either non-β-blocker medications or no prescriptions for hypertension.

2.5 Statistical analyses

A total of 54 participants (27 in each group) entered the two-treatment parallel design study, which included individual leisure walking and viewing in forest and urban environments. Baseline characteristics were assessed using the chi-square test for categorical variables and the Student's *t*-test for continuous variables. The Shapiro–Wilk test ($p < 0.01$) was applied to both the TMT and HRV datasets. Overall, the normal distribution assumption was not met in 2 out of 6 HRV data groups. Possible outliers in the normally distributed data were identified through the Dixon's test at the significance level of $p < 0.01$. In the non-normally distributed data, outliers were flagged through the Tukey's fences procedure, as values lying below and above the first and third quartiles, respectively, by a distance of 3 times the interquartile range or more. When detected, the most distant outlier was removed from each concerned group. One outlier (1.9% of the sample size) identified in the urban group was removed from the TMT analysis. Before the HRV analysis of the first intervention period, one outlier (1.2% of the sample) was removed from the forest group. In the dataset for the entire period, one outlier representing 0.6% of the respective sample was also excluded from the forest group sample. This approach was taken because our experiment was conducted in real-world forests characterised by potential, uncontrolled for events with unknown probability. Furthermore, a potential intervention routine disturbance, arising from technical issues like a misunderstood time or place for participant pick-up, could significantly impact momentary HRV data.

Two-way repeated measures ANOVA was used to evaluate interaction effects of time as the within-subject factor (baseline to endline) and environment as the between-subjects factor (forest vs. urban) on TMT-A, TMT-B, and TMT-B – A scores. The homogeneity of variance assumption in the repeated measures ANOVA was met according to the Levene's test ($p > 0.10$). With only two levels for each factor, the sphericity test was not applicable. In our specific case with two factors and two levels, the repeated measures ANOVA approach can also be looked at as the comparison of the difference or change scores between forest and urban groups (Winer, 1971; Izakova et al., 2020). When an interaction effect on TMT scores emerged as significant, we examined the simple effects of each independent variable (baseline to endline, forest versus urban) on the dependent variable (TMT) at individual levels of the other independent variable. The *F*-tests with Bonferroni-adjusted *p*-values were utilized to compare baseline to endline scores within each environment and to evaluate forest and urban scores separately at baseline and endline. Otherwise, only main effects were reported.

The post-and pre-walk HRV change (Δ HRV) scores in the forest and the urban groups were compared through the independent *t*-test during the first, the second, and the entire periods. Given that *t*-test was found to be sufficiently robust against deviations from non-normal distribution on samples >100 or even smaller (Lumley et al., 2002), it was also applied on the non-normally distributed samples ($85 \leq N \leq 168$). The simple effects were determined when a respective change score was found significant. Specifically, differences between pre-and post-walk HRV values in the two environments, as well as the differences between the environments prior to and after walking, were separately appraised through paired and independent *t*-tests. Their results were screened through the Bonferroni–Holm correction (Cramer et al., 2016). Moderation analysis relying on the Johnson-Neyman technique (Lin, 2020) was employed to establish whether air temperature modulated the relationship between Δ HRV and the environment, as well as the modulation region of significance. The assessment of binarized Δ HRV changes (Δ HRV > 0 vs. Δ HRV ≤ 0) expressed as proportions of positive Δ HRV cases relative to all measurements (*N*) in a given cell was conducted using chi-square contingency table.

The respective effect sizes were expressed as partial eta-squared (η^2_p) in the repeated measures ANOVA, Cohen's *d* for *t*-tests, and phi (φ) for the chi-square contingency test. The results were considered statistically significant when $p < 0.05$. All analyses were performed with SPSS statistical software (version 28; IBM SPSS Statistics, Armonk, NY, United States), except the Dixon's test implementation in ControlFreak (Contchart Software, Sechelt, Canada).

3 Results

The results encompass the evaluation of cognitive function in older adults, focusing on three components: rote memory (TMT-A), executive functioning index (TMT-B), and cognitive flexibility (TMT-B – A). Additionally, the analysis of autonomic nervous system functioning is presented in terms of HRV change (Δ HRV) scores, binarized Δ HRV, and the modulation of the relationship between Δ HRV and environment by ambient temperature.

