Pandemic Disruptions and Their Consequences: A Comparative Analysis of Physical and Cognitive Development in Preschool Children

Huiqi Song, Jingjing Wang, Patrick Lau, Jing Liu, Lei Shi

Submitted to: JMIR Public Health and Surveillance
on: November 28, 2024

Table of Contents

Pandemic Disruptions and Their Consequences: A Comparative Analysis of Physical and Cognitive Development in Preschool Children

Huiqi Song[1]; Jingjing Wang[2]; Patrick Lau[3]; Jing Liu[4]; Lei Shi[4]

[1]China Institute of Sport Science Beijing CN
[2]Hong Kong Baptist University Hong Kong HK
[3]Beijing Normal University - Hong Kong Baptist University United International College Zhuhai CN

Corresponding Author:
Huiqi Song

Abstract

Background: The COVID-19 pandemic significantly disrupted the daily routines of preschool children, potentially impacting their fundamental movement skills (FMS), physical activity (PA), physical fitness (PF), and executive function (EF).

Objective: This study aimed to compare FMS, PA, PF, and EF in preschool children during the COVID-19 pandemic with those after its peak. It also investigated the associations between these components to inform potential interventions for cognitive and physical development.

Methods: The study involved two cohorts of preschool children aged 5 to 6 years from four kindergartens in Zhuhai, China. Data were collected in two phases: the pandemic cohort during September to November 2021 and the post-pandemic cohort from September to November 2023. Participants' demographic data, anthropometric measurements, and performance in FMS, PA, PF, and EF were assessed. FMS was evaluated using the Test of Gross Motor Development, PA was monitored with accelerometers, and EF was measured through computerized tasks assessing cognitive flexibility, inhibitory control, and working memory. Statistical analyses included independent sample t-tests and generalized linear mixed models.

Results: A total of 174 children participated in the pandemic cohort, and 189 in the post-pandemic cohort. Post-pandemic participants demonstrated significantly better performance in locomotor skills ($p < 0.001$), balance ($p < 0.001$), cardiorespiratory fitness ($p = 0.002$), flexibility ($p < 0.001$), muscular strength ($p < 0.001$), muscular endurance ($p = 0.019$), speed-agility ($p < 0.001$), inhibitory control ($p < 0.001$), and working memory ($p = 0.004$) compared to their pandemic peers. Conversely, pandemic participants exhibited higher scores in ball skills ($p < 0.001$) and spent more time in moderate-to-vigorous physical activity (MVPA) ($p = 0.002$). Notably, associations between FMS, PA, PF, and EF varied between cohorts, with PF positively correlating with EF components post-pandemic.

Conclusions: The findings highlight significant differences in FMS, PA, PF, and EF between preschool children during and after the COVID-19 pandemic. The post-pandemic cohort showed improvements in various physical and cognitive skills, suggesting that interventions to restore and enhance these abilities are necessary. Furthermore, the study emphasizes the need for integrated approaches to support holistic development in preschool children, particularly in the wake of significant disruptions such as the pandemic.

(JMIR Preprints 28/11/2024:69375)
DOI: https://doi.org/10.2196/preprints.69375

Preprint Settings

1) Would you like to publish your submitted manuscript as preprint?
✔ **Please make my preprint PDF available to anyone at any time (recommended).**
Please make my preprint PDF available only to logged-in users; I understand that my title and abstract will remain visible to all users.
Only make the preprint title and abstract visible.
No, I do not wish to publish my submitted manuscript as a preprint.
2) If accepted for publication in a JMIR journal, would you like the PDF to be visible to the public?
✔ **Yes, please make my accepted manuscript PDF available to anyone at any time (Recommended).**

Yes, but please make my accepted manuscript PDF available only to logged-in users; I understand that the title and abstract will remain v
Yes, but only make the title and abstract visible (see Important note, above). I understand that if I later pay to participate in <a href="http

Original Manuscript

Pandemic Disruptions and Their Consequences: A Comparative Analysis of Physical and Cognitive Development in Preschool Children

Abstract

Background: The COVID-19 pandemic significantly disrupted the daily routines of preschool children, potentially impacting their fundamental movement skills (FMS), physical activity (PA), physical fitness (PF), and executive function (EF).

