Motor performance before, during and after COVID-19 and the role of socioeconomic background: A 10-year cohort study of 68,996 third grade children

Till Utesch (till.utesch@uni-muenster.de)
University of Münster https://orcid.org/0000-0001-7185-4239

Robert Stojan
University of Muenster

Katharina Geukes
University of Münster

Ludwig Piesch
University of Muenster

Malte Jetzke
University of Muenster

Jochen Zinner
DHGS German University of Health and Sports

Dirk Büsch
University of Oldenburg

Article

Keywords: motor development, corona pandemic, lockdown, physical literacy, socioeconomic background

Posted Date: September 20th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-3239599/v1

Abstract

In response to the Coronavirus Disease 2019 (COVID-19) pandemic, various measures were taken to contain its spread, including restrictions on physical education and sports clubs. These measures substantially limited children's physical activity behaviors and may have compromised their motor development. Such compromising effects may be particularly prevalent among children from lower socioeconomic background (SEB) who tend to be less physically active than higher SEB peers. In this study, the impact of COVID-19 pandemic-related restrictions on children's motor development was investigated with respect to children's SEB within the PESCov DFG project. Data from 68,996 children from a metropolitan region in Germany (Age: 8.83 years +- 0.56, range: 6.4–13 years, 35,270 female, 51.1%) assessed between 2011/2012 and 2022/2023 were analyzed as part of the longitudinal cohort study “Berlin hat Talent”. Assessment took place before and after the onset of the pandemic using the German Motor Fitness Test. The test includes assessments of various motor skills covering endurance, strength, coordination, and flexibility. Demographic variables (e.g., age, gender) were collected via questionnaires. SEB was derived on school level, which was determined using the official school type classifications of the state of Berlin. Cross-classified linear mixed effect models were fitted to account for hierarchies in the data, with individual test values (level 1) being nested in motor domains (level 2a) and in participants (level 2b) and participants being nested in schools (level 3b). Outcome measure was motor skill performance transformed from German reference percentiles to z-scores per motor skill. The effects of Time (pre, post LD I, post LD II), Motor Domain, and SEB (continuous, -2–2) were estimated while controlling for Age, Gender, and Secular Trends. Main effects of Time, Motor Domain, and SEB were significant. Further, a significant Time x Motor Domain interaction revealed that motor skills differentially developed during the pandemic. Coordination, strength, and flexibility decreased, while endurance increased. SEB had a negative effect on overall motor development of third graders. However, this effect varied between motor domains (coordination = endurance > strength > flexibility). Totally, motor skills were on average about 4 percentile points lower after lockdown I, and the effect of the pandemic was stronger after controlling for domain-specific secular trends. Results suggest highly differential effects of the pandemic on children's motor development, which should be considered when recovering motor skills in the post-pandemic era. To avert these trends and the lifelong consequences of impaired motor development in childhood, comprehensive monitoring of children’s motor performance levels is needed as well as support programs for children with compromised motor performance, particularly for children from lower SEBs.

Introduction

In response to the COVID-19 pandemic, governments worldwide have taken an unprecedented array of measures since early 2020 to contain the spread of the virus (ECDC, 2022). For example, in Germany, various restrictions were imposed on travel (e.g., airplanes/trains), public gatherings (e.g., concerts), leisure facilities (e.g., restaurants/bars), schools, and sports clubs, with the stringency of these restrictions increasing considerably during episodes of higher incidence/prevalence. Many of these pandemic measures were evaluated to effectively control the virus's spread. However, the social distancing associated with these measures also led to several detrimental consequences for large parts of the population, such as (i) increased feelings of loneliness and lack of motivation, (ii) higher prevalence of neuropsychiatric disorders and mental health problems, and (iii) growing rates of sedentariness and physical inactivity in some parts of the population (Bourmistrova et al., 2022; Dawel et al., 2020; O'Sullivan et al., 2021). While much of the discussion about the adverse effects of the pandemic has focused on adults, emerging evidence suggests that children's mental health and quality of life may also be affected (Hamatani et al., 2022; Kauhanen et al., 2022; Ravens-Sieberer et al., 2021). Thus, there is a growing body of research suggesting that the abrupt cessation of daily routines brought about by the pandemic and associated policies had far-reaching adverse collateral effects for various age groups. However, few studies have also investigated the development of children's motor performance levels in the context of the COVID-19 pandemic.

Physical inactivity in children and adolescents, already considered an epidemic (Sallis et al., 2016), has been identified as one of the various adverse epiphenomena of the current pandemic (Rossi et al., 2021). Following pandemic measures, children and adolescents have been observed to be less physically active than at pre-pandemic levels. The restricted access to or closing of facilities for organized forms of physical activity, such as at schools and sports clubs during the pandemic, particularly during nationwide lockdowns, contribute to these findings (Schmidt et al., 2020; Wunsch et al., 2021). In school, children and adolescents are physically active in a structured way, ensuring a minimum level of weekly physical activity. With this space for curricular physical engagement being not available during the pandemic, children were deprived opportunities for physical activity. In addition to that, leisure time activities were also restricted during early stages of pandemic-related lockdowns. The resulting lack of physical activity may have led to compromised motor development trajectories and thus resulted in persistent adverse effects on motor performance. Additionally, physical activity during childhood and motor performance levels at an early age can predict physical activity behavior in (later) adulthood and adolescence (Stodden et al., 2008). Previous studies showed that being less active as a child resulted in lower physical activity as an adult. Lower physical activity, in general, is associated with compromised physical and mental health, neurocognitive functioning, and well-being (Biddle & Asare, 2011; Ludyga et al., 2020; Rodriguez-Ayllon et al., 2019), all of which are important for maintaining a healthy lifestyle throughout the lifespan. Hence, the effects of the current pandemic may have widespread and long-lasting adverse effects on several health-related factors.

As part of the holistic understanding of the physical literacy concept, physical (in)activity is assumed to be closely interrelated with motor performance, particularly in children (Cairney et al., 2019; Schmutz et al., 2020; T. Utesch et al., 2018). Here, motor performance consists of both motor domains and physical fitness. Various motor tests are mostly administered to measure children or adolescents motor performance levels (Hands et al., 2015; Utesch et al., 2019). Important domains are, for instance, cardiovascular endurance (e.g., running), postural control (balance), strength (e.g., sit-ups), speed (e.g., sprint), coordination under time pressure (e.g., jumping sideways) or flexibility (e.g., forward bending/stretching). Different Motor Domains typically show differential developmental trajectories throughout childhood and adolescence (Fühner et al., 2021; Stodden et al., 2008). While some skills display a relatively linear progression (e.g., gross Motor Domains, flexibility), other skills evolve during critical developmental periods (e.g., motor coordination, endurance). Since the pandemic spanned a considerable period in the lives of children and adolescents, including these critical developmental periods, there may have been differential effects on the development of different Motor Domains. Some Motor Domains may have suffered exceptionally from the lack of physical activity during the pandemic. In contrast, others may have remained somewhat more stable as they are less sensitive to critical environmental or life events. The absence of organized forms of physical activity during the pandemic may also have led to differences in Motor Domains development. Physical education, for example, explicitly aims for holistic motor development that incorporates all aspects of motor performance (Escalie et al., 2017; Fairclough & Stratton, 2004). Due to these forms of physical activity being substantially reduced during the pandemic, only leisure-time physical activities were possible; as such, it is conceivable that only specific motor domains primarily associated with leisure-time physical activity could be maintained. In summary, it is plausible that the reorganization of physical activity in children and adolescents during the pandemic resulted in differential effects on the development of different motor domains.

In addition to physical activity, various other factors can influence motor development in children and adolescents. One important factor is children's socioeconomic background (Rahman & Chandrasekaran, 2021). On average, children and adolescents from lower socioeconomic background tend to show lower motor performance across different Motor Domains than those from higher socioeconomic background (Ferreira et al., 2018). This difference is often explained by the parents' different knowledge regarding the importance of and interest in being physically active. Moreover, the socioeconomic disparities in children's physical activity levels may also be attributed to time and financial constraints of parents with lower socioeconomic status. As such, the socioeconomic background can be determined at the level of the parents, i.e., the socioeconomic status of the parents, as well as, for example, at the school or district level. Schools are typically assigned to a particular socioeconomic type for which the average socioeconomic background of the population of a catchment area is considered.

During the pandemic, these socioeconomic differences may have been exacerbated, as parents with higher levels of education may have been more supportive of their children's physical activity than parents with lower levels of education. However, it is also conceivable that these differences were somewhat mitigated during the pandemic, as children and adolescents from wealthier socioeconomic background were more physically active before the pandemic. However, during the pandemic, active children and adolescents could not maintain their higher activity levels. In contrast, the physical activity levels of children and adolescents from lower socioeconomic background may have remained similar to pre-pandemic levels, which may have mitigated the differences in motor performance between differential socioeconomic background. Therefore, it remains up for debate to which extent child's socioeconomic background may have been decisive for their motor development in the context of the COVID-19 pandemic.