3.1 Cognitive function

This study primarily aimed to examine the interaction effect of time and environment on the cognitive function, i.e., to establish whether the baseline to endline TMT change scores differ between the two environments, i.e., treatment (forest walking) and active control (urban walking). The results of the two-way repeated measures ANOVA of the effects of time (within subject: baseline to endline), environment (between subjects: forest versus urban), and their interaction (time*environment) on the TMT-A, TMT-B, and TMT-B – A scores are presented in Table 1; Figure 4. Time (baseline to endline) had a large effect on all TMT scores, environment showed a strong influence on TMT-A, and only TMT-B – A was affected by the interaction of the two factors with a medium effect size ($\eta^2_p = 0.09$).

3.1.1 The main effects of time and environment

The significant main effects of time on TMT-A and TMT-B are shown in Table 2. The baseline to endline decrease of TMT-A and TMT-B values was to a large extent attributable to the repeated test administration after 4 weeks, and environment had no effect on the corresponding change scores. However, the average TMT A values (i.e., irrespective of baseline and endline) in the forest group were significantly higher than those in the urban group (Table 2; Figure 4A).

3.1.2 The simple effects of time and environment

While the main effect of time on TMT-B – A score was found significant, $F_{1,46} = 5.70$, $p = 0.021$, $\eta^2_p = 0.11$, it was qualified by a significant interaction between time and environment, $F_{1,46} = 4.30$, $p = 0.044$, $\eta^2_p = 0.09$ (Table 1). The Bonferroni-adjusted comparisons in Table 3 indicated that forest walking group participants had their TMT-B – A score 19.05 ms lower at endline than at baseline ($p = 0.004$). Concurrently, there was no significant difference between the baseline and endline TMT-B – A scores in the urban group members. Taken together, the repeated measures ANOVA followed by the analysis of the simple effects on TMT-B – A documented that forest walking intervention had a significant positive effect on the cognitive flexibility.

3.2 Heart rate variability

The HRV analysis examined whether environment had an effect on the pre-to post walk HRV changes related to the autonomic nervous system functioning. Subsequently, Johnson-Neyman technique was applied to explore the modulation of the relationship between Δ HRV and environment by ambiental temperature. Finally, binarized HRV changes were used to establish whether the intervention affected the majority of participants.

3.2.1 HRV change scores

Independent *t*-tests showed that a difference between pre-to post-walk HRV change (Δ HRV) scores existed only during the first half of the intervention, i.e., during the first 2 weeks (Table 4). Specifically, forest (treatment) group exhibited a higher pre-to post-walk HRV change score compared to the urban (active control) group ($p = 0.047$), with a small to medium effect size (Cohen's $d = 0.32$). The subsequent analysis of the simple effects involving the Bonferroni–Holm correction (Table 5) showed a significant pre-to post-walk HRV increase in the forest group ($p = 0.001$, Cohen's $d = 0.37$), and, at the same time, a higher average pre-walk HRV in the urban group

TABLE 1 Two-way repeated measures ANOVA of the effects of time (within subject: baseline to endline), environment (between subjects: forests versus urban), and the interaction of the two factors (time × environment) on the TMT-A, TMT-B, and TMT-B – A scores.

Outcome	Factor	*N*		*df*	*F*	*p*	η^2_p
		Forest	Urban				
TMT-A	Time	22	25	1	17.89	**< 0.001**	0.28
	Environment	22	25	1	8.76	**0.005**	0.16
	Time × environment	22	25	1	0.01	> 0.9	–
TMT-B	Time	22	25	1	20.48	**< 0.001**	0.31
	Environment	22	25	1	5.32	0.061	–
	Time × environment	22	25	1	4.14	0.053	–
TMT-B – A	Time	22	25	1	5.70	**0.021**	0.11
	Environment	22	25	1	0.59	> 0.4	–
	Time × environment	22	25	1	4.30	**0.044**	0.09

Statistical significance ($p < 0.05$) is denoted in bold.