Objectives: This study aimed to compare FMS, PA, PF, and EF in preschool children during the COVID-19 pandemic with those after its peak. It also investigated the associations between these components to inform potential interventions for cognitive and physical development.

Methods: The study involved two cohorts of preschool children aged 5 to 6 years from four kindergartens in Zhuhai, China. Data were collected in two phases: the pandemic cohort during September to November 2021 and the post-pandemic cohort from September to November 2023. Participants' demographic data, anthropometric measurements, and performance in FMS, PA, PF, and EF were assessed. FMS was evaluated using the Test of Gross Motor Development, PA was monitored with accelerometers, and EF was measured through computerized tasks assessing cognitive flexibility, inhibitory control, and working memory. Statistical analyses included independent sample t-tests and generalized linear mixed models.

Results: A total of 174 children participated in the pandemic cohort, and 189 in the post-pandemic cohort. Post-pandemic participants demonstrated significantly better performance in locomotor skills ($p < 0.001$), balance ($p < 0.001$), cardiorespiratory fitness ($p = 0.002$), flexibility ($p < 0.001$), muscular strength ($p < 0.001$), muscular endurance ($p = 0.019$), speed-agility ($p < 0.001$), inhibitory control ($p < 0.001$), and working memory ($p = 0.004$) compared to their pandemic peers. Conversely, pandemic participants exhibited higher scores in ball skills ($p < 0.001$) and spent more time in moderate-to-vigorous physical activity (MVPA) ($p = 0.002$). Notably, associations between FMS, PA, PF, and EF varied between cohorts, with PF positively correlating with EF components post-pandemic.

Conclusion: The findings highlight significant differences in FMS, PA, PF, and EF between preschool children during and after the COVID-19 pandemic. The post-pandemic cohort showed improvements in various physical and cognitive skills, suggesting that interventions to restore and enhance these abilities are necessary. Furthermore, the study emphasizes the need for integrated approaches to support holistic development in preschool children, particularly in the wake of significant disruptions such as the pandemic.

Keywords: fundamental movement skills; physical activity; physical fitness; executive function; preschool children; COVID-19

Introduction

Executive function (EF) is defined as a set of top-down cognitive processes that reflect the ability to flexibly adapt to contextual demands in goal-directed behaviors. Working memory, inhibitory control, and cognitive flexibility have been considered as the fundamental components of EF [1]. Early childhood is a notably critical period for EF emergence and development. EF in early childhood is positively associated with academic achievement, social-emotional development, and school success in late childhood [2-4].

Fundamental movement skill (FMS) is the basis of more complex movements required to participate in sports, games, or other activities [5]. Physical activity (PA) is any body movement produced by skeletal muscles that requires energy expenditure [6]. Physical fitness (PF) refers to the general ability to perform PA, including aerobic fitness, muscular strength, endurance, flexibility, speed, and balance [7]. Early childhood is also characterized by rapid development in FMS, PA, and PF. Mastering FMS provides more opportunities for sports participation during early childhood [8]. Sufficient PA during the early years improves physical and mental health [9]. PF is one of the most powerful markers for health and daily life activities in preschoolers [10]. FMS, PA, and PF are based on body movements, which are closely related and differentiated.

Empirical studies suggest that FMS is positively associated with EF in preschool children. Stein et al. (2017) found that FMS was positively related to EF, especially cognitive flexibility in 5-6 year-old children [11]. A cross-sectional study showed that FMS was moderately and positively correlated with EF [12]. There are explanations for the association between children's FMS and EF. The underlying processes, such as sequencing, monitoring, and planning are shared between motor skills and cognitive abilities [13]. In higher demanding complex tasks, motor and cognitive tasks are assumed to share neural mechanisms and take advantage of common resources to enable information processing, behavioral organization, and attention or suppression of irrelevant stimuli [14]. Another explanation for the relationship is that motor and cognitive abilities may have similar developmental timelines during childhood, are acquired comparably, exhibit similar learning stages, and have related training effects [15].