Another critical aspect to consider when examining the impact of the pandemic on children's motor development is the option of a secular trend, i.e., a long-term change in children's motor performance levels over a longer period of years. The results of previous studies vary widely and include negative, positive, as well as stagnating trends in motor performance over the past several years (Fühner et al., 2021; Knaier et al., 2023; Schlag et al., 2021; Spengler et al., 2017; Tomkinson et al., 2021; Tomkinson et al., 2003). Although there is no clear pattern of secular trends in motor development, an important consensus among these studies is that temporal trends for individual Motor Domains appear to be specific and should be considered as such (Fühner et al., 2021). This finding is important to consider when examining the pandemic's potential negative impact on motor performance, especially differentiating this impact from recent secular trends. Lower motor performance during the pandemic compared with before the pandemic could otherwise be falsely attributed to the pandemic, whereas this result could also be due to a negative secular trend. Therefore, to correctly determine the impact of the pandemic and related lockdowns on motor performance, this trend must be considered, for example, by comparing actual motor performance during the pandemic with the predicted motor performance based on the secular trend of previous years. Thus, the true impact of the pandemic can be separated from the 'normal', i.e., non-pandemic, secular motor development.

In this study, we aimed to investigate the adverse effects of the global COVID-19 pandemic on children's motor performance levels in a metropolitan region. We analyzed data from the "Berlin hat Talent" study, a longitudinal cohort-sequence study examining the motor performance of third graders across different schools in Berlin each year since 2011, including the pandemic years from 2020 to 2022. We were particularly interested in the impact of the pandemic on different Motor Domains, including the influence of school-level based socioeconomic background, specifically in the sense that we assumed socioeconomic disparities may have influenced the pandemic's impact on motor performance. We hypothesized that both pandemic related lockdowns had a negative impact on children's motor performance, such that motor performance measured after the two pandemic lockdowns would be worse for children than children's motor performance in pre-pandemic years. In addition, we expected that the negative effects of the pandemic would differentially affect different motor domains, as a result of the absence of physical education classes in schools and a shift in favor of leisure-time physical activities. In this vein, we also assumed that children's school-based socioeconomic background also moderated the pandemic's impact on motor performance. Most importantly, all analyses also considered recent secular trends to provide a more accurate picture of the true impact of the pandemic on children's motor performance levels. This study contributes to a better understanding of the adverse effects of the pandemic on motor development of children and adolescents and aims to support the development of tailored and individualized rehabilitation programs to counteract these consequences.

Methods

2.1 Study characteristics and participants

The current study was funded by the German Research Foundation (DFG; PESCov project) as a secondary analysis of data from the independent “Berlin has Talent” program (BHT). BHT is an initiative of the Landessportbund Berlin (LSB) and the Berlin senate that aims at promoting more specialized physical activity programs to facilitate physical fitness and activity in children with compromised or superior sports performance. The program started in 2011 and since then follows a quasi-longitudinal panel design (e.g., Zinner & Büsch, 2014, 2016; Zinner, Büsch, et al., 2015; Zinner, Werner, et al., 2015). That is, each year, primary school third graders are tested for their motor performance using the German Motor Test (GMT; Bös & Schlenker, 2011; Bös et al., 2009). Each year, various public primary schools were selected to participate in the program, with the aim to continuously include a larger amount of schools over the course of the program. All schools were located in different districts of Berlin covering a wide variety of regions with different socioeconomic background. Before participation, the schools received a written invitation from the Berlin school administration to participate in the project. Data assessment was then carried out by a professional assessment team with trained assessors over the past 10 years. The assessment team took care of the selection of children per school, based on recommendations of the State Sports Federation of Berlin and the Berlin school administration. All children participated voluntarily, and their parents provided written informed consent for them to participate. The reporting of this study was implemented in accordance with the STROBE guidelines (von Elm et al., 2008).

2.2 Measures – German Motor Fitness Test & Socioeconomic Background

The German Motor Fitness Test (GMT; Bös & Schlenker, 2011; Bös et al., 2009) is a test battery that is recommended by the German Association for Sport Science to assess motor performance and physical fitness in school children and adolescents from 6 to 18 years. It has been validated multiple times for six items: 6-minute run, sit-ups, push-ups, standing long-jump, 20m sprint, and jumping sideways (Utesch et al., 2015; Till Utesch et al., 2018). The items cover various domains of motor performance, including endurance, strength, speed, and coordination.

Endurance (aerobic) was assessed using the 6-minute run test. Participants had to run around a volleyball court (54 m) for six minutes. They motivated the children, who were instructed to complete as many rounds as possible. The distance covered within six minutes was measured for each subject. The covered distance (in m), derived from the number of laps completed within six minutes, plus the distance covered in the last lap was used for analysis.

Strength was assessed by performing sit-ups, push-ups, and long-jump, which require muscular endurance of the trunk and lower and upper extremities musculature. For both tests, participants were instructed to perform as many repetitions as possible within 40 s. For sit-ups, participants lay down on their back. They were asked to put down their feet on the floor, and to bend their knees. The experimenter held down the feet during testing and made sure that the knees were bent by approx. 80°. The hands had to be placed at the temples. Sit-ups were performed by raising the upper body from the supine position until both knees could be touched with the elbows, after which they had to return to the supine position with both shoulders touching the mat. For push-ups, participants were instructed to start from a lying position with both hands fold together behind their back. After the start command, they had to do push-ups by placing their hands next to their shoulders, pushing off the ground, then releasing one hand from the ground to touch the other hand, and then returning to the starting position. For both sit-ups and push-ups participants were instructed to complete as many repetitions as possible within 40s. One trial was performed per test. The experimenter controlled for correct performance. Outcome measure was the number of correct repetitions (n) within 40s. Next to these tests, jumping strength was measured using the standing long-jump test. Participants were asked to stand at a starting markup line with their feet parallelly aligned to the markup line. They then had to jump as wide as possible starting from that position, and they were instructed to land with both feet simultaneously. Two runs were performed. The outcome measure was defined as the distance (in cm) between their landing position at the heel of their rear foot and the markup line. The better run was forwarded to analysis.

Speed was measured with the 20-meter sprint test. The participants start from a standing position. After a short starting command, the participants were instructed to run as fast as possible over a distance of 20 m. Two runs were performed. False starts were stopped and repeated by the experimenter. Time was measured with a hand-held stopwatch (accuracy 1/100 of a second). Performance was defined as the time (in seconds) taken to run the 20m. The better of two runs was used for analysis.

Coordination under time pressure was measured using the side jumping test. Participants were instructed to jump sideways across a mark-up line (XX cm width) centered to their body (sagittal) and that was placed on a rubber mat (size: 50 cm x 100 cm). They were asked to jump with both legs simultaneously and to try to cross the line as often as possible while not stepping on the markup line or crossing the marked area of the rubber mat. Two runs at 15s each were performed, with a short rest period of at least 60s to recover. The outcome measure was the number of jumps (n) completed within 15s. The average of the two runs was analyzed.

Socioeconomic Background

The socioeconomic background (SEB) of children was derived at the school level, which was determined using the official but confidential school type classifications of the state of Berlin. Here, each school type is defined by various SEB characteristics of the school's catchment area, such as parental income or employment rate. These aspects are summarized in a school type score ranging from 1 (very low SEB) to 7 (very high SEB). However, in the present sample, too few schools had a school type of 1 or 7. Therefore, these two types were combined with school types 2 and 6, respectively. The final school type score (1 very low SEB to 5 very high SEB) was used in the statistical analysis.

2.3 Procedure

Beginning in 2011/2012, several schools were invited each school year to participate in the BHT program. After acceptance to participate, a date was set for a professional assessment team to come to the schools to conduct the tests. The tests took place mainly between August and April because of the spring and summer vacations in Germany. All the equipment needed for the tests was brought by the assessment team and prepared in a gymnasium or larger room before the children and adolescents arrived. All children in a class coming to the GMT test, received a short overall instruction of the general procedure, and were then divided into eight groups. They started at one station and were sent to the next testing station after completing each test until they had completed all eight tests. Experimenters always remained at their test station. The children's performance measures were protocolled by the experimenters per test station and entered into a predefined database by the assessment team after the tests. The same procedures were applied before and during the pandemic, i.e., after LD I (March 22, 2020 – Mai 04) and after LD II (Nov 02, 2021 – Mai 2022; see Figure 1) in Germany.

2.4 Data Analysis and Statistics

All data analyses and statistics were performed with R Studio (v 4.2.1; R Core Team, 2020).

First, raw data on motor performance were categorized into percentile values based on German norm values (Niessner et al., 2020) per test measure (6 min run, sit-ups, push-ups, long-jump, 20m run, jumping sideways) and biological sex (female, male), to convert motor performance raw data into age- and sex-normalized values. This transformation is particularly important to consider, when investigating secular trends in motor performance over multiple years, because current trends in motor performance can influence the effect and interpretation of other influencing variables or events, such as the impact of the pandemic. After transformation in percentiles, data was transformed to standardized z-values per test measure for statistical analysis, and back-transformed to quantile normalized percentile values after analysis to facilitate interpretation of the results.