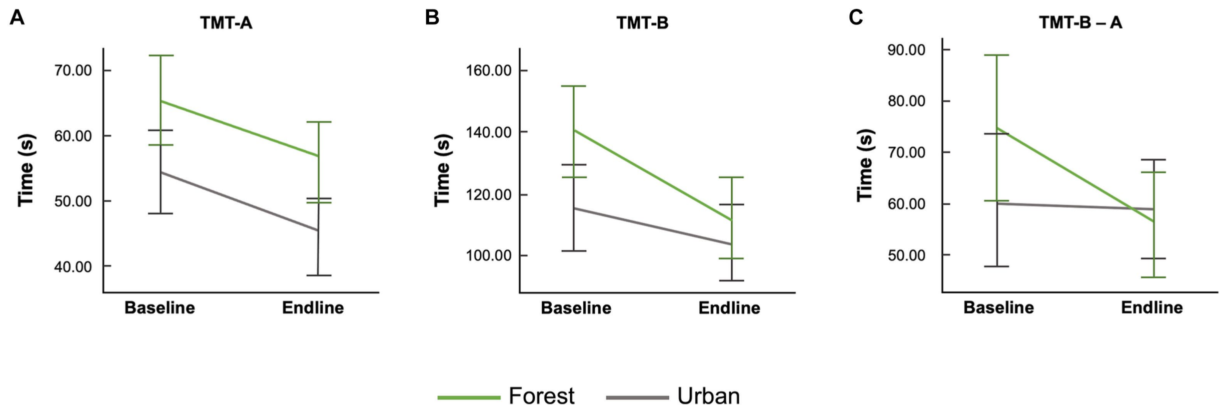

FIGURE 4
(A) Baseline to endline average scores for TMT-A; **(B)** Baseline to endline average scores for TMT-B; **(C)** Baseline to endline average scores for TM-B – A. The error bars indicate the 95% CI of the marginal means.

TABLE 2 The *F*-tests of the main effects of time and environment on TMT scores.

TMT measure	Time	Environment	*N*	Mean (s), [95% CI]	*df*	*F*	*p*	η^2_p
TMT-A	Baseline	–	47	59.83, [55.29, 64.36]	1	17.89	**< 0.001**	0.28
	Endline		47	50.30, [46.14, 54.46]				
TMT-B	Baseline	–	47	127.46, [117.22, 137.69]	1	20.48	**< 0.001**	0.31
	Endline		47	107.73, [98.66, 116.81]				
TMT-A	–	Forest	22	60.53, [55.11, 65.95]	1	8.76	**0.005**	0.16
		Urban	25	49.60, [44.52, 54.69]				

Significance levels (*p*) are Bonferroni-adjusted. Statistical significance ($p < 0.05$) is denoted in bold.

TABLE 3 The *F*-tests of the simple effects of the within group and between groups factors on TMT-B – A within each level of the other effects.

TMT measure	Time	Environment	*N*	Mean (s) [95% CI]	*df*	*F*	*p*	η^2_p
TMT-B – A	Baseline	Forest	22	74.83 [60.78, 88.88]	1	9.36	**0.004**	0.17
	Endline		22	55.78 [45.51, 66.05]				
	Baseline	Urban	25	60.43 [47.25, 73.61]	1	0.53	> 0.80	–
	Endline		25	59.09 [49.46, 68.72]				
	Baseline	Forest	22	74.83 [60.78, 88.88]	1	2.27	> 0.10	–
		Urban	25	60.43 [47.25, 73.61]				
	Endline	Forest	22	55.78 [45.51, 66.05]	1	0.22	> 0.60	–
		Urban	25	59.09 [49.46, 68.72]				

Significance levels (*p*) are Bonferroni-adjusted. HRV, heart rate variability, *N*, the number of forest or urban visits within the respective period, η^2_p, partial eta squared. Statistical significance ($p < 0.05$) is denoted in bold.

TABLE 4 Independent *t*-test of the pre-to post-walk HRV change (∆ HRV) scores between the forest and urban groups.