The developmental and learning mechanisms suggest that engagement in PA can provide valuable learning experiences that promote the development of EF and may even serve as prerequisites for EF development [16]. Besides, PA can trigger specific biochemical and hormonal changes, such as improving cerebral blood flow and increasing neurotransmitter levels in brain regions associated with EF [17,18]. However, the relationship between PA and EF in preschoolers is still in their inception due to divergent results in previous studies [19]. McNeill et al. (2018) found a positive association between PA and EF [20]. Another study indicated that a higher level of MVPA was associated with lower EF skills [21]. The above findings conflict with the results that the association between PA and EF was not significant [22].

Individuals with higher levels of PF are more able to carry oxygen and confer the ability to compensate for the negative effects of vigorous exercise while performing EF tasks. Thus, EF performance can be improved through the improvement of PF [23]. There are scarce studies on the relationship between PF and EF in preschoolers and their findings are inconsistent. Hermahayu et al.

(2019) indicated that muscular strength and agility were positively related to EF [24]. Health-related PF was positively associated with inhibitory control in preschoolers [25]. A cross-sectional study indicated that CRF was not associated with any cognitive variables [26].

The continuation of the COVID-19 pandemic and large-scale quarantine has resulted in massive changes in preschoolers' daily routines, subsequently having detrimental consequences to physical and cognitive function. A cross-sectional study reported that the COVID-19 pandemic impeded FMS development, especially for object control skills [27]. MVPA time was significantly short due to insufficient opportunities for exercise during the COVID-19 pandemic [28]. The reduction in physical fitness outcomes in all preschool children was found during the pandemic [29]. Preschool children showed slower growth of cognitive flexibility and working memory during the lockdown compared to their peers before the pandemic [30].

However, little is known about whether the adverse impacts of COVID-19 on physical and cognitive function changed after the end of the epidemic. Besides, evidence of the association between FMS, PA, PF, and EF is limited and inconsistent [31]. Therefore, this study aimed to examine the differences in FMS, PA, PF, and EF between preschool children during the COVID-19 pandemic and those after the pandemic. This study also explored the association between FMS, PA, PF, and EF during and after the COVID-19 pandemic. Specifically, this study aimed to examine whether the components of FMS, PA, and PF are associated with the different components of EF (cognitive flexibility, inhibitory control, and working memory). By identifying which components of physical function are associated with cognitive development, it is possible to promote optimal cognitive development for prevention, intervention, and educational purposes in preschool children after this challenging period.

Methods

Participants

Preschool education is provided by kindergartens for children aged 3–6 years in mainland China.

This study invited 45 registered kindergartens of the Zhuhai Early Childhood Education Association in Zhuhai, Guangdong Province, China for assessments. Four kindergartens agreed to participate in this study and all participants were of Han ethnicity. The four kindergartens were administrated by the same early childhood education provider and catered for children from urban areas with medium family socio-economic status (SES). Therefore, there is no difference between all participants in SES background and the pre-school education syllabus.

This study included two cohorts of children aged 5 to 6 years old. Between September 2021 to November 2021, pandemic cohort data was collected. During this period, the Guangdong government requested a reduction in the movement and gathering of people, and that all teachers and students in kindergartens should refrain from going out for non-essential purposes to strictly implement preventive and control measures against the outbreak of the disease (Guangdong Provincial Command Office for Prevention and Control of Coronavirus Disease, 2021). In May 2023, the COVID-19 pandemic no longer constitutes a 'public health emergency of international concern' (World Health Organization, 2023). The post-pandemic cohort invited children of the same age from the same kindergartens. Data were collected between September 2023 to November 2023.

Children were included in the study if (1) their parents provided written informed consent; (2) they were not diagnosed with important organ diseases or any neurological disorders; and (3) they were normally developing children with the corresponding cognitive ability.

This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines.

Measures

Demographic data

Participants' demographic data including birth date, gender, and SES was collected through parent-reported questionnaire. SES consisted of fathers' and mothers' education levels and income. According to the Chinese education system, parental education level was divided into low (secondary school or below), middle (high school), and high (university or above). Parental income included low (≤US$603/month), middle (US$604- US$757/month), high (US$758- US$2682/month), and highest (> US$2683/month) [32]. The score for each variable was transformed into a z-score and used to calculate a mean to represent the SES [33,34].

Anthropometric measurements

The measurements of height and weight were conducted using a stadiometer (Seca) and a weight scale (Wujin, RGT-120), respectively, while the participants were barefoot and lