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Conditions of distance learning and teaching and their relation to elementary school children's basic number skills after the suspension of face-to-face teaching during the COVID-19 pandemic

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The suspension of face-to-face teaching, due to the COVID-19 social distancing regulations, raised serious concerns about the impacts on children's academic learning. Because the implementation of distance education in Germany was entirely the responsibility of individual schools, and because the home learning environments varied across households, school children had very different learning conditions during the pandemic. This fact raises questions whether the conditions of distance learning has impacted children's development of basic number skills. In this paper, descriptive information on children's home learning conditions and teachers' distance teaching approaches during the pandemic, socio-cultural capital, and basic number skills of 484 third and fourth grade students (51.2% girls) in the state of North Rhine-Westphalia (Germany) are assessed. The data revealed risk factors such as not having a tablet/laptop, lack of access to the internet, or a learning environment with siblings without an adult family member present. A negative association was found between multiple risk factors (at-risk levels) in home learning and basic number skills. This link was partially mediated by socio-cultural capital and moderated by teachers' distance teaching approach. Children whose teachers applied a more personalized teaching approach showed fewer negative relations between at-risk levels and basic number skills. While no evidence was observed for positive effects of videoconferencing, school-based emergency classes, or private tutoring on basic number skills, children whose learning was supported by learning management systems showed better skills than their peers. The findings highlight the differential impact of home-based learning conditions during the pandemic and provide practical implications for realization of distance teaching.

KEYWORDS

COVID- 19, math achievement, distance learning, learning loss, primary education, home-learning environment, e-learning

1. Introduction

The coronavirus disease (COVID-19) has led to more than one hundred million infected humans and millions of deaths worldwide (John Hopkins University, 2022). Confronted with these huge impacts on public health, most governments have implemented social distancing regulations and lockdown measures to reduce the spread of COVID-19. Consequently, more than 90% of the children worldwide were affected by temporary school closures during the pandemic (UNESCO, 2022). Although it is still unclear how the suspension of face-to-face teaching in schools impacted children's academic skills and achievement in detail, research raises serious concerns about its social, economic, and public health consequences for society (Kuhfeld et al., 2020; Lee, 2020; Engzell et al., 2021; Psacharopoulos et al., 2021; Raw et al., 2021; Waite et al., 2021; Blaskó et al., 2022; Ravens-Sieberer et al., 2022).

In March 2020, school closures in many places were implemented within days and schools had to shift their traditional classroom face-to-face teaching to distance teaching approaches (Fickermann and Edelstein, 2020). For a year and a half, the German school system was predominantly characterized by distance teaching (Ministerium für Schule und Bildung des Landes Nordrhein-Westfalen, 2022). The implementation of distance teaching was under the full responsibility of each individual school. German schools were very different in their readiness to implement distance learning. Likewise, the home learning conditions varied widely across households (e.g., in terms of learning resource, parental learning support, and home learning environment). These together lead to a situation that there were great variations in German children's learning conditions during the COVID-19 pandemic (Fickermann and Edelstein, 2020; Huber et al., 2020; Huber and Helm, 2020; Porsch and Porsch, 2020; Helm et al., 2021; Steinmayr et al., 2021).

Initial studies indicate great learning gaps compared to typical school years, which could lead to a reduction in global economic growth and a lifetime decrease in individual' earnings (Engzell et al., 2021; Hammerstein et al., 2021; Psacharopoulos et al., 2021; König and Frey, 2022). Current estimates predict severe socio-economic consequences, especially for low- and middle-income families (Bonal and González, 2020). In particular, students from low-income families seem to have pronounced learning losses and did not experience marked home-based learning opportunities (Engzell et al., 2021; Goudeau et al., 2021). A recent large-scale study showed that the learning losses have been especially marked in mathematics (van der Berg et al., 2022).

To the best of our knowledge, the interrelationships between distance learning and teaching conditions during the pandemic and performance-based outcomes in math have not yet been studied. Until now, the variables were mostly examined in separate research designs and the studies on the relation between distance learning conditions and academic outcomes were measured through observer-ratings by parents, teachers or self-ratings by students (Huber and Helm, 2020; Helm et al., 2021; Steinmayr et al., 2021). Considering this scarcity of research about the impacts of distance education during the COVID-19 pandemic on children's basic numeracy skills, the necessity for further research to examine this interaction becomes clear.

The suspension of face-to-face learning due to the COVID-19 pandemic has significantly changed children's mathematics learning in schools. This fact raises questions whether the switch to distance learning has impacted children's basic number skills. To date, it is unclear whether there are associations between risk factors in the home and digital learning environments during the suspension of face-to-face teaching and primary school children's basic number skills at the time of returning to face-to-face teaching. Furthermore, it is not known whether distance teaching approaches had an impact on math learning of at-risk children. By examining the interplay between home-based learning environments, distance teaching conditions and basic math skills, the present project will address this gap in educational research.

1.1. Basic mathematical skills and distance learning in Germany

The school subject of mathematics is considered as crucial for educational attainment and professional success (Parsons and Bynner, 2005; Ritchie and Bates, 2013). Basic math skills remain a matter of outstanding importance throughout one's entire life span, not only for mastering social, practical and professional life, but also for individuals' health and well-being. Large cohort surveys provided evidence that adults with lower basic math skills have higher risks of being unemployed and of developing mental or physically health problems (Parsons and Bynner, 2005; Ritchie and Bates, 2013; Aro et al., 2019). Considering these consequences, it is alarming to note that – already before the COVID-19 pandemic – 24% of the 15-year-old students from OECD countries (Germany 21%) and more than 50% of the 15-year-old students in 24 participating countries of the international comparative study of education PISA 2018 (OECD, 2019a) did not attain the baseline math proficiency level 2. Children who did not attain level 2 cannot interpret and recognize, in what way a simple situation can be represented mathematically (e.g., distance comparison between two routes). Already at the end of primary school many children show clear weaknesses. According to TIMSS 2019 (Schwippert et al., 2020), about 37% of all children worldwide (Germany 28%) have only rudimentary mathematical knowledge.