Period	Environment	*N*	Mean ∆ HRV difference [95% CI] (ms)	*df*	*t*	*p*	Cohen's *d*
1	Forest	85	5.57 [0.07, 11.07]	149.63	2.00	**0.047**	0.32
	Urban	72					
2	Forest	83	−3.36	131.57	1.40	0.16	–
	Urban	71					
1 & 2	Forest	168	1.14	288.86	0.62	> 0.50	–
	Urban	143					

HRV, heart rate variability, *N*, the number of forest or urban visits within the respective period, CI, confidence intervals. Statistical significance ($p < 0.05$) is denoted in bold.

($p = 0.002$, Cohen's $d = 0.50$), resulting in the positive Δ HRV difference score in the forest group compared to the urban group. There was no significant difference between pre-to post-walk HRV change scores for the two environments measured in participants on β-blockers or with unspecified medication for hypertension treatment ($p > 0.60$).

3.2.2 Modulation by air temperature

The breakdown of the relationship between Δ HRV and environment in the second sub-period (Table 4) suggests a potential modulation through an ambient factor, specifically temperature, which decreased by 2.8°C between the first and second periods. The modulating effect of temperature, interacting with the environment, was identified using the Johnson-Neyman technique [$R^2 = 0.05$, $b = 2.56$, CI (0.35, 4.77), $t = 2.33$, $t_{crit} = 2.03$, $p = 0.024$]. This indicates that, after adjusting for the interaction, the average Δ HRV in the forest group was 2.56 ms higher than in the urban group. The interaction plot in Figure 5A illustrates that as temperature decreased, Δ HRV decreased in the forest settings and increased in the urban settings. However, statistical significance for this modulation was only observed within the Johnson-Neyman region of significance, approximately below 9.9°C ($p = 0.05$), as depicted in Figure 5B. Notably, the partial overlap between the interaction's region of significance and the decline in average 9:00 a.m. to 4:00 p.m. air temperature—from 9.2°C in the first period to 6.4°C in the second period—contributed to the loss of Δ HRV score differences between the two environments during the second sub-period.

3.2.3 Binarized Δ HRV changes

The full chi-square contingency table (Table 6) and the proportions of binarized Δ HRV (Δ HRV > 0 vs. *N*) according to environment (Table 7) mirror the results from the analysis of Δ HRV as an interval variable (Table 4). The chi-square test of the difference in proportions, with time as the layering variable, showed a directional relationship between the binarized Δ HRV and environment, as well as a medium effect size during the first sub-period, χ^2 (1) = 6.22, $p = 0.013$, $\varphi = 0.20$. In other words, the number of cases with increased HRV relative to *N* tended to be higher in the forest group than in the urban group. Importantly, these results indicate that the intervention and modulation through air temperature had an effect on the majority of participants in the two groups.

3.3 External influences

The study was implemented smoothly according to the protocol. Only two participants dropped out during the intervention period and two external disturbances were observed during the entire 4-week

TABLE 5 **Paired and independent *t*-tests of the simple effects of the within subject (pre-to post-walk) and between subjects (forest versus urban) factors on the heart rate variability (HRV) within each level of the other effect during the first period.**

Period	Environment	Time	*N*	Mean HRV, 95% CI (ms)	*df*	*t*	*p*	Cohen's *d*
1	Forest	Pre-walk	85	34.50 [31.13, 37.87]	84	3.41[a]	**0.001**	0.37
		Post-walk		40.85 [36.60, 45.10]				
	Urban	Pre-walk	72	43.27	71	0.37[a]	> 0.70	–
		Post-walk		44.04				
	Forest	Pre-walk	85	34.50 [31.13, 37.87]	137.29	3.07[b]	**0.002**	0.50
	Urban		72	43.27 [38.80, 47.74]				
	Forest	Post-walk	85	40.85	149.34	0.98[b]	> 0.20	–
	Urban		72	44.04				

[a] Paired *t*-test.

[b] Independent *t*-test.*N*, the number of forest or urban visits within the respective period, CI, confidence intervals. Statistical significance ($p < 0.05$) is denoted in bold.