The aim of the analysis was to investigate the effect of the COVID-19 pandemic related lockdowns on general motor performance in primary school-aged children (H1). Additionally, we analyzed whether the pandemic had differential negative effects on different motor domains, (H2), and we investigated the moderating effects of SEB to identify whether motor performance in children from lower or higher SEB has been differently affected during the pandemic (H3).

The analysis was twofold: First, motor performance during the pandemic was compared to the average motor performance in pre-pandemic years (August 2011/12 – March 2019/20). However, these analyses can be affected by recent secular trends and therefore may not reflect the true effect of the pandemic. Therefore, in the second part of our analyses, we accounted for secular trends by comparing actual motor performance with the predicted motor performance following recent secular trends. More detailed information on these analyses is presented below.

Comparison of motor performance before and during the pandemic

In the first analysis approach, we performed a cross-classified linear mixed effects model ('lme4' package; Bates et al., 2015) with all data available (2011/12 to 2022/23) with individual test values (level 1) are in motor domains (level 2a) and nested in participants (level 2b) and participants are nested in schools (level 3). Here, we analyzed the difference between pre-pandemic motor performance and motor performance after LDI and LDII (H1). Secular trends were not yet considered at this point. The dependent variable was motor performance (z-values, continuous scale). Further, level 2 and level 3 variables were included in the model: Sex (level 2; male, female), Time (level 2; pre, post LDI, post LDII), and SEB (level 3; continuous integers from 1-5, higher values indicate higher SEB) as well as all interactions between independent variables, i.e., two-way and three-way, were added to the model as fixed effects. For the random effects term, random intercepts were added for Motor Domain and School, with Participants nested in Schools. The model was fitted using maximum likelihood estimation (ML), which is assumed to provide better estimates for fixed effects than restricted maximum likelihood estimation (REML) (Field et al., 2012). In addition to the model estimated, F-statistics were obtained for main and interaction effects using type-III sum of squares ANOVA ("anova"; R base package) with Satterthwaite-Approximation, a slightly more liberal procedure than the Kenward-Roger method (Halekoh & Højsgaard, 2014). Significance level was set to $\alpha < .05$. Post-hoc tests were performed on significant main and interaction effects using planned contrasts with estimated marginal means (for factor variables) and estimated marginal trends (for continuous variables) both from the *emmeans* package (Lenth, 2020). Because we were particularly interested in the effects of the pandemic on motor performance and to provide a parsimonious and hypothesis-driven analysis, we only performed post-hoc tests on the main effect of Time and its interactions, but not on the other significant main or interaction effects. For example, significant interactions of Motor Domain x SEB were not planned to be followed up by post hoc tests.

Trend Analysis – Differences between actual and predicted motor performance during the pandemic

The second part of our statistical analysis aimed at considering secular trends in investigating the effects of the pandemic on motor performance. Here, we aimed to use the secular trends to make the most accurate predictions of what motor performance the children would have achieved without the influence of the pandemic. These predictions can then be compared to the children's actual motor performance during the pandemic to better assess the true effect of the pandemic. However, different secular trends may result in varying predictions depending on the data/years used. To also account for this variability in secular and varying predictions, respectively, different starting years (2011-2017) were used in an iterative process to predict motor performance during the pandemic school years.

In the first step, linear secular trends were calculated, i.e. the effect of the independent variable Year on the outcome measure motor performance. These trends were calculated by using cross-classified linear mixed effects models ('lme4', cf. above), separately for each Motor Domain (20m run, side jumps, sit-ups, push-ups, long-jump, 6min run) and each SEB (factorized to 5-level factor) with Motor Domain as level 1, and Participant as level 2. The outcome measure was motor performance (z-scaled). The main independent variable was Year (continuous, 2011/12 – 2019/20), which was entered as fixed effect. In an iterative process, the starting year for the variable Year was systematically increased from 2011/12 to 2018/19, while the end year remained at 2019/2020. This procedure was used to calculate different secular trends, i.e., estimates for Year, to account for the variability of secular trends depending on the time period used for the estimation as it was a political decision to start the project BHT in 2011/12. Additionally, Sex was added as a fixed effect control variable, and random intercepts were included for School. ML estimation was applied for calculating fixed effects estimates (cf. above). In a second step, we then predicted motor performance for the two pandemic school years 2020/2021 and 2021/2022 based on the model estimate obtained for Year, which reflects the linear secular trend calculated for the years included. That is, for each child, we obtained a predicted and an actual value for motor performance at the two post-lockdown time points (LDI and LDII). In a third step, these data were forwarded to another linear mixed model to estimate the difference between predicted and actual motor performance. Hence, the outcome measure was motor performance. The independent variable was Type (predicted, actual), which was added as fixed effect, and random intercepts were added for participants. Again, models were fitted with ML. In total, 480 linear mixed models were computed, resulting in 480 estimates for the difference between predicted and actual motor performance for Time, Motor Domain, SEB, and Starting Year of the secular trend, i.e., 2 (LD) x 6 (Motor Domain) x 5 (SEB) x 8 (Starting Year).

Finally, these model estimates were forwarded to the final analysis investigating the true effect of the pandemic on motor performance. That is, a final linear mixed effects model was performed. The outcome measure was the estimate of the difference between predicted and actual motor performance. In the first model, we only added random intercepts for Starting Year of the secular trend. Here, we examined the significance of the intercept only, to investigate whether the estimates of the difference between predicted and actual motor performance are not equal to zero, thus indicating a non-zero overall effect of the pandemic related lockdown on motor performance. After that, we also added fixed effects for the independent variables, Lockdown (LDI and LDII), Motor Domain (6-level factor, cf. above), and SEB (5-level factor, cf. above), and their interaction, to investigate the true effect of the pandemic on motor performance (H1), distinct effects of the pandemic on different Motor Domains (H2), and the moderating effect of school-level SEB (H3). ML was applied for estimation of fixed effects (cf. above). Significant interaction effects were followed up using planned contrast with estimated marginal means.

For all analyses, the partial eta-squared (η^2) is reported as a measure of effect size. However, to further facilitate the interpretation of the results, the z-values based on the linear mixed effect models were back-transformed into quantile-normalized percentile values. Based on these values, the differences between actual and predicted motor performance can be interpreted with practical relevance.

Results

3.1 Motor Performance during Covid-19 compared to pre-pandemic

The first cross-classified linear mixed effects model was performed to investigate the effects of Time, Motor Domain, SEB, and their interaction on motor performance. First, we observed a significant main effect of Time ($F(2, 32199) = 3.59$, $p = 0.028$, $\eta^2 < .01$). Post-hoc contrasts revealed trend-level lower motor performance at LDII compared to pre ($p = .061$), but no significant differences between LDII and LDI and between LDI and pre. Second, the main effect of the Motor Domain ($F(5, 335151) = 7102.35$, $p < .001$, $\eta^2 = .10$) was significant, indicating differential motor performance in different Motor Domains. Post-hoc tests were not performed as described above, because we were not interested in differences between Motor Domains in this study. The main effect of SEB was also significant ($F(1, 789) = 450.50$, $p < .001$, $\eta^2 = .36$), indicating that children from lower SEB generally have worse levels of motor performance than children from higher SEB.

In addition to these main effects, we also found significant interactions, including an interaction of Time x Motor Domain ($F(10, 335{,}085) = 117.85$, $p = .001$, $\eta^2 < .01$). Pairwise post-hoc tests were performed to investigate the effect of Time on each Motor Domain separately. For the 20m run, performance was lower at LDI ($p < .001$) and LDII ($p < .001$) compared to pre, and also trend-level lower at LDII compared to LDI ($p = .074$). For side jumps, performance was lower at pre and LDI compared to LDII ($p < .001$), and there was no difference between pre and LDI. For push-ups, there was no significant difference between pre, LDI and LDII. For sit-ups, in contrast, performance was lower at pre compared to LDI ($p < .011$) and performance at LD I was higher compared to LDII ($p < .001$), with no significant difference between pre and LDII. For the long-jump, performance was higher at pre compared to LDI ($p = .045$) and LDII ($p = .001$), but there was no difference between LDI and LDII. Lastly, the performance of the 6 min run was lower at pre compared to LDI ($p = .016$) but higher compared to LDII ($p = .001$), and higher at LDI compared to LDII ($p < .001$). The interaction of Motor Domain x SEB ($F(5, 335{,}055) = 26.92$, $p < .001$, $\eta^2 < .01$) was also significant, but not further evaluated given the above reasons. Lastly, the interaction of Time x SEB was not significant ($F(2, 36{,}451) = 0.48$, $p < .618$, $\eta^2 = .01$), indicating that the effect of SEB on motor performance was similar at pre, LDI and LDII.

However, the triple interaction of Time x Motor Domain x SEB was significant ($F(10, 335{,}059) = 9.67$, $p < .001$, $\eta^2 = .01$). That effect was followed up with post-hoc estimated marginal trend analysis to examine whether the effect of SEB on motor performance differed between pre, LDI and LDII, and further varied between Motor Domains. Stronger effects (i.e., trends) of SEB indicated larger differences between children from lower compared to higher SEB. For the 20 m run, the effect of SEB was not significantly different between pre, LDI and LDII. For side jumps, the effect of SEB was stronger at LDII compared to pre ($p = .01$), but both LDII and pre were not different from LDI. Likewise, for push-ups, the effect of SEB was more pronounced at LDII compared to pre ($p = .017$), but there was no difference between pre and LDI or between LDI and LDII. For sit-ups, the effect of SEB on motor performance was also higher, at trend level, at LDII compared to pre ($p = .087$) and compared to LDI ($p = .044$). However, there was no difference between pre and LDI. For the long-jump, there was an inverse effect, such that the trend of SEB was higher at pre compared to LDI ($p = .029$), but there was no difference in trends between pre and LDII or between LDI and LDII. Lastly, for 6 min run, there was a higher effect of SEB on motor performance at pre compared to LDII ($p < .001$), but neither a significant difference between pre and LDI nor between LDI and LDII.

3.2 Predicted vs actual motor performance based on different secular trends.

The second part of our analyses aimed to consider secular trends in examining the effects of the pandemic on motor performance by comparing actual motor performance during the pandemic with the predicted motor performance levels children would have achieved in the absence of the pandemic. Figure 2 illustrates the rationale for considering secular trends for the whole period of time: It shows the secular trend in motor performance per Motor Domain (boxes) and SEB (colors) from 2011 to 2019 (linear predictions) in addition to actual motor performance during the pandemic (rhombs). As Figure 2 shows, motor performance during the pandemic should not be compared only to average motor performance in previous years (e.g., average between 2017-2019 or 2011-2019), because these analyses do not account for recent secular trends in specific Motor Domains. These data suggest that recent trends in motor performance would have resulted in higher (e.g., push-ups) or lower (e.g., 6-minute run) motor performance in the two years of the pandemic. Therefore, not including these trends in statistical analyses could lead to underestimation or overestimation of the impact of the pandemic on motor performance.

In the second part of our analyses, 480 linear mixed effects models were run systematically to calculate different secular trends in motor performance, to predict children's motor performance during the two pandemic years, and to investigate the difference to their actual motor performance during pandemic years, separately per Motor Domain, SEB, lockdown period, and starting year. These linear mixed models were not intended to reach statistical conclusions, but to make predictions about estimated motor development based on differential recent secular trends. The resulting 480 estimates of the differences between predicted and actual motor performance are presented in Figure 3, which provides a first overview of the differential effects on the various Motor Domains and moderating effect of SEB. These estimates were analyzed in a final linear mixed effects model.

First, we found that the intercept was significantly different from zero ($t(7) = -5.39$, $p = 0.001$, $\beta = -0.10$, -3.85%). That is, the actual motor performance during pandemic was significantly different from the motor performance predicted from secular trends. The main effect of Lockdown, however, was not significant ($F(1, 413) = 2.09$, $p = 0.148$, $\eta^2 < .01$). That is, there was no difference between LDI and LDII in their overall effect on motor performance. The main effect of Motor Domain was significant ($F(5, 413) = 182.06$, $p < .001$, $\eta^2 = .69$), indicating differential effects of the pandemic on individual Motor Domains. Further details on pairwise post-hoc tests can be found in the supplement (Table S1). Push-ups were affected most negatively ($\beta = -0.40$, -15.47%), followed by 20m run ($\beta = -0.26$, -10.32%), long-jumps ($\beta = -0.12$, -4.63%), and side-jumps ($\beta = -0.06$, -2.58%). The two other skills, 6min run ($\beta = .19$, 7.56%) and sit-ups ($\beta = 0.07$, 2.75%) improved during pandemic. The effect of SEB also was significant ($F(4, 413) = 57.48$, $p > .001$, $\eta^2 = 0.36$). The higher negative effect was found for children from very high SEB (β =

-0.22, -8.56%), followed by children from high SEB (β = -0.15, -5.85%), children from low SEB (β = -0.15, -5.80%), and children from average SEB (β = -0.04, -1.50%). Children from very low SEB showed higher actual motor performance than predicted motor performance (β = 0.06, 2.51%). Post-hoc tests were performed using consecutive contrasts between the five levels of SEB. Given the non-linear results, we then also performed pairwise post-hoc tests contrasting all levels of SEB against each other. Results of mean differences can be found in the supplement (Table S2). In addition to these main effects, all interactions were significant, including the interaction of Lockdown x Motor Domain ($F(5, 413) = 18.94$, $p < 001$, $\eta^2 = .19$). Planned contrast post-hoc tests revealed that LDI had a stronger effect than LDII on push-ups ($p < .001$) and sit-ups ($p < .001$), and that LDII had a more pronounced effect than LDI on 20m run ($p < .001$) and side jumps ($p < .001$). There was no difference between LDI and LDII in their effect on 6min run (p = .541) and long-jump (p = .665). Furthermore, the interaction of Lockdown x SEB was significant ($F(4, 413) = 11.24$, $p < .001$, $\eta^2 = .10$). Post-hoc tests showed that during LDI had a stronger effect than LDII on motor performance in children will very low SEB ($p = .013$), and that LDII had a more pronounced effect on LDI on children with low SEB ($p < .001$) and very high SEB ($p = .016$). There was no difference between the effects of LDI and LDII on motor performance in children from average SEB and high SEB. Moreover, the interaction of Motor Domain x SEB ($F(20, 413) = 7.28$, $p < .001$, $\eta^2 = .26$) was significant. Lastly, also the triple interaction of Lockdown x Motor Domain x SEB was significant ($F(20, 413) = 1.68$, $p = .034$, $\eta^2 = .08$), indicating that the two lockdowns had differential effects on specific Motor Domains that further varied between different SEBs.

Discussion

Our main objective was to investigate the effects of the COVID-19 pandemic on motor performance of school children, including differential consideration of different Motor Domains and moderating effects of SEB. In general, motor performance in Berlin third graders was overall lower compared to German norm values. While we found a slightly negative effect of the pandemic on motor performance, the effects were highly differential between Motor Domains and with respect to children's SEB. For example, we observed that children performed worse on push-ups and 20m run during the pandemic compared to pre-pandemic levels. For the 6min run in contrast, children performed better during the pandemic as compared to pre-pandemic. Similarly, the pandemic had differential effects on specific Motor Domains between children from different SEB, such that the difference in motor performance in children from lower and higher SEB became more pronounced during the pandemic compared to pre-pandemic for side-jumps, push-ups, and sit-ups, but decreased for long-jump and 6min run. After controlling for secular trends, the impact of the pandemic was stronger, further supporting the above results. Compared with the predicted motor performance following recent secular trends, children's actual motor performance was decreased by about 4% in the order of quantile-normalized percentile values. However, again, these effects were highly specific to individual Motor Domains, such that, for example, push-up performance decreased by -15.47% and 20m run by -10.32%. In contrast, performance in the 6min run increased by + 7.56% and sit-up by + 2.75%. These differential effects on Motor Domains may reflect adapted physical activity behaviors in children during the pandemic, such as fewer physical education classes and higher leisure-time physical activity. In addition, the secular trend analysis showed that motor performance was particularly compromised in children with very high SEB (-8.56%) and high SEB (-5.85%), while children with very low SEB showed minor improvements (+ 2.51%). Thus, the pandemic slightly closed the current SEB gap in motor performance. It should be noted, however, that while it is generally desirable for the motor performance of low SEB and high SEB groups to converge, it would be preferable if this convergence were to occur by the low SEB children catching up to the high SEB children rather than by the high SEB children having their motor performance impaired. In summary, the pandemic had various effects on motor performance, some of which were strongly negative (e.g., push-up performance), while others also had a positive impact (e.g., 6min run or smaller SEB gap). Further steps are now to consider, develop, and implement specialized (physical activity and motor performance promoting) programs to rehabilitate the performance losses in the most compromised Motor Domain domains and provide solutions to facilitate motor performance across children from different SEB.

General Discussion

Consistent with previous research, we found an overall negative effect of the pandemic on children's motor performance (Basterfield et al., 2022). Although this effect appears to be rather small (-4%), it should be kept in mind that even such a small average effect can have serious and persistent negative consequences for various health-related factors, both for childhood and adolescence and beyond. For example, lower levels of physical fitness and activity have been found to lead to lower motivation for physical activity in later adulthood, which in turn may affect physical, cognitive, and psychosocial health (Hirvensalo & Lintunen, 2011; Telama et al., 1997; Telama et al., 2005). In other words, the pandemic may have latent long-term effects that should be counteracted promptly to prevent these negative late effects. Further, from a developmental perspective, 4% equal about one year of development (cf. Niessner et al., 2020). Estimating the delay in motor development that has occurred in response to the pandemic is important in itself, but also because delayed motor development may compromise development in other domains, such as cognitive, social, and emotional development (Bushnell & Boudreau, 1993; Slining et al., 2010; Thelen, 1985). Interpretation of these results should also take into account that the pandemic had highly varying effects on different Motor Domains, both positive and negative, which offset each other to some extent when the overall impact is examined. Thus, a differential analysis is critical. For example, some Motor Domains received significantly less training during the pandemic, potentially at critical stages of development. Therefore, performance in these Motor Domains suffered the most significant drop during the pandemic (e.g., push-ups or 20m run), while others tended to remain stable (e.g., side jumps) or even improved (e.g., 6-minute run). Another reason for these differential effects could also be, in particular, the discontinuation of physical education classes and activity in sports clubs. In these organized forms of physical activity, the focus is more on promoting Motor Domains in a holistic way. Leisure time physical activity, on the other hand, potentially improves specific Motor Domains only in specific developmental stages. During the pandemic, children were constrained to be more active during their leisure time and could only participate in physical education classes or sports clubs to a very limited extent. This change in physical activity behavior could have led to the observed differential effects on Motor Domains and explain the improvement in the 6min run, an endurance-related skill that might benefit especially from leisure-time physical activity. What effects these specific changes could have on future physical activity behavior or physical, neurocognitive, and psychological health in children remains to be determined. It therefore is important to continue to monitor these aspects to be able to intervene at an early stage with adapted physical activity and training programs. Here, beside traditional approaches such as local school communities (e.g., Naul et al., 2018), exergaming technology could play an important role (cf. Oppici et al., 2022).