In light of the COVID-19 pandemic, the face-to-face teaching in German schools was suspended within a few days in spring 2020 (Fickermann and Edelstein, 2020; Ministerium für Schule und Bildung des Landes Nordrhein-Westfalen, 2022). The ministries of education in Germany assigned the implementation and realization of distance education to the schools, which had to change their traditional classroom teaching to distance learning without any preparation time (Fickermann and Edelstein, 2020). This fundamental shift in teaching posed major challenges to teachers and schools, as most German schools do not have the digital infrastructure and most teachers do not have the media skills to offer digital learning environments for their students (Eickelmann and Gerick, 2020; Huber et al., 2020). These conditions in Germany's educational system led to very different approaches to distance teaching, varying by class and school (Huber and Helm, 2020; Steinmayr et al., 2021). While some children were able to learn with learning management systems (LMS), videoconferencing or interactive webinars other children did only receive worksheets without any feedback by their teachers (Porsch and Porsch, 2020). In general, recent findings suggest that technology-enhanced personalized learning can lead to better learning outcomes, higher motivation to learn, and more positive student perceptions of learning (Major et al., 2021; Zheng et al., 2022) when educational technologies are used effectively (Cheung and Slavin, 2013; Delgado et al., 2015; Tondeur et al., 2017). Given the positive effects for personalized learning (Zhang et al., 2020) and feedback (Wisniewski et al., 2020) that have been known for decades in traditional classrooms settings, more complex models of personalized feedback are now being integrated into digital learning systems (Vasilyeva et al., 2007). At the present time, it is not yet possible to make

sufficient findings on their effectiveness, as the application of these technologies is still in its infancy (Shemshack and Spector, 2020). Nonetheless, there are many benefits associated with these applications, so a digital approach to mathematics education that taken into account learners' individual needs, goals, and abilities is gaining more attention in today's educational discussions (FitzGerald et al., 2018; Van Schoors et al., 2021).

Besides of the varying conditions in distance teaching during the pandemic, the suspension of face-to-face classes changed the role of parents in children's learning environment at home (Thorell et al., 2022). Especially, in elementary school the distance teaching required learning support by parents, which they perceived as stressful and challenging (Wildemann and Hosenfeld, 2020; Jungmann et al., 2021; Canales-Romero and Hachfeld, 2022). Moreover, the shift from face-to-face teaching to distance learning at home, highlighted the role of technical equipment and learning conditions at home (Huber and Helm, 2020; Helm et al., 2021). Surveys show differences in the availability of digital devices, internet access, learning materials and learning workplaces in households (Helm et al., 2021). Some of these variables (e.g., quality of digital conditions at home) seem to be affected by the socioeconomical background of the families (Helm et al., 2021). Children with more resources appear to have had a better quality of digital conditions at home. Based on the findings presented above, the conditions for distance teaching and learning during the COVID-19 pandemic were very different for children in Germany.

Until now, the consequences of distance learning on academic outcomes in Germany were only investigated with observer-ratings by parents, teachers or self-ratings by students and did not differentiate between home learning conditions or distance teaching approaches (Huber and Helm, 2020; Helm et al., 2021; Steinmayr et al., 2021). Here, very divergent results were found for self-ratings of learning success by students, while the observer-ratings by parents and teachers indicated concerns that students will not meet the regular school curricula. However, also the observer ratings showed inconsistent findings (Helm et al., 2021), which raises doubts about the validity of instruments.

In the federal state of North Rhine-Westphalia the suspension of face-to-face teaching began in March 2020 and lasted to summer vacations 2020. The school year 2020/21 began with face-to-face teaching, but before Christmas 2020, there was a switch back to distance learning until summer 2021. After the summer holiday 2021, children returned to their classes and received regular face-to-face teaching again. In total, of possible 53 school weeks since the suspension of face-to-face teaching, children in North Rhine-Westphalia formally received 21 weeks of regular face-to-face instruction in the classroom (Ministerium für Schule und Bildung des Landes Nordrhein-Westfalen, 2022).

1.2. Research questions in the present study

The COVID-19 pandemic has profoundly changed the daily social lives and school learning of primary school students. These changes raise questions about the extent to which the conditions of distance learning (e.g., technical conditions at home, learning support, learning environment at home) and teaching (e.g., use of digital learning tools, personalized teaching approaches, emergency classes at school) impacted children's math learning outcomes. First studies point to general learning gaps compared to typical school years. However, more nuanced results are needed to determine whether different risk factors in home-based learning influenced the development of basic numeracy skills and how teaching approaches in distance education affected children's learning. Until now, it has been unclear whether there are logical relationships between these variables, as they have been studied in separate research designs. To our knowledge, no study to date has examined this relationship between risk factors in home-based learning, distance teaching approaches and math achievement.

The present study collected descriptive information about the distance learning and distance teaching during the COVID-19 pandemic and evaluated children's basic number skills after the suspension of face-to-face teaching in fall 2021. The aim of this study is to identify risk factors of home-based learning and to examine the extent to which multiple risk factors have affected the development of basic number skills during the pandemic. If such a relationship can be observed, the study will analyze whether this relationship can be explained by sociocultural background alone, and further will examine whether instructional offerings for students and a personalized teaching approach have influenced this relationship.

The research questions of the present study are as follows:

1. To what extent did home learning conditions during distance learning differ as a function of sociocultural background?
2. To what extent did basic number skills after the suspension of face-to-face teaching differ as a function of home learning conditions?
3. To what extent did multiple risk factors (at-risk level) during home-based learning relate to basic number skills after the suspension of face-to-face teaching?
4. Is the potential relation between children's risk level and basic number skills mediated by the sociocultural background?
5. In what way did teaching approaches, participation in school-based emergency classes, and private tutoring programs relate to basis number skills after the suspension of face-to-face teaching?
6. Is the potential relation between children's risk level and basic number skills moderated by teachers' use of personalized teaching approaches?

2. Materials and methods

2.1. Participants

The study described formed part of a wider research project on the interplay of mental health and math achievement (MeHeMa-project), which is a longitudinal project in Brazil, Finland, and Germany. In this report, the cross-sectional data of the 1st measurement period of the MeHeMa-project from North Rhine-Westphalia (Germany) are presented.

This sample consisted of 484 elementary school students of third and fourth grade (51.2% girls; 111.92 ± 9.2 months old). One entire class within one school was assessed and except for one school, the classes of the entire grades participated in the survey. Six students with intellectual disabilities, disorders affecting communication and language comprehension problems were not included into the final sample. All students attended regular comprehensive schools in the state of North Rhine-Westphalia, Germany. To ensure that the sample reflected the sociodemographic characteristics of North Rhine-Westphalia, elementary schools with different school social indices (Parsons and

Bynner, 2005; Ritchie and Bates, 2013) were recruited (Table 1). The study was approved by the Institutional Review Board of Instituto De Psicologia Da Universidade Federal Do Rio Grande Do Sul.

2.2. Procedure

In-class assessments were conducted by grad students during the first 3 weeks after the school summer break (autumn 2021). Grad students were trained 1 week prior to the survey on how to administer the in-class assessment. A standardized instruction guide was used for the survey so that all classes had a comparable testing situation. The children were guided through the test situation by the test administrators in front of the whole class. Each questionnaire was explained with examples and the children had sufficient time to answer the questions. Care was taken to ensure that the children did not discuss the questionnaires, copy from each other, or read their classmates' answers. Children could ask comprehension questions at any time (except in the math test), which were answered for all children in front of the class. Data collection was conducted in 1 day in a session of 1 to 2 h and included several instruments that also considering mental health variables. At first, students filled out a questionnaire about their distance learning during the covid-pandemic and completed one mental health questionnaire. Afterwards math achievement was measured by the basic number skill test. Finally, the participants responded to another mental health questionnaire. In addition, a questionnaire for math teachers was used to assess the design of the distance education program in mathematics. In North Rhine-Westphalia, university education for the teaching profession at elementary schools includes the compulsory subjects German and mathematics. For this reason, teaching in elementary school classes is predominantly done by one teacher (the class teacher). Only minor subjects are taught by other teachers (Ministerium für Schule und Bildung des Landes Nordrhein-Westfalen, 2020, 2023).