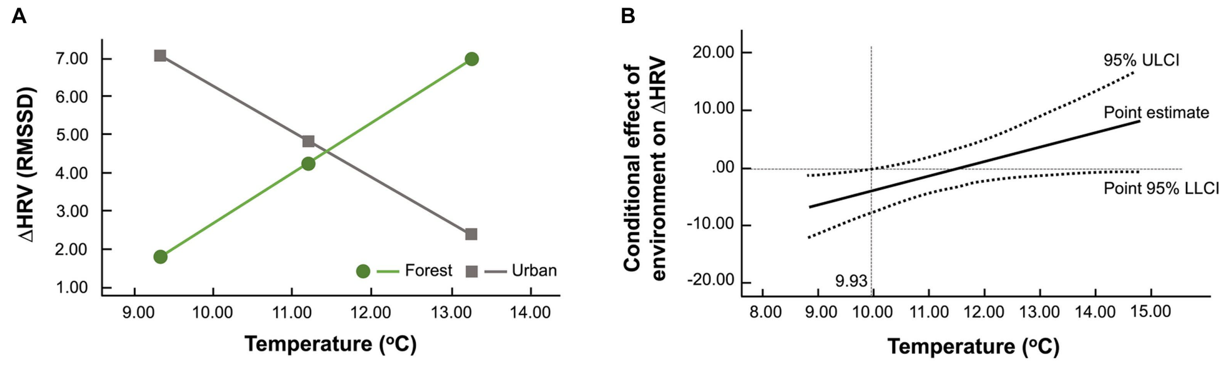

FIGURE 5
(A) Influence of the interaction between environment and temperature on HRV (RMSSD) change; **(B)** Johnson-Neyman plot for the effect of environment on HRV (RMSSD) change modulated by temperature within the region of significance.

TABLE 6 Chi-square contingency table with the numbers of cases of increased and decreased HRV (Δ HRV > 0, Δ HRV ≤ 0, respectively) in the forest and urban groups during the intervention sub-periods (walks 1–4 and 5–8) and for the whole intervention period (walks 1–8).

Group	Intervention period 1		Intervention period 2		Whole intervention	
	Δ HRV > 0	Δ HRV ≤ 0	Δ HRV > 0	Δ HRV ≤ 0	Δ HRV > 0	Δ HRV ≤ 0
Forest	58	27	48	35	106	62
Urban	35	37	44	27	79	64

TABLE 7 The chi-square test of the proportions of cases with positive pre-to post-walk heart rate variability change (Δ HRV > 0) between the forest and the urban groups for the first period (walks 1–4), the second period (walks 5–8), and for the entire intervention period (walks 1–8).

Period	Group	Proportion of cases with Δ HRV > 0 vs. N	N	DP, 95% CI	χ^2 (df)	p	φ
1	Forest	0.68	85	0.19, [0.038, 0.342]	6.22 (1)	**0.013**	0.20
	Urban	0.49	72				
2	Forest	0.57	103	−0.05	0.27 (1)	> 0.60	–
	Urban	0.62	106				
1 & 2	Forest	0.63	168	0.08	1.98 (1)	> 0.10	–
	Urban	0.55	143				

N, the number of forest or urban visits within the respective period; DP, difference in proportions. Bold font indicates statistical significance ($p < 0.05$).

intervention. There was moderate but persistent rain in both forest and urban locations for two consecutive days. During the second week, one participant reported a sighting of a brown bear (*Ursus arctos*) approximately 1 km from one of the forest intervention sites while being transported home after forest walk. The sighting was confirmed by the driver on duty. Potential influence of the uncontrolled-for incident on HRV is briefly explored in the Discussion (section 4.2 Heart rate variability).