Another important finding is the moderating effect of children's SEB on pandemic-related changes in Motor Domains. Although there was no overall effect of children's SEB on pandemic-related changes in motor performance, we found differential effects for individual Motor Domains that were in line with the differential findings described above. For some Motor Domains, we observed that the difference in motor performance between children with lower and higher SEB increased (side jumps, push-ups, and sit-ups), whereas on the other hand, for other skills, the difference between them decreased (long-jump and 6-minute run). This pattern of results could also be related to a change in the children's physical activity behavior, including their SEB. Children with higher SEB were more likely to be active in sports clubs, whereas children with lower SEB were less likely to be physically active in sports clubs. Because sports clubs were largely closed during the pandemic, children with higher SEB could not maintain their physical activity levels, while children with lower SEB remained similarly (in)active. That is, children from higher SEB were more likely to fall behind in their motor development because they started from a higher baseline level, so the gap closed to some degree. However, it is very likely that other SEB-related factors had differential effects on physical activity and Motor Domain changes during the pandemic, such as parental employment and income. Children with higher SEB are more likely to have both parents employed, whereas children with lower SEB are more likely to have one parent unemployed who could have cared for the children during the pandemic and beyond, such as going to the playground. Children with higher SEB, on the other hand, may be more likely to have stayed at home with their siblings or grandparents, resulting in lower levels of physical activity. However, it also should be considered that SEB was assessed at the school level. The quality and focus of physical education classes may differ to some degree between schools with higher and lower school types, e.g., due to infrastructure. Physical education classes are more likely to be more advanced and effective in schools with higher SEB, i.e. with catchment areas of higher SEB. The loss of higher-quality physical education could therefore have had a greater impact than the lack of lower-quality physical education, which also narrowed the gap between lower- and higher SEB.

The results of this study have several implications. First, given that impaired motor development can compromise various aspects of lifelong health, communities and policymakers should take effective action to compensate for the pandemic-based negative trends in children's motor performance. Second, SEB-related disparities in motor performance have decreased during the pandemic, although they may increase again once sport clubs and physical activity facilities reopen. Therefore, authorities are called into action to promote and subsidize access to physical activity facilities and sport clubs, particularly for low SEB neighborhoods. Third, further and comprehensive monitoring of children's motor development in whole Germany is strongly needed in the future to a) evaluate the long-term impact of the pandemic in prospective years, and b) design and evaluate effective physical activity programs for children with compromised motor performance. This monitoring should pay special attention to specific motor domains within physical fitness and motor competence (cf. Utesch et al., 2019). Further, support programs are needed especially in neighborhoods with low SEB for whom declines in motor performance levels were observed the most providing programs that are effective, tailored and individualized to the specific needs of the children.

The strength of this study is the large sample and the fact that motor performance was tracked since 2011 which allowed us to account for secular trends. Sophisticated statistical analyses were utilized to examine potential effects of COVID-19 related lockdowns on children's motor performance. The German Motor Test was used in this study, which is supported by both the German Government and the German Sport Association. However, this study is not without limitations. The data stems only from one large city and metropolitan area in Germany and is not representative for rural areas. The secular effects might result from political strategies which came together with the project BHT as local sports support groups were created in the different city districts and schools, however, this cannot be answered in this study. Socio-economic status was not measured on individual levels, but on the school level. While the sample was large, aggregated effects on the school level might have led to biased results.

Conclusion

The special circumstances related to the COVID-19 lockdowns on a global scale had an impact with sustained implications for all levels of society. However, the situation can be seen as a natural experiment to examine the motor development of children and the related effects of pandemic-related lockdowns. This study shows that the lockdowns went along with detrimental developmental effects on children's motor performance levels. The severity and chronicity of COVID-19 will test the resilience, the resourcefulness of communities, and the political will to counteract unpleasant consequences of political decisions. Children require continued individual support and activity also in a pandemic situation. To counteract the described development, comprehensive monitoring across different regions of children's motor performance levels is needed. Further, local support programs should be implemented in order to foster children's motor development as it is important for their overall development. Hence, education, early interventions, and social services must take responsibility and collaborate to focus on the needs of children's health and development.

References

Basterfield, L., Burn, N. L., Galna, B., Batten, H., Goffe, L., Karoblyte, G., Lawn, M., & Weston, K. L. (2022, May 19). Changes in children's physical fitness, BMI and health-related quality of life after the first 2020 COVID-19 lockdown in England: A longitudinal study. *Journal of Sports Sciences, 40*(10), 1088-1096. https://doi.org/10.1080/02640414.2022.2047504

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015, Oct 7). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software, 67*(1), 1 - 48. https://doi.org/10.18637/jss.v067.i01

Biddle, S. J., & Asare, M. (2011, Sep). Physical activity and mental health in children and adolescents: a review of reviews. *British Journal of Sports Medicine, 45*(11), 886-895. https://doi.org/10.1136/bjsports-2011-090185

Bös, K., & Schlenker, L. (2011). Deutscher Motorik-Test 6–18 (DMT 6–18). In M. Krüger & N. Neuber (Eds.), *Bildung im Sport: Beiträge zu einer zeitgemäßen Bildungsdebatte* (pp. 337-355). VS Verlag für Sozialwissenschaften. https://doi.org/10.1007/978-3-531-94026-7_21

Bös, K., Schlenker, L., Büsch, L., Lämmle, L., Müller, H., Oberger, J., Seidel, I., & Tittlbach, S. (2009). *Deutscher Motorik-Test 6–18 (DMT 6–18)*. Czwalina.

Bourmistrova, N. W., Solomon, T., Braude, P., Strawbridge, R., & Carter, B. (2022, Feb 15). Long-term effects of COVID-19 on mental health: A systematic review. *Journal of Affective Disorders, 299*, 118-125. https://doi.org/10.1016/j.jad.2021.11.031

Bushnell, E. W., & Boudreau, J. P. (1993, Aug). Motor development and the mind: the potential role of motor abilities as a determinant of aspects of perceptual development. *Child Development, 64*(4), 1005-1021.

Cairney, J., Dudley, D., Kwan, M., Bulten, R., & Kriellaars, D. (2019). Physical Literacy, Physical Activity and Health: Toward an Evidence-Informed Conceptual Model. *Sports medicine (Auckland, N.Z.), 49*(3), 371–383. https://doi.org/10.1007/s40279-019-01063-3

Dawel, A., Shou, Y., Smithson, M., Cherbuin, N., Banfield, M., Calear, A. L., Farrer, L. M., Gray, D., Gulliver, A., Housen, T., McCallum, S. M., Morse, A. R., Murray, K., Newman, E., Rodney Harris, R. M., & Batterham, P. J. (2020, Oct 6). The Effect of COVID-19 on Mental Health and Wellbeing in a Representative Sample of Australian Adults [Original Research]. *Frontiers in Psychiatry, 11*. https://doi.org/10.3389/fpsyt.2020.579985

ECDC. (2022). *Data on country response measures to COVID-19.* Retrieved from https://www.ecdc.europa.eu/en/publications-data/download-data-response-measures-covid-19

Escalie, G., Recoules, N., Sébastien, C., & Legrain, P. (2017, Nov 2). Helping students build competences in physical education: theoretical proposals and illustrations. *Sport, Education and Society, 24*, 1-14. https://doi.org/10.1080/13573322.2017.1397507

Fairclough, S., & Stratton, G. (2004). 'Physical education makes you fit and healthy'. Physical education's contribution to young people's physical activity levels. *Health Education Research, 20*(1), 14-23. https://doi.org/10.1093/her/cyg101

Ferreira, L., Godinez, I., Gabbard, C., Vieira, J. L. L., & Caçola, P. (2018, Nov). Motor development in school-age children is associated with the home environment including socioeconomic status. *Child: Care, Health and Development, 44*(6), 801-806. https://doi.org/10.1111/cch.12606

Field, A., Miles, J., & Field, Z. (2012). *Discovering statistics using R: and sex and drugs and rock 'n' roll*.

Fühner, T., Kliegl, R., Arntz, F., Kriemler, S., & Granacher, U. (2021, Feb 1). An Update on Secular Trends in Physical Fitness of Children and Adolescents from 1972 to 2015: A Systematic Review. *Sports Medicine, 51*(2), 303-320. https://doi.org/10.1007/s40279-020-01373-x

Halekoh, U., & Højsgaard, S. (2014, Sep 12). A Kenward-Roger Approximation and Parametric Bootstrap Methods for Tests in Linear Mixed Models – The R Package pbkrtest. *Journal of Statistical Software, 59*(9), 1 - 32. https://doi.org/10.18637/jss.v059.i09

Hamatani, S., Hiraoka, D., Makita, K., Tomoda, A., & Mizuno, Y. (2022, Nov 15). Longitudinal impact of COVID-19 pandemic on mental health of children in the ABCD study cohort. *Scientific Reports, 12*(1), 19601. https://doi.org/10.1038/s41598-022-22694-z

Hands, B., Licari, M., & Piek, J. (2015, Jun-Jul). A review of five tests to identify motor coordination difficulties in young adults. *Research in Developmental Disabilities, 41-42*, 40-51. https://doi.org/10.1016/j.ridd.2015.05.009

Hirvensalo, M., & Lintunen, T. (2011, Apr 1). Life-course perspective for physical activity and sports participation. *European Review of Aging and Physical Activity, 8*, 13-22. https://doi.org/10.1007/s11556-010-0076-3

Kauhanen, L., Wan Mohd Yunus, W. M. A., Lempinen, L., Peltonen, K., Gyllenberg, D., Mishina, K., Gilbert, S., Bastola, K., Brown, J. S. L., & Sourander, A. (2022, Aug 12). A systematic review of the mental health changes of children and young people before and during the COVID-19 pandemic. *European Child and Adolescent Psychiatry*. https://doi.org/10.1007/s00787-022-02060-0

Knaier, E., Chaouch, A., Caflisch, J. A., Rousson, V., Wehrle, F. M., Kakebeeke, T. H., & Jenni, O. G. (2023, Mar 27). Secular trends in motor performance in Swiss children and adolescents from 1983 to 2018 [Original Research]. *Frontiers in Public Health, 11*. https://doi.org/10.3389/fpubh.2023.1095586

Lenth, R. (2020). *emmeans: Estimated Marginal Means, aka Least-Squares Means.* In https://CRAN.R-project.org/package=emmeans

Ludyga, S., Gerber, M., Pühse, U., Looser, V. N., & Kamijo, K. (2020, Mar 30). Systematic review and meta-analysis investigating moderators of long-term effects of exercise on cognition in healthy individuals. *Nature Human Behaviour*. https://doi.org/10.1038/s41562-020-0851-8

Naul, R., Utesch, T., & Niehues, D. (2018). Linking physical education with local sport organizations: Implementation of an "active school community".. *European Journal of Physical Education and Sport Science, 4*(11), 1-27. https://doi.org/10.5281/zenodo.1411519

Niessner, C., Utesch, T., Oriwol, D., Hanssen-Doose, A., Schmidt, S. C. E., Woll, A., Bös, K., & Worth, A. (2020, Sep 11). Representative Percentile Curves of Physical Fitness From Early Childhood to Early Adulthood: The MoMo Study [Brief Research Report]. *Frontiers in Public Health, 8*. https://doi.org/10.3389/fpubh.2020.00458

Oppici, L., Stell, F. M., Utesch, T., Woods, C. T., Foweather, L., & Rudd, J. R. (2022). A skill acquisition perspective on the impact of exergaming technology on foundational movement skill development in children 3–12 years: a systematic review and meta-analysis. *Sports Medicine-Open*, *8*(1), 1-15.

O'Sullivan, R., Burns, A., Leavey, G., Leroi, I., Burholt, V., Lubben, J., Holt-Lunstad, J., Victor, C., Lawlor, B., Vilar-Compte, M., Perissinotto, C. M., Tully, M. A., Sullivan, M. P., Rosato, M., Power, J. M., Tiilikainen, E., & Prohaska, T. R. (2021, Sep 23). Impact of the COVID-19 Pandemic on Loneliness and Social Isolation: A Multi-Country Study. *International Journal of Environmental Research and Public Health, 18*(19). https://doi.org/10.3390/ijerph18199982

R Core Team. (2020). *R: A Language and Environment for Statistical Computing.* In R Foundation for Statistical Computing. https://www.R-project.org/

Rahman, A. M., & Chandrasekaran, B. (2021, Nov). Estimating the Impact of the Pandemic on Children's Physical Health: A Scoping Review. *Journal of School Health, 91*(11), 936-947. https://doi.org/10.1111/josh.13079

Ravens-Sieberer, U., Kaman, A., Erhart, M., Devine, J., Schlack, R., & Otto, C. (2021). Impact of the COVID-19 pandemic on quality of life and mental health in children and adolescents in Germany. *European Child and Adolescent Psychiatry*. https://doi.org/10.1007/s00787-021-01726-5

Rodriguez-Ayllon, M., Cadenas-Sánchez, C., Estévez-López, F., Muñoz, N. E., Mora-Gonzalez, J., Migueles, J. H., Molina-García, P., Henriksson, H., Mena-Molina, A., Martínez-Vizcaíno, V., Catena, A., Löf, M., Erickson, K. I., Lubans, D. R., Ortega, F. B., & Esteban-Cornejo, I. (2019). Role of Physical Activity and Sedentary Behavior in the Mental Health of Preschoolers, Children and Adolescents: A Systematic Review and Meta-Analysis. *Sports Medicine, 49*(9), 1383–1410. https://doi.org/10.1007/s40279-019-01099-5

Rossi, L., Behme, N., & Breuer, C. (2021, Oct 30). Physical Activity of Children and Adolescents during the COVID-19 Pandemic-A Scoping Review. *International Journal of Environmental Research and Public Health, 18*(21). https://doi.org/10.3390/ijerph182111440

Sallis, J. F., Bull, F., Guthold, R., Heath, G. W., Inoue, S., Kelly, P., Oyeyemi, A. L., Perez, L. G., Richards, J., & Hallal, P. C. (2016). Progress in physical activity over the Olympic quadrennium. *The Lancet, 388*(10051), 1325-1336. https://doi.org/10.1016/S0140-6736(16)30581-5

Schlag, E., Ferrari, N., Koch, B., Dordel, S., & Joisten, C. (2021). Secular trends in motor performance of children and adolescents between 2010 and 2020. *TRANSLATIONAL SPORTS MEDICINE, 4*(6), 882-891. https://doi.org/https://doi.org/10.1002/tsm2.292

Schmidt, S. C. E., Anedda, B., Burchartz, A., Eichsteller, A., Kolb, S., Nigg, C., Niessner, C., Oriwol, D., Worth, A., & Woll, A. (2020). Physical activity and screen time of children and adolescents before and during the COVID-19 lockdown in Germany: a natural experiment. *Scientific Reports, 10*(1), 21780. https://doi.org/10.1038/s41598-020-78438-4

Schmutz, E. A., Leeger-Aschmann, C. S., Kakebeeke, T. H., Zysset, A. E., Messerli-Bürgy, N., Stülb, K., Arhab, A., Meyer, A. H., Munsch, S., Puder, J. J., Jenni, O. G., & Kriemler, S. (2020). Motor Competence and Physical Activity in Early Childhood: Stability and Relationship. *Frontiers in Public Health, 8*, 39. https://doi.org/10.3389/fpubh.2020.00039

Slining, M., Adair, L. S., Goldman, B. D., Borja, J. B., & Bentley, M. (2010, Jul). Infant overweight is associated with delayed motor development. *Journal of Pediatrics, 157*(1), 20-25.e21. https://doi.org/10.1016/j.jpeds.2009.12.054

Spengler, S., Rabel, M., Kuritz, A. M., & Mess, F. (2017, Sep 29). Trends in Motor Performance of First Graders: A Comparison of Cohorts from 2006 to 2015 [Original Research]. *Frontiers in Pediatrics, 5*. https://doi.org/10.3389/fped.2017.00206

Stodden, D. F., Goodway, J. D., Langendorfer, S. J., Roberton, M. A., Rudisill, M. E., Garcia, C., & Garcia, L. E. (2008, May 1). A Developmental Perspective on the Role of Motor Skill Competence in Physical Activity: An Emergent Relationship. *New Quest, 60*(2), 290-306. https://doi.org/10.1080/00336297.2008.10483582

Telama, R., Yang, X., Laakso, L., & Viikari, J. (1997, Jul 1). Physical Activity in Childhood and Adolescence as Predictor of Physical Activity in Young Adulthood. *American Journal of Preventive Medicine, 13*, 317-323. https://doi.org/10.1016/S0749-3797(18)30182-X

Telama, R., Yang, X., Viikari, J., Välimäki, I., Wanne, O., & Raitakari, O. (2005, May 1). Physical activity from childhood to adulthood - A 21-year tracking study. *American Journal of Preventive Medicine, 28*, 267-273. https://doi.org/10.1016/j.amepre.2004.12.003

Thelen, E. (1985, Jan). Developmental origins of motor coordination: leg movements in human infants. *Developmental Psychobiology, 18*(1), 1-22. https://doi.org/10.1002/dev.420180102

Tomkinson, G. R., Kaster, T., Dooley, F. L., Fitzgerald, J. S., Annandale, M., Ferrar, K., Lang, J. J., & Smith, J. J. (2021, Mar). Temporal Trends in the Standing Broad Jump Performance of 10,940,801 Children and Adolescents Between 1960 and 2017. *Sports Medicine, 51*(3), 531-548. https://doi.org/10.1007/s40279-020-01394-6

Tomkinson, G. R., Léger, L. A., Olds, T. S., & Cazorla, G. (2003). Secular trends in the performance of children and adolescents (1980-2000): an analysis of 55 studies of the 20m shuttle run test in 11 countries. *Sports Medicine, 33*(4), 285-300. https://doi.org/10.2165/00007256-200333040-00003

Utesch, T., Bardid, F., Büsch, D., & Strauss, B. (2019). The relationship between motor competence and physical fitness from early childhood to early adulthood: A meta-analysis. *Sports Medicine*, *49*, 541-551.