2.3. Materials

2.3.1. Distance learning

A self-developed questionnaire for children was used to assess the general conditions of distance learning at home. Children indicated whether they had a digital device at home (no device, smartphone, tablet/laptop) and whether they have access to the internet. Another question was about learning support. Children indicated whether they had direct support by a parent or another adult family member at home (yes/no) and whether they went to private tutoring. Furthermore, children descriptively indicated the learning environment in which they studied during distance learning (alone in a room, with siblings but without parents in a room, with siblings and parents in a room, alone with parents) and whether they used the emergency care classes offered by the school (learning groups of children, who could not stay at home and were supervised by different professions at school).

2.3.2. Multiple risk factors at home-based learning

To examine the influences of multiple risk factors at home during distance learning, statistical analyses were calculated using different levels of risk scores. Based on theoretical models (Helm et al., 2021), a risk point was assigned for each of the following criteria: no availability of a tablet or laptop for distance learning (1 risk point); no access to the internet (1 risk point); no support from a parent or another adult family member during distance learning (1 risk point); distance learning in a room with siblings but without parents (1 risk point). Thus, this computed variable has a range from 0 to 4 risk points.

2.3.3. Digital learning environments

A self-developed questionnaire for math teachers was applied to measure the conditions of distance teaching. To capture the digital learning environment used, teachers were asked to indicate whether they used an e-learning platform/learning management system (LMS) to organize the learning material, whether they used digital communication with their students (chats/instant messaging), or how often they held math classes *via* video conferencing during the suspension of face-to-face teaching.

2.3.4. Personalized teaching approaches

In the teacher questionnaire, math teachers were asked to indicate whether they used a personalized teaching approach during the suspension of face-to-face teaching (always/often or rarely/never). The total score was calculated based on following 3 items: children received always/often individual weekly plans with tasks that were oriented to their individual performance level (1 point); children received always/often individual feedback on tasks (1 point); the parents received always/often individual feedback (1 point). Thus, this computed variable has a range from 0 to 3 points. The reliability (internal consistency) of the scale is $\alpha = 0.70$. The questionnaire builds on the first dimension of Stebler et al. (2018) theoretical model of personalized learning, which describes an instructional approach that adapts instructional opportunities to learners' abilities and needs. To provide an economical measure, the questionnaire was designed and tested with the help of elementary school teachers who did not participate in the study.

2.3.5. Basic number skills

Basic number skills were measured with the Lost in Math test (LoMa: Ehlert et al., 2022), which assesses math abilities in the domains of the part-part-whole concept (8 items), multiplication/division (8 items), and understanding of the place value system (10 items). The test situation had no time pressure, and the inventory was designed to assess basic skills that children should have developed before entering secondary school in accordance with the national curriculum for

TABLE 1 Sample composition and school social index.

School social index	1	2	3	4	5	6	7	8	9
Proportion of schools in North Rhine-Westphalia	23.7%	30.3%	19.5%	11.1%	6.4%	5.3%	2.6%	0.5%	0.1%
Number of schools in the sample	–	2	2	1	1	–	1	–	–
Proportion of students in the sample	–	25.0%	33.3%	15.7%	5.6%	–	20.5%	–	–

The school social index indicates the support needs of schools on a scale from 1 (low support needs) to 9 (high support needs). For more information, see section "Socio-cultural capital".

Germany. The total raw score was calculated as the sum of all correct item responses. All raw scores were converted to *z*-scores based on the present sample distribution for each grade. The reliability (internal consistency) of the basic number skill test is $\alpha = 0.87$.

2.3.6. Socio-cultural capital

Socio-cultural capital was assessed using three different variables. At the school level, the official school social index (Schräpler and Jeworutzki, 2021) was used, which measures the support needs of schools on a scale from 1 (low support needs) to 9 (high support needs). The school social index captures the social composition of a school's student body in North Rhine-Westphalia on the basis of four indicators: child and youth poverty, proportion of children with a non-German family language, proportion of children with their own migration background, proportion of children with the special needs areas of learning, emotional and social development, and language. At the individual level, the home possessions of books and the home possession of an own room and own desk was applied. Children indicate whether they have their own room and desk at home (yes/no) and how many books their family has at home (5-point Likert-type scale with pictures of a bookshelf: 0 = none or very few; 1 = enough to fill one shelf board; 2 = enough to fill one complete shelf; 3 = enough to fill three shelves; 4 = more than 200 books). The possessions of books at home and educational resources such as a desk for studying is a widely used and economical indix to capture socio-cultural capital (Schwippert, 2019; Avvisati, 2020; Eriksson et al., 2021).

2.4. Data analysis

All statistical analyses were performed using IBM SPSS Statistics (Version 27). To investigate differences between groups, one-way analysis of variance (ANOVA) was performed and evaluated using η^2 or Chi-square test of independence was used and evaluated using Cramers *V*. According to (Cohen, 1988), values of $\eta^2 \geq 0.01$ were interpreted as a small, $\eta^2 \geq 0.06$ a medium and $\eta^2 \geq 0.14$ a large effect size and values of $V \geq 0.1$ were interpreted as a small, $V \geq 0.3$ a medium and $V \geq 0.5$ a large effect size To examine relations between variables, Pearson's correlation analyses were used. In line with Cohen (1988) correlation values of $r \geq 0.1$ were considered small, $r \geq 0.3$ medium and $r \geq 0.5$ large. Mediation models (model 4) and a moderation model (model 1) were calculated by means of the PROCESS macro to analyze whether there were mediation or moderation effects between the variables (Hayes, 2013). In accordance with Cohen, 1994), an alpha level of 0.05 was used in this study.

3. Results

3.1. Home learning conditions and their relation to sociocultural background and basic number skills

Descriptive statistics (relative frequencies, test of independence) for home learning conditions during distance learning are reported in Table 2. Chi-square tests of independence indicated interactions between technical conditions at home and socio-cultural capital. Children with fewer family resources were less likely to have a tablet/laptop at home or have access to the internet. While there were no interactions between learning supports and socio-cultural capital, the learning environment at home differs with respect to family resources. Children with fewer family resources were more likely to learn with siblings but without a parent in a room.

In Table 2 and Figure 1, basic number skills are compared across home learning conditions. The one-way ANOVA reveals differences in math proficiency between technical conditions and the learning environments at home. Tukey post-hoc analyses demonstrated that children, who learned in one room with siblings but without an adult, had significantly lower basic number skills than their peers ($p < 0.001$ to $p = 0.008$). While no difference in basic numeracy skills were found among children who received learning support from parents (or another adult family member) at different frequencies, differences in math skills were observed with respect to availability of technology at home. Children without internet access performed weaker in the basic number skill test than their peers. Furthermore, children, who were able to use a tablet/laptop during distance learning performed significant better in basic number skills than children, who had no technical device ($p = 0.003$) or only a smartphone at home ($p = 0.038$).

3.2. Multiple risk factors and their relation to basic number skills

To investigate the impact of multiple risk factors during distance learning on basic number skills, different levels of risk factors were calculated on basis of the unavailability of conducive conditions during home-based learning. Descriptive statistics are reported in Table 3. Approximately 47% of the students in this sample had at least one risk point and about 12% had two or more risk points. Chi-square tests of independence and ANOVA indicated interactions between the number of risk points and socio-cultural capital. Children with fewer family resources were more likely to have multiple risks for distance learning at home.

The presence of multiple risk factors was associated with lower basic number skills. One-way ANOVA showed a significant difference in basic math skills between different numbers of risk points. Boxplots of basic number skills among different numbers of risk points are presented in Figure 2. In addition, basic number skills correlated negatively with higher risk levels during home-based learning ($r(478) = -0.203$; $p < 0.001$).

To analyze whether the link between risk levels and basic number skills is mediated by socio-cultural capital, a mediation model (model 4) was applied by means of the PROCESS macro (Hayes, 2022) (see Figure 3). The direct effect of risk levels on basic number skills was significant (BTOTAL = −0.258, SE = 0.059, $p < 0.001$, 95%CI: −0.38; −0.14; BDIRECT = −0.224, SE = 0.059, $p < 0.001$, 95%CI: −0.34; −0.11), when the mediator HOMEPOS (books) was added to the model. There was also significant indirect effect of risk level on basic number skills through HOMEPOS (books) (BINDIRECT = −0.034, SE = 0.013, 95%CI: −0.063; −0.012). Similar results were found, when the mediator school social index was added to the model (BTOTAL = −0.268, SE = 0.059, $p < 0.001$, 95%CI: −0.38; −0.15; BDIRECT = −0.213, SE = 0.059, $p < 0.001$, 95%CI: −0.33; −0.10; BINDIRECT = −0.056, SE = 0.018, 95%CI: −0.093; −0.025). Thus, the relationship between risk level and basic number skills is only partially mediated by socio-cultural capital.

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TABLE 2 Home learning conditions during the suspension of face-to-face learning and their relation to social-cultural capital and basic number skills.

			Socio-cultural capital			Basic math skills	
		Percentage of students % (*n*)	HOMEPOS (books)	HOMEPOS (room/desk)	School social index	Standardized *z*-scores	ANOVA
						M (SD)	
Technical conditions at home							
Item 1	No Device	7.6% (37)	**χ^2 (8) = 25.032, p = 0.002; Cramer's V = 0.161**	**χ^2 (2) = 14.791, p = 0.001; Cramer's V = 0.175**	**χ^2 (8) = 28.775, p < 0.001; Cramer's V = 0.172**	−0.48 (0.86)	**F(2, 481) = 7.787; p < 0.001;**
	Smartphone	11.0% (53)				−0.27 (0.98)	**η^2 = 0.031**
	Tablet/Laptop	81.4% (394)				0.08 (1.00)	
Item 2	Internet	87.6% (424)	χ^2(2) = 6.632, p = 0.157;	**χ^2(1) = 6.509, p = 0.011; Cramer's V = 0.116**	**χ^2(8) = 18.292, p = 0.001; Cramer's V = 0.194**	−0.37 (0.96)	**F(1, 482) = 9.628; p = 0.002;**
	No Internet	12.4% (60)				0.05 (0.99)	**η^2 = 0.020**
Learning support							
Item 3	Support by parents/another adult family member	83.8% (404)	χ^2(4) = 0.895, p = 0.925;	χ^2(1) = 0.028, p = 0.867;	χ^2(4) = 2.507, p = 0.643;	0.12 (1.05)	F(1, 480) = 1.207; p = 0.272;
	No support by parents/ another adult family member	16.2% (78)				−0.02 (0.99)	η^2 = 0.003
Learning environment							
Item 4	Alone in a room	25.9% (124)	**χ^2 (12) = 21.154, p = 0.048; Cramer's V = 0.122**	**χ^2 (3) = 11.172, p = 0.011; Cramer's V = 0.153**	**χ^2 (12) = 24.038, p = 0.020; Cramer's V = 0.129**	0.15 (1.05)	**F(3, 475) = 5.791; p = 0.001;**
	With siblings without an adult in a room	14.0% (67)				−0.44 (1.00)	**η^2 = 0.035**
	With siblings and parents in a room	18.0% (86)				0.10 (1.02)	
	Alone with parents in a room	42.2% (202)				0.00 (0.92)	

Significant values are printed in bold.

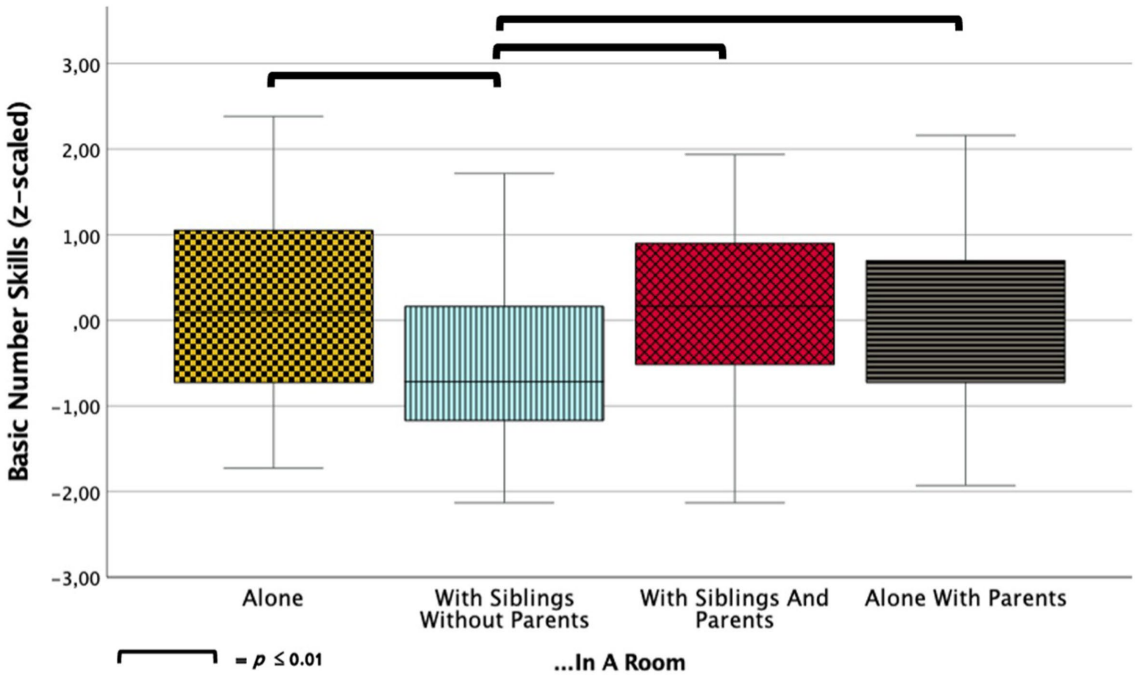

FIGURE 1
Box plots of basic number skills among learning environments at home.