4 Discussion

The obtained results allow for revisiting the working hypotheses: (1) The first hypothesis that both forest and urban interventions reduce stress and improve cognitive function was contradicted by the lack of association between improved cognitive function and the urban walking. (2) In contrast, forest walks were associated not only with sizeable improvement in cognitive flexibility, but also with greater HRV gain scores in the forest walking group (treatment) than those in the urban walking group (active control) in the first intervention period ($p = 0.047$). These findings lend support to the second hypothesis postulating that forest walks reduce stress and improve cognitive function more than urban walks. (3) The results partially align with the third hypothesis suggesting that the intervention effect size on the cognitive function is greater than on HRV change. While it was true for the forest intervention, whose positive effect on the cognitive function and HRV change, relative to the urban intervention, was medium ($\eta^2_p = 0.09$) and small to medium (Cohen's $d = 0.32$), respectively, the urban intervention failed to produce significant effect on the cognitive function. (4) Finally, the fourth hypothesis asserting the role of ambient temperature as the modulator of the relationship between HRV change and environment was upheld by the established modulation of that relationship by air temperature below approximately 10°C ($p = 024$). Overall, all four working hypotheses were productive as their pursuit revealed the necessity to examine different intervention environments and to consider specific intervention goals, target groups, and potential modulators.

4.1 Cognitive function

The obtained results revealed a significant improvement in the executive function and cognitive flexibility (TMT-B – A) among participants who engaged in frequent individual forest walks, in comparison to those who walked in urban environments. The medium-size effect on the cognitive flexibility manifested in the significantly greater baseline to endline TMT-B – A difference score in the forest group compared to the urban group. These findings suggest that the forest intervention considerably enhanced the ability to switch between different mental sets, tasks, or strategies that constitute cognitive flexibility, as defined by Diamond (2013) and Miyake and Friedman (2012). Recent systematic reviews documented partial evidence for improved cognitive flexibility after exposure to natural environments (Ohly et al., 2016; Stevenson et al., 2018) coming almost entirely from studies with university students and general population but not with older adults. As an exception, Setti et al. (2017) and Cassarino et al. (2019) found absence of cognitive restoration in older adults exposed to either natural or urban scenes on pictures. Our study, which exclusively focused on older adults, showed that the markedly improved cognitive flexibility was associated with forest walking in the presence of elements characterised by high fractal dimension, such as old trees (Seidel et al., 2019) in all three forest intervention sites. Specifically, higher fractal complexity of nature scenes supports higher perceptual fluency (Franěk et al., 2019) and in turn, higher perceptual speed contributes to better cognitive flexibility (Cepeda et al., 2001). Relatedly, Davis et al. (2023) established that navigational and switching abilities demonstrated by highly mobile Bolivian first nation forager-farmers remained without significant decline at mid-life through older age (40–70 years old), owing to their exposure to complex forest environments.

4.2 Heart rate variability

The significantly larger pre-to post-walk HRV difference score in the forest group compared to the urban group, also when represented in terms of the proportion of cases with Δ HRV > 0 relative to the total number of cases, was observed in the forest group compared to the urban group during the first 2 weeks of the intervention (walks 1–4), and when adjusted for the interaction between environment and ambient temperature. A loss of Δ HRV differences between the forest and urban environments was detected in the second sub-period, resulting from the interaction between environment and air temperature and its effect on Δ HRV, revealed by the Johnson-Neyman procedure. As the average temperature dropped from 9.2°C during the first period to 6.4°C during the second intervention period, Δ HRV decreased under the forest canopy but increased in open urban settings HRV (RMSSD) values can be expected to decline in non-thermally comfortable environments (Nkurikiyeyezu et al., 2017). Concurrently, it is possible that an adaptive change occurred after approximately four forest walks as a positive intervention outcome in the forest group members. The lack of significant difference between HRV change scores of the forest and urban subgroups, which comprise participants on β-blockers or with undeclared medication for hypertension treatment, may be partly caused by the tendency of β-blockers to increase total background HRV variability (Zhang et al., 2013).

The individual effect size of forest walking on Δ HRV was small to medium, but even minor individual-level effects can translate to large population health effects (Matthay et al., 2021). Some other studies detected no HRV differences between intervention outcomes from green areas or forest environments and those from built-up or industrial urban areas (Brown et al., 2014; Stigsdotter et al., 2017). However, they involved university students, office workers, and shorter (approx. 20 min) exposures to distinct environments. Martinez et al. (2022), who, in agreement with the present study, also reported a significant but small relationship between perceived stress and HRV in IT workers, suggested that the association strength diminishes in real-life settings in the absence of specific and isolated stressors. This type of situation prevailed by design in our experiment before the bear sighting as an uncontrolled-for event. We can only speculate that the incident could have an impact on Δ HRV and the proportion of cases with positive HRV change via anxiety and the demand on sustained attention in the forest group members who eventually learnt about it by word of mouth. The demand on sustained attention was shown to have an overriding effect on HRV decrement (Luque-Casado et al., 2016).