Utesch, T., Dreiskämper, D., Naul, R., & Geukes, K. (2018). Understanding physical (in-) activity, overweight, and obesity in childhood: Effects of congruence between physical self-concept and motor competence. *Scientific Reports, 8*(1), 5908. https://doi.org/10.1038/s41598-018-24139-y

Utesch, T., Strauß, B., Tietjens, M., Büsch, D., Ghanbari, M.-C., & Seidel, I. (2015). Die Überprüfung der Konstruktvalidität des Deutschen Motorik-Tests 6-18 für 9- bis 10-Jährige. *Zeitschrift für Sportpsychologie, 22*(2), 77-90. https://doi.org/10.1026/1612-5010/a000143

Utesch, T., Zinner, J., & Büsch, D. (2018, Apr 17). Stabilität der physischen Fitness im Kindesalter: Konstruktvalidität der Referenzkategorien für den Deutschen Motorik-Test 6–18 im Projekt „Berlin hat Talent" über fünf Jahre. *German Journal of Exercise and Sport Research, 48*. https://doi.org/10.1007/s12662-018-0500-9

von Elm, E., Altman, D. G., Egger, M., Pocock, S. J., Gøtzsche, P. C., & Vandenbroucke, J. P. (2008, Apr). The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *Journal of Clinical Epidemiology, 61*(4), 344-349. https://doi.org/10.1016/j.jclinepi.2007.11.008

Wunsch, K., Nigg, C., Niessner, C., Schmidt, S. C. E., Oriwol, D., Hanssen-Doose, A., Burchartz, A., Eichsteller, A., Kolb, S., Worth, A., & Woll, A. (2021). The Impact of COVID-19 on the Interrelation of Physical Activity, Screen Time and Health-Related Quality of Life in Children and Adolescents in Germany: Results of the Motorik-Modul Study. *Children (Basel, Switzerland), 8*(2). https://doi.org/10.3390/children8020098

Zinner, J., & Büsch, D. (2014). *Berlin hat Talent: Zwischenbericht für das Schuljahr 2012/13*.

Zinner, J., & Büsch, D. (2016). Berlin hat Talent: Ausgewählte Ergebnisse des Schuljahres 2014/15. In (pp. 109-124).

Zinner, J., Büsch, D., Poller, T., & Bartko, R. (2015, May 1). Berlin hat Talent: Zwischenbericht für die Jahre 2012 und 2013. *45*, 14-18.

Zinner, J., Werner, C., Mehler, S., & Rois, L. (2015). *Berlin hat Talent: Ergebnisse der Untersuchungen in Berlin 2014*.

Declarations

Ethics Approval and Consent to Participate

The study and the consent forms signed by the subjects were approved by the Senate of Berlin.

Conflicts of Interest

The authors declare no conflict of interest.

Funding

This research is part of the PESCov project ('Physical Education, Sport, and Corona-Virus Pandemic: Understanding consequences of COVIF-19 pandemic lockdowns on children's and youth physical literacy') that was funded by the German Research Foundation (DFG, Nr.: UT 158/1–1). Data were obtained from the Berlin hat Talent Study. The Berlin hat Talent Study is funded by the Senate of Berlin and is carried out by the DSHS Berlin. The funders had no role in study design, data collection, analysis, and interpretation..

Author Contributions

RS: Conceptualization, Writing-Reviewing and Editing, Methodology, Analyses **KG**: Writing-Reviewing and Editing, Analyses **LP**: Writing-Reviewing and Editing, Analyses. **MJ**: Writing-Reviewing and Editing, Analyses **JZ**: Data, Writing-Reviewing and Editing. **DB**: Data, Writing-Reviewing and Editing **TU**: Conceptualization, Writing-Reviewing and Editing, Methodology, Analyses

Acknowledgements

We thank all former and current staff of the 'Berlin Hat Talent' study for project administration, investigation, data assessment, cleaning, and preparation. We also thank all participants and their parents for taking part in this study.

Data Availability Statement

The data that support the findings of this study are available upon reasonable request from the principal investigators of the MoMo Study. Please contact the corresponding author for further information.

Figures

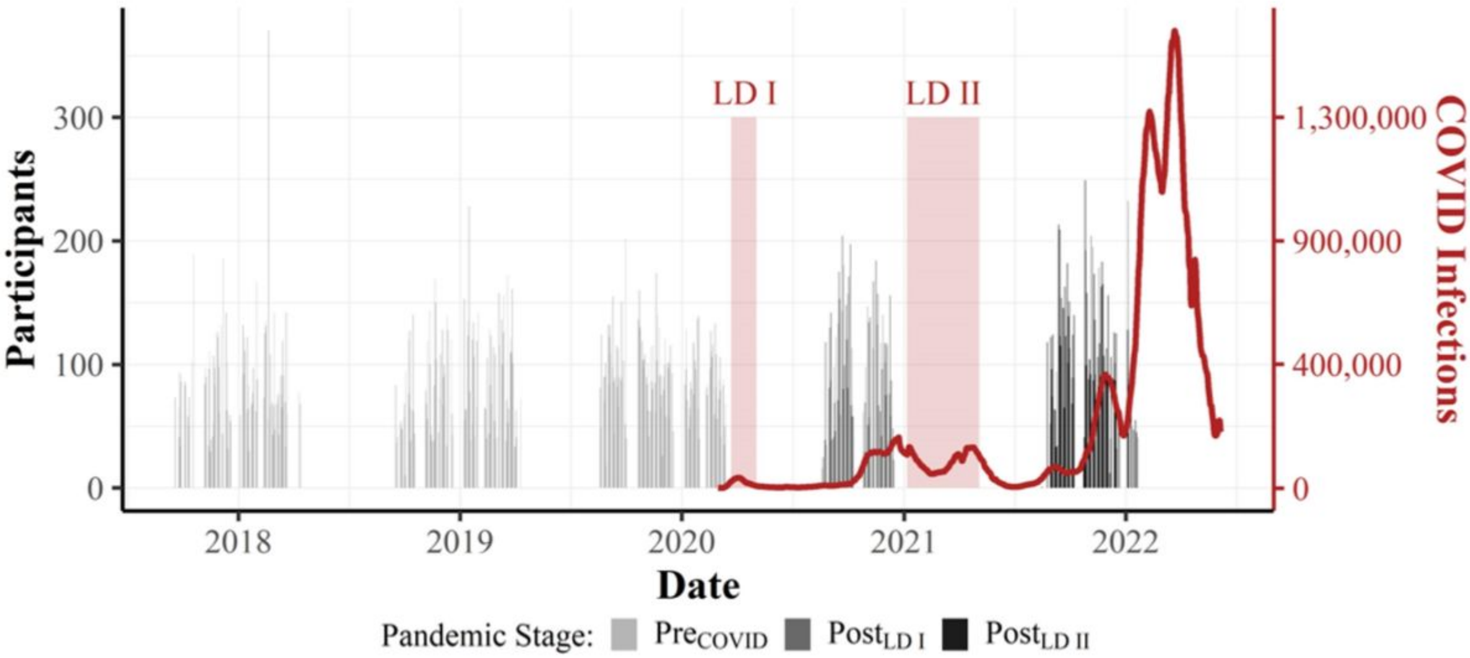

Figure 1

Exemplary overview of the number of third graders assessed in the two years before COVID-19 and after the two major lockdown periods in Germany (LD 1 and LD II) from 2018 to 2022 illustrating that the dates of assessments throughout the year.

In the current study, data from 68,996 children were analyzed (Age: 8.83 years +- 0.56, range: 6.4-13 years, 35,270 females, 51.1 %, which were assessed between school years 2011/2012 and 2021/2022.