TABLE 3 Descriptive data, test of independence and analysis of variance between risk points profiles.

	Risk points					Test of independence	ANOVA
	0	1	2	3	4		
Percentage of students % (*n*)	54.0% (258)	33.5% (160)	10.9% (52)	1.5% (7)	0.2% (1)		–
Basic number skills *M* (SD)	0.15 (0.94)	−0.08 (1.08)	−0.32 (0.83)	−1.05 (1.03)	−1.17		**$F(4, 473) = 5.484$; $p < 0.001$; $\eta^2 = 0.044$**
HOMEPOS (books)	2.25 (1.23)	1.99 (1.23)	1.75 (1.32)	1.57 (0.79)	2.00	$\chi^2(16) = 21.428$, $p = 0.163$; Cramer's $V = 0.106$	**$F(4, 469) = 3.349$; $p = 0.010$; $\eta^2 = 0.028$**
HOMEPOS (room/desk) *Dummy-coded*	0.59 (0.49)	0.44 (0.50)	0.38 (0.49)	0.00 (0.00)	0.00	**$\chi^2(4) = 20.741$, $p < 0.001$; Cramer's $V = 0.208$**	**$F(1, 476) = 19.418$; $p < 0.001$; $\eta^2 = 0.039$**
School social index	3.57 (1.71)	4.04 (1.86)	4.31 (1.74)	5.43 (2.07)	7.00	**$\chi^2(16) = 33.502$, $p = 0.006$; Cramer's $V = 0.132$**	**$F(4, 473) = 5.426$; $p < 0.001$; $\eta^2 = 0.044$**

Higher school social indices indicate higher support needs. Significant values are printed in bold.

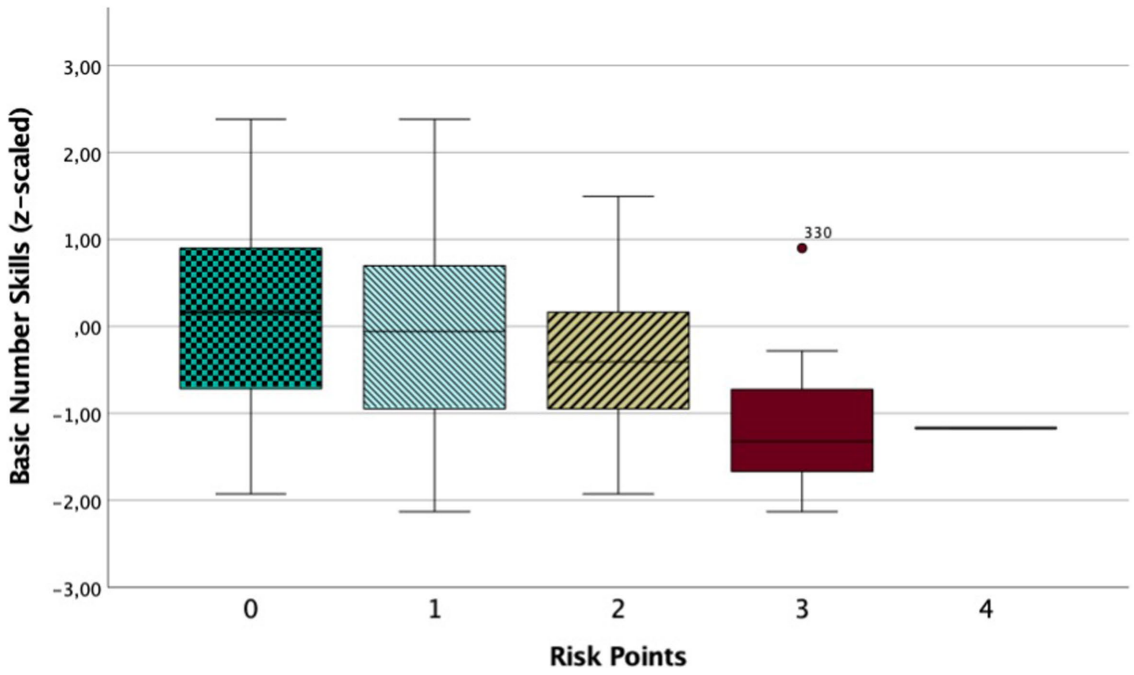

FIGURE 2
Box plots of basic number skills among different risk points.

3.3. Impact of distance teaching environments, approaches, and tutoring on the link between risk levels and basic number skills

To analyze whether private tutoring programs, school-based emergency classes or digital teaching approaches during distance learning promoted the development of basis number skills and counteract risk factors of home-based learning, several subgroup comparisons were made. Descriptive statistics (relative frequencies, means and standard deviation, ANOVA's) for private tutoring and school-based emergency classes are shown in Table 4. No differences could be found in basic number skills of children at different risk levels for participation in private tutoring programs or school-based emergency classes.

For the analysis of the impact of digital learning opportunities in distance teaching, the risk criterion "no access to the internet" was excluded. While there were no differences in basic number skills of children at different risk levels for the use of videoconferencing in math or the use of digital communication, group differences emerged for the use of LMS. Children of risk level 0 and 1 whose distance learning was supported by LMS showed better basic number skills compared to their peers.