4.3 Interdisciplinary novelty

By linking the FES framework with the attention restoration and stress reduction theories, the presented study filled the existing knowledge gap by providing evidence for a meaningful effect of the exposure to forests on the cognitive function and stress level in older adults. Thus far, positive effects of forest walks on some cognitive outcomes and the state of anxiety were observed in studies involving younger people and students (Shin et al., 2011; de Brito et al., 2020). In addition, connecting the biophysical foundation of FES with stress reduction theory elucidated the role of air temperature as the modulator of the relationship between HRV and environment. Our results indicate that the association between perceived stress reduction and forest settings with lower temperatures and higher relative humidity postulated by Park et al. (2011) may dissolve under forest canopy when air temperature drops below 10°C. Overall, the obtained results highlight the need for differentiated FES management and planning according to specific target group (such as older adults in this study), the likelihood of obtaining desired intervention effects on specific mental health characteristics, and the public health priorities, e.g., societally and individually affordable healthy aging.

4.4 Study limitations

The nature of the forest intervention meant that the study was exposed to external factors that could not be controlled for, such as weather or the possible presence of potentially dangerous wildlife. In the Slovak context, between 2000 and 2015, there were 54 cases of brown bear attacks on humans (Bombieri et al., 2019). Next, the use of PPG sensors embedded in commercial wearable devices entailed lesser accuracy and precision relative to dedicated but less comfortable and more intrusive wearable devices relying on chest strap HR readings. Easy-to-use features are especially important in outdoor settings (Byrom et al., 2018; Gradl et al., 2019).

4.5 Implication for further research, forest management, and public health policy

Further research should focus on analysing patterns of HRV change throughout interventions to capture the potential influence of other modulators and conditioning factors. Also, the optimum intervention length required for the restoration of the cognitive and the autonomous nervous system functions warrants further investigation. Recently, White et al. (2019) postulated that spending at least 120 min per week in contact with nature is associated with well-being and good health. The longer minimum time in the latter study may reflect a broader definition of the natural environment, including city parks and farmland. Importantly, the presented study suggests that forest conservation and management should promote the availability of elements enhancing complexity and fractal dimension of forest scenes, mainly the presence of old trees, to achieve positive effect on the cognitive function as a health-related forest ecosystems service for older adults of the paramount importance.

5 Conclusion

The presented study showed that walking and viewing in forest settings offering structurally rich elements can significantly improve the cognitive function and, to a lesser degree, elicit higher heart rate variability as a parasympathetic activity marker in older adults. The lack of association between urban walking and improved cognitive function and comparatively smaller effect on HRV change suggest that forest walking should be preferred to urban walking by older adults, when possible. The implications of this study for public health and the management of forests and their ecosystem services underscore that policies promoting access to forests, particularly during pandemics or analogous events, can support cognitive function and mental health of older adults as a vulnerable group. However, public health and forest management experts need to develop and implement scalable frameworks integrating selection, designing, and servicing suitable forest restorative areas, with a particular emphasis on older adults' needs, mainly safety and accessibility.

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 humans were approved by the Independent Ethical Committee of the Banska Bystrica Self-Governing Region (BBSK) for Biomedical Research, registration No. 37828100. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

KL: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. MP: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Visualization, Writing – review & editing. JH: Conceptualization, Writing – review & editing, Methodology. MK: Conceptualization, Methodology, Writing – review & editing. DT: Methodology, Writing – review & editing, Investigation. DJ: Methodology, Writing – review & editing, Conceptualization. VP: Conceptualization, Writing – review & editing, Supervision.

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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

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/ffgc.2024.1287266/full#supplementary-material

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