Note. Assessments prior to 08/2018 are not shown here because the date of the assessment was not available. The two lockdown periods are highlighted as transparent red areas. Light gray color indicates assessments before COVID (Pre_{Covid}, left), darker gray color indicates assessments after Lockdown I ($Post_{LD\ I}$), dark gray color indicates assessments after Lockdown II ($Post_{LD\ II}$). The prevalence of COVID-19, i.e. the number of actively infected individuals, is shown as red solid line.

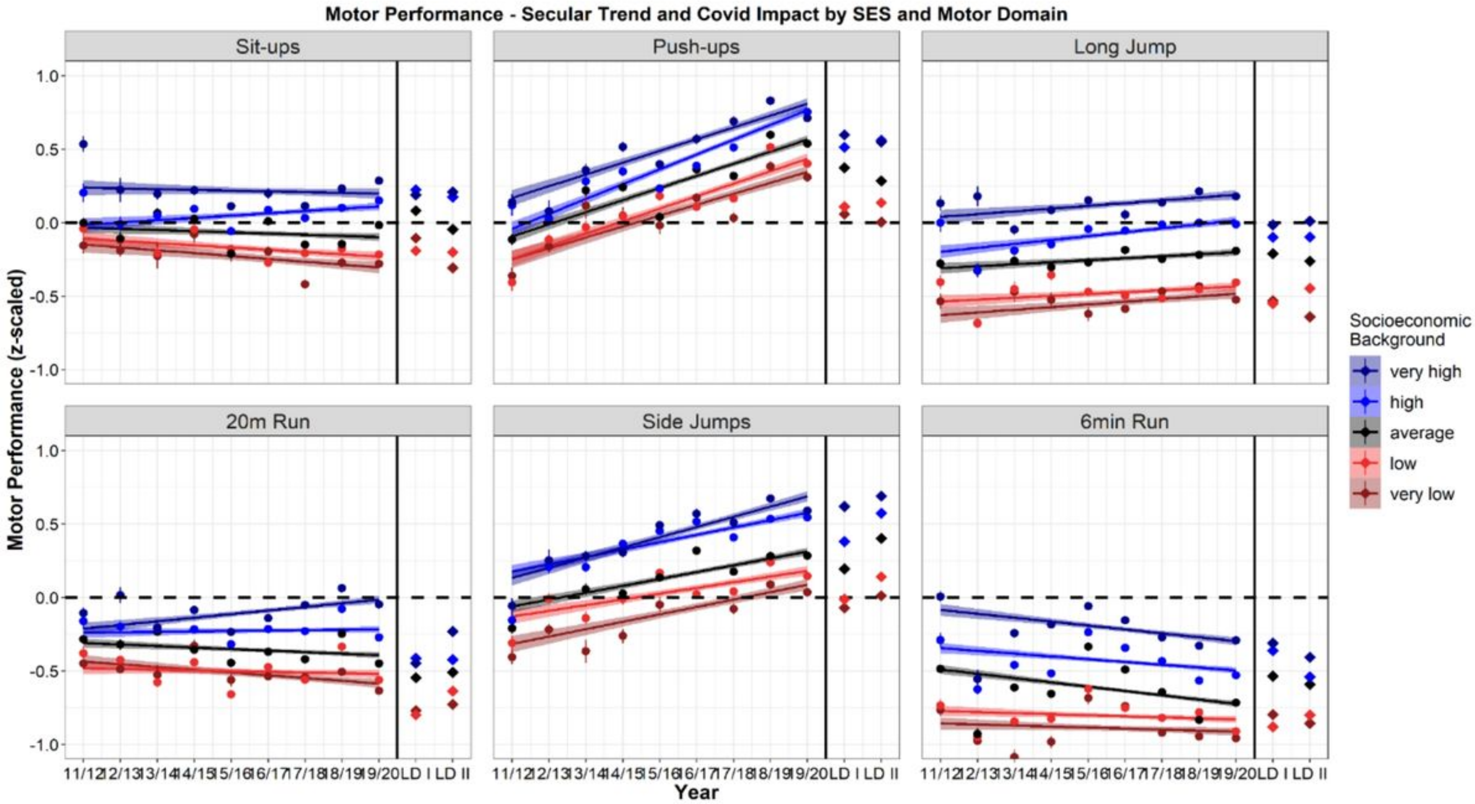

Figure 2

Secular trend of motor performance between 2011 to 2019 and motor performance during the pandemic (after LDI and LDII) per Motor Domain (panel) and school-level socioeconomic background (color).

Note. Motor Performance (z-transformed quantile-normalized percentile values) are presented on the y-axis, school years from 2011/12 to 2022/23 are given on the x-axis. Linear secular trends (straight lines) were calculated based on data from 2011/12 to 2019/20 (points) for each Motor Domains and socioeconomic background separately. Motor performance values during pandemic (rhombs) are also presented per Motor Domain and socioeconomic background to the right of the straight black line per panel.

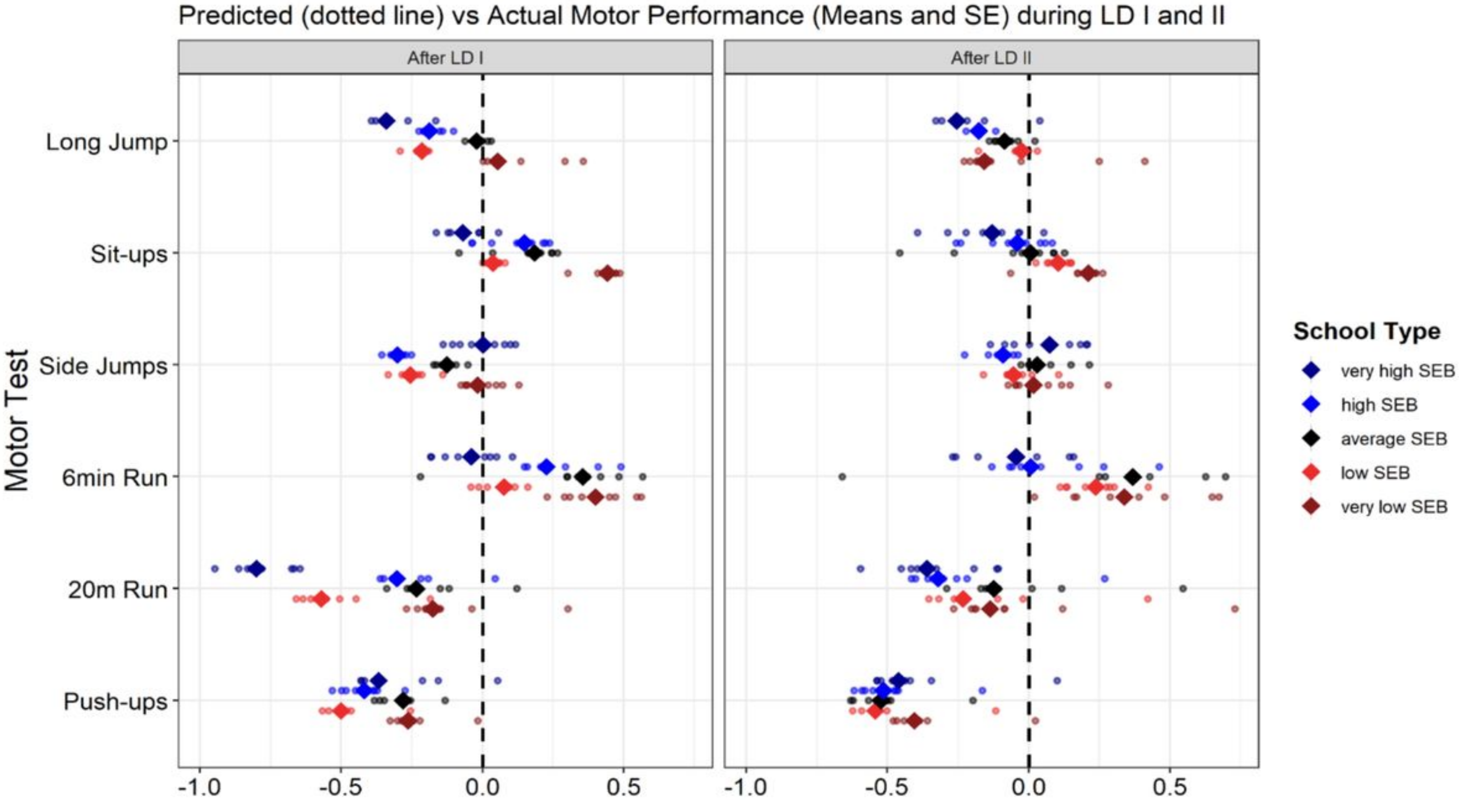

Figure 3

Predicted (dotted line) and actual motor performance (colored dots) during pandemic lockdowns LDI (left) and LDII (right) per Motor Domain (y-axis) and school-based socioeconomic background (by color) using different starting years for secular trend prediction.

Note. Rhombs reflect the median of estimates for the different starting years. Estimates located to the left of the dotted black prediction line indicate lower actual motor performance during pandemic compared to the predicted motor performance, while estimates to the right indicate higher actual motor performance compared to predicted motor performance during pandemic.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- ReadMeCode.txt
- NATHUMBEHAV23082557nrsoftwarepolicy002.pdf
- Supplement.docx