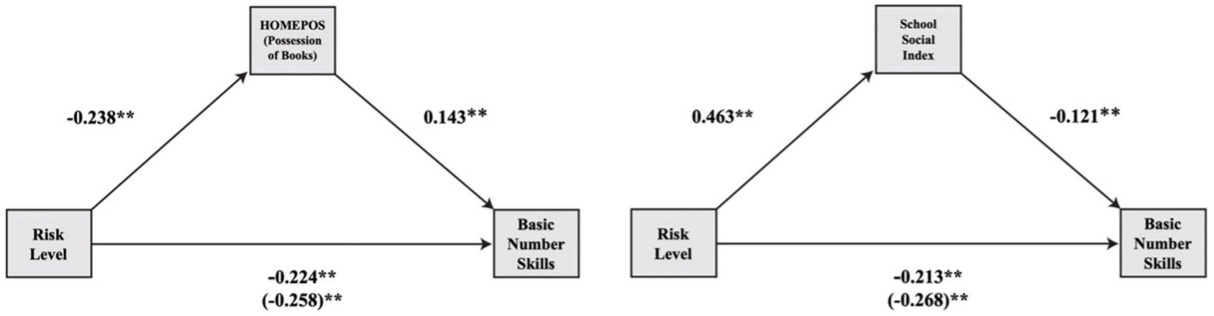

FIGURE 3
Mediation models (unstandardized coefficients are reported). **$p < 0.001$.

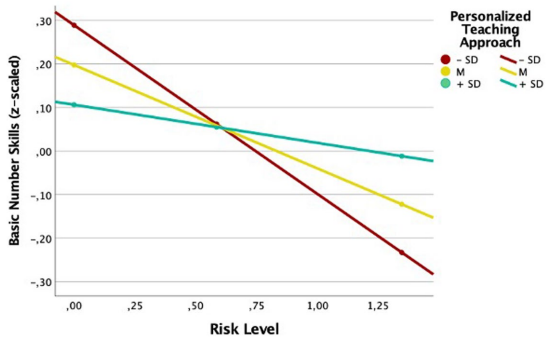

FIGURE 4
Moderation graphs risk level × personalized teaching approach (variables are plotted at 1 SD above and below *M*).

The use of a personalized teaching approach during distance teaching was not correlated with basic number skills ($r(404) = 0.007$; $p = 0.890$). A moderation analysis was conducted to examine whether the interaction between risk level and personalized teaching approach predicted basic number skills (Figure 4). Results show a moderation effect of personalized teaching approach on the link between students' risk level and their basis number skills ($\Delta R^2 = 1.38\%$, $F(1, 395) = 5.74$, $p = 0.017$, 95% CI[0.037, 0.220]). Children whose teachers applied a more personalized teaching approach showed fewer negative associations between risk level and basic number skills.

4. Discussion

The suspension of face-to-face teaching during the COVID-19 pandemic changed greatly the learning environment of elementary school children and posed major challenges to teachers and parents (Fickermann and Edelstein, 2020; Jungmann et al., 2021). Because of different approaches to implementing distance teaching in schools and varying home learning conditions across household, children in Germany had very different learning conditions during the pandemic (Helm et al., 2021; Steinmayr et al., 2021). This fact raises the question of whether these conditions have affected the development of children's basic number skills. Therefore, the aim of this study was to identify risk factors of home-based learning and to examine whether multiple risk factors were related to basic number skills after the suspension of face-to-face teaching.

The data provide first empirical evidence that certain conditions during distance learning were associated with weaker basic math skills after the interruption of face-to-face teaching. The absence of a laptop or internet at home can be considered as risk factors for children's basic number skills. Logically, these children were less likely to participate in digital learning opportunities offered by their teachers or to take up digital learning opportunities on their own initiative. Another risk factor was identified in the learning environment at home. Children who were learning in a room with other children and without adult guidance showed clear deficits in their basic number skills. Since most elementary school children are not yet able to manage self-regulated learning processes in a group setting without adult guidance (Stoeger and Ziegler, 2011; Godwin et al., 2016), it is very likely that these children more often engage in non-task behavior compared to peers who have been supported by an adult. Interestingly, children who learned alone did not show poorer math skills. One explanation for this could be that this group consists of rather high-achieving children who are trusted by their parents to learn on their own. Analyses of the influence of multiple risk factors (at-risk levels) showed a negative association with basic number skills. Children affected by multiple risk factors during distance learning – which applied to 12% of children – were more likely to have deficits in their basic number skills. The more risk factors were present, the worse basic skills were observed after the interruption of face-to-face teaching. However, the question arose as to whether these differences were due solely to socioeconomic resources and thus may have existed prior to the pandemic.

Consistently with previous research (Helm et al., 2021), the data revealed that some of these risk factors were related to the sociocultural background. Children from families with more resources were more likely to have the digital prerequisites to participate in digital learning opportunities and were less likely to learn in non-conducive learning environments at home (without adult guidance, but with siblings or friends). In light of the predictive value of socioeconomic status on the development of children's math skills (Sirin, 2005; Lee et al., 2016) and the particularly large differences in math performance according to social background in Germany (compared to OECD average: OECD, 2019b), the question arises whether the observed risk factors and their influences on basic skills were not confounded by sociocultural background. Mediation analysis provided evidence that the link between risk levels and basic math skills was only partially mediated by sociocultural capital. Accordingly, although the influence of risk factors on basic math skills could be partially explained by differences in sociocultural capital, there was also a direct impact of risk factors on mathematical skills after the interruption of face-to-face teaching. It therefore appears that the differences are not due to socioeconomic factors alone, but that specific conditions of distance education are responsible for individual differences in basic mathematical skills.

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TABLE 4 Link between risk factors and basic number skills as a function of private tutoring and emergency classes at school.

	Percentage of students % (*n*)	Risk factors					
		0	1	2	3	4	At least 1 risk factor
Tutoring							
Private tutoring	21.4% (97)	−0.03 (1.0)	−0.12 (0.9)	−0.48 (0.9)	−0.23 (0.3)	–	−0.32 (1.0)
No private tutoring	87.6% (356)	0.23 (0.9)	−0.04 (1.1)	−0.31 (0.8)	−1.82 (1.1)	–	−0.11 (1.0)
ANOVA		$F(1, 242) = 5.484$; $p = 0.062$	$F(1, 148) = 0.118$; $p = 0.732$	$F(1, 47) = 0.298$; $p = 0.588$	$F(1, 4) = 5.780$; $p = 0.074$	–	$F(1, 203) = 1.355$; $p = 0.246$
Emergency classes at school							
Attendance at emergency classes	14.7% (71)	0.16 (0.9)	−0.04 (1.2)	−0.38 (0.9)	–	–	−0.13 (1.1)
No attendance at emergency classes	84.9% (411)	0.15 (1.0)	−0.09 (1.1)	−0.31 (0.8)	–	–	−0.18 (1.0)
ANOVA		$F(1, 256) = 0.004$; $p = 0.950$	$F(1, 158) = 0.052$; $p = 0.820$	$F(1, 50) = 0.052$; $p = 0.821$	–	–	$F(1, 218) = 0.072$; $p = 0.789$

Basic number skills are reported as *M* (SD). Significant values are printed in bold.

TABLE 5 Link between risk factors and basic number skills as a function of digital learning environments.

	Percentage of students % (*n*)	Risk factors				
		0	1	2	3	At least 1 risk factor
Learning management system						
E-learning platform/LMS	70.7% (342)	0.22 (0.9)	0.18 (1.0)	−0.50 (1.0)	–	−0.32 (1.0)
No E-learning platform/LMS	23.0% (102)	−0.28 (1.0)	−0.64 (0.8)	−0.67 (0.7)	–	−0.11 (1.0)
ANOVA		**$F(1, 261) = 12.573$; $p < 0.001$; $\eta^2 = 0.046$**	**$F(1, 142) = 18.456$; $p < 0.001$; $\eta^2 = 0.115$**	$F(1, 29) = 0.232$; $p = 0.633$	-	**$F(1, 174) = 16.607$; $p < 0.001$; $\eta^2 = 0.087$**
Digital communication						
Always or often digital communication with students	72.7% (323)	0.12 (1.0)	0.02 (1.0)	−0.72 (0.8)	–	−0.11 (1.0)
Rarely or no digital communication with students	27.3% (121)	0.10 (1.0)	−0.14 (1.1)	−0.13 (0.9)	–	−0.14 (1.0)
ANOVA		$F(1, 261) = 0.017$; $p = 0.896$	$F(1, 142) = 0.657$; $p = 0.419$	$F(1, 29) = 2.991$; $p = 0.094$		$F(1, 174) = 0.017$; $p = 0.876$
Number of video conferences with class						
Less than 1 h per week	33.6% (144)	0.10 (1.0)	−0.11 (1.0)	−0.46 (0.8)	–	−0.18 (1.0)
1 to 2 h per week	32.9% (141)	0.04 (0.9)	−0.10 (1.0)	−0.45 (0.9)	–	−0.18 (1.0)
More than 2 h per week	33.4% (143)	0.14 (1.0)	0.02 (1.1)	−0.73 (1.0)	–	−0.12 (1.1)
ANOVA		$F(1, 249) = 0.231$; $p = 0.794$	$F(1, 136) = 0.237$; $p = 0.789$	$F(1, 28) = 0.341$; $p = 0.714$	–	$F(1, 168) = 0.066$; $p = 0.936$

Basic number skills are reported as *M* (SD); risk criterion "no access to internet" was excluded for this analysis; significant values are printed in bold.

Based on the findings on the negative impact of risk factors on basic numeracy skills, the question was whether specific teaching or tutoring services during the pandemic were able to reduce these negative repercussions. At the beginning of the pandemic, elementary schools in Germany were asked to take children from families whose parents worked in critical infrastructure into emergency care classes. These classes were taught by teachers or other educational professionals (e.g., social worker) and the children often did not attend these classes consistently (Fickermann and Edelstein, 2020; Blum and Dobrotić, 2021; Ministerium für Schule und Bildung des Landes Nordrhein-Westfalen, 2022). The data provided no evidence that children who participated in these classes showed different math skills after the interruption of face-to-face teaching. Similar results were observed for private tutoring. These services do not appear to have been able to reduce the negative effects of risk factors in home-based learning. One could hypothesize that due to the varying frequency of participation as wells as the different didactic concepts and qualities, the assumed benefits of face-to-face settings did not materialize.

Although information and communications technology (ICT) has been considered important for improving the quality of math teaching for several years, the implementation of digital technologies in German schools was not well advanced at the beginning of the pandemic (De

Witte and Rogge, 2014; Huber and Helm, 2020; Eickelmann and Drossel, 2020a). There was a lack of digital infrastructure and sufficient training for teachers in the use of digital media (Eickelmann et al., 2019; Schuknecht and Schleicher, 2020; Eickelmann and Drossel, 2020b). This limited experience led to significant difficulties in providing digital learning opportunities (e.g., video conferencing, LMS, video tutorials), especially shortly after the suspension of face-to-face teaching (Helm et al., 2021). To date, there are no empirical studies focusing math skills and digital learning environments during the pandemic in Germany. Only one study (Steinmayr et al., 2021) measured children's academic outcomes (learning progress) and activities of teachers by means of parent ratings. Using this indirect assessment method, an association was found between teaching *via* videoconferencing and learning progress. The data from the present study provide no evidence of a positive effect of videoconferencing or digital communication between students and teachers. These findings could be explained by the likely low teaching quality of videoconferencing, possibly due the lack of teacher training (Eickelmann et al., 2019). It could be assumed that a more frontal class teaching approach *via* videoconferencing – a logical adaption of traditional teaching methods given the low digital literacy of teachers – might be difficult for primary school children. However, for these conclusions, differentiated methods are needed that can capture the teaching design of videoconferencing.

Online learning methods are likely to increase in use, even where school learning is not currently disrupted, and may be useful both in conjunction with face-to-face instruction, and where necessary as a substitute for it. Spitzer and Musslick (2021) found quite positive results for German pupils from a curriculum-based online learning software for mathematics. This had been in place before the school closures of 2020 but was used more during these closures. Pupils showed better performance on this mathematical software during the school closures than the previous year; and there appeared to be some narrowing of the gap in performance between low- and high-achieving students. However, it must be noted that children, who experience the risk factors discussed here, and especially those who lack access to the internet, are not able to benefit fully from such software.

In this study, teachers indicated whether they used LMS to organize learning material for their students. The results showed a positive relationship between the use of LMS and basic math skills after the suspension of face-to-face teaching. Children appeared to benefit from a structured digital presentation of their learning material, which is consistent with studies that report a positive effect on student academic performance when digital learning programs are used to supplement classroom instruction (Skryabin et al., 2015; Comi et al., 2017; Hu et al., 2018; Laakso et al., 2018). Nevertheless, latest findings highlight that it is not so much the mere use of LMS that can be conducive for learning, but rather the specific design of digital learning opportunities by teachers (De Witte and Rogge, 2014; Mergoni et al., 2022). Consequently, further research is needed here that takes other teacher variables into account.

A key and, to our knowledge, unexplored question is whether a personalized teaching approach during distance teaching was able to counteract the negative repercussions for children with home-based risk factors during distance teaching. Personalized teaching is not clearly defined and functions as an umbrella term for didactic approaches that focus individualized student support (Stebler et al., 2018). Several meta-analyses highlighted the positive effect of feedback on student performance (Hattie and Timperley, 2007; Wisniewski et al., 2020) and a long research tradition focuses adaptive teaching concepts, in which teachers adjust their teaching approach to individual students learning (Hattie, 2009; Brühwiler and Blatchford, 2011; Hardy et al., 2011). In recent years, this personalized learning has been linked to digital media in educational research, and it has been found that it can have positive impacts on learning outcomes (Major et al., 2021; Zheng et al., 2022) when the technological applications are used effectively by the teaching staff (Cheung and Slavin, 2013; Delgado et al., 2015; Tondeur et al., 2017). The data from the present study did not show an overall positive effect of personalized teaching. However, an interaction effect was observed suggesting that students with home-based risk factors for distance learning benefit more from personalized teaching. Adaptive teaching that provided frequent feedback to children and parents may have counteract negative effects for children at-risk. This is an interesting and important finding, as further implications for school practice can be derived from it. In addition to differentiated education and training opportunities on personalized instruction for teachers, it would seem appropriate in schools with a higher number of at-risk students to have more staff resources to adequately implement individualized support (e.g., feedback to children and parents). These findings are consistent with research that demonstrates the positive impact of teacher-student interaction on learning in online education (Lin et al., 2017), as well as recent studies during the COVID-19 pandemic that highlighted the importance of teacher-student interaction for learning satisfaction and success in distance education (Schneider et al., 2021; Sun et al., 2022).

Technology-enhanced personalized learning is gaining more and more attention in research, governmental agencies, and popular media (FitzGerald et al., 2018). However, personalized learning technologies are still in their infancy (Shemshack and Spector, 2020), even though, already today, rather complex models of personalized feedback can be implemented into digital learning systems (Vasilyeva et al., 2007). However, this algorithm-driven learning management, which expanded during the pandemic, is not without problems (Williamson, 2021). Effective use of educational technologies should be one of the key topics of research in the post-pandemic schools.

Future studies should investigate the relationships between the factors studied here and other factors that may influence home learning and mathematical performance. One would expect that the effects both of school closures in general and of particular distance learning techniques would vary not only with home resources but with a variety of aspects of parental and child characteristics, and with home-school relationships. For example, Darragh and Franke (2021) found that a sample of New Zealand parents had very varied perspectives on home-learning of mathematics during lockdown. 35.5% were positive; 29.9% were negative, 29.5% gave mixed responses and 5.24% were neutral. Parents of younger children were more positive than parents of older children. Negative reactions were associated with parental levels of stress and anxiety, though it was not possible to determine direction of causation. School provision of materials and guidance was perceived by parents as an important influence on the experience of home-learning. Harper et al. (2021) looked at American parents' responses to surveys about home mathematics education during the pandemic; and at their 'tweets' on the subject. It is likely that these parents, especially those in the Twitter study, were particularly interested in mathematics education and had particularly fast internet access. Nevertheless, their views seemed similar to those found in other studies: they worked a lot with their children on mathematical activities, focusing mainly on elementary-level content, and they expressed a need for more opportunities to interact directly with their children's teachers.

Moreover, the effects of the pandemic go beyond school closures and include things like isolation from friends and relatives; physical restriction, especially for those living in small houses and flats without gardens; financial insecurity and increases in poverty; health anxiety; and in some cases,

bereavement (Ravens-Sieberer et al., 2021; Feinberg et al., 2022). While children in the age-group studied here usually do not experience serious illness from Covid themselves, it does happen occasionally (Kompaniyets et al., 2021), and far more are and (especially pre-vaccines) were affected by the serious illness of parents, grandparents and other family members.

Implications of the findings are that children's home learning is likely to be affected both by general social and economic disadvantages, and by specific practical risk factors, such as limited or absent access to the internet; lack of a device such as a tablet or laptop; not having a quiet room where to study and lack of adult support for schoolwork at home. Awareness of such problems may make it possible to identify and provide assistance to children at risk, both as regards routine home learning activities such as homework, and for children experiencing long-term disruption to face-to-face learning at school, due to individual problems such as family illness or large-scale problems such as future pandemics.

It would be interesting to investigate whether the effects of the risk factors were similar for other subjects besides mathematics. In at least some countries, including the United Kingdom, persistent numeracy difficulties are significantly commoner than persistent literacy difficulties (Parsons and Bynner, 2005; BIS, 2012); and it therefore seems at least possible that numeracy would be even less resilient than other subjects to a significant disruption such as that caused by the pandemic. Kuhfeld et al. (2020) reported results suggesting that performance in mathematics was particularly seriously affected by the pandemic. There needs to be future research on the nature, extent and long-term persistence of effects of the pandemic and school closures on children's attainment in different subjects. This knowledge is needed, as even though large-scale school closures like during this pandemic are rare, local disruptions of school-going occur regularly in many countries for a variety of reasons: e.g. extreme weather conditions.

5. Limitations

Some limitations of the applied research approach should be noted. First, the cross-sectional design did not allow to draw conclusions about the development of math skills over time, as no data were assessed before the pandemic. Therefore, the study can only provide hypotheses about the cause-effect relationships. Secondly, the study did not look at possible differential effect on different aspects of mathematics, or on other subjects in the curriculum. Third, the study excluded children with special educational needs, so it cannot provide any information about them. Fourth, the research design used student self-reports to assess the conditions of distance learning at home and used teacher self-reports to assess the conditions of distance teaching. It cannot be guaranteed that their ratings are influenced by memory biases. To ensure the validity of the information, the assessments were conducted immediately after the suspension of face-to-face teaching. In addition, teacher responses were compared to other evidence as to resources available at the school, in order to check whether their responses might be influenced by social desirability effects. Not all teachers responded similarly, suggesting that there were likely differences in how much they used personalized approaches. Fifth, the study was carried out in a single area of Germany, and it is possible that the findings might not be fully applicable to other places, especially internationally. Moreover, this study focused only on children at grade levels 3 to 4. Having a larger sample with children from younger and older age-groups would be important to better understand the connections in studying and learning mathematics under distance learning conditions.

6. Conclusion

The present study provides first empirical evidence on the relationship between distance learning conditions during the COVID-19 pandemic and basic number skills after the interruption of face-to-face teaching. By applying a performance test of basic numeracy skills, the study extends the previous descriptive research on the realization of distance teaching in Germany and provides risk factors of home-based learning. Based on the findings, concepts can be derived to ensure effective implementation of distance learning for future pandemics or emergencies causing suspension of face-to-face teaching. In view of the serious economic (Psacharopoulos et al., 2021), health (Ravens-Sieberer et al., 2022) and educational consequences (König and Frey, 2022) of the suspension of face-to-face teaching, every effort should be made in the future, even in exceptional circumstances, to provide all children with equal educational opportunities in terms of human rights (UN General Assembly, 1948). For this purpose, schools and educational ministries should provide a stable digital infrastructure and support families with fewer resources. A mere consideration of socioeconomic background does not seem entirely sufficient here, even though this index reveals many educational disadvantages. In the context of teacher education and in-service training, ICT, personalized teaching approaches and the exchange with the parental home should play a greater role to counteract the negative repercussions for children at-risk. Nevertheless, the question arises to what extent elementary schools in Germany have adequate staffing (Bieber et al., 2020) for an intensive and professional exchange with parents and children outside the classroom.

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 Institutional Review Board of Instituto De Psicologia Da Universidade Federal Do Rio Grande Do Sul. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

LO, AF, VH, AD, and PR conception and design of the study. LO performed the statistical analysis and wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, 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.

Publisher's note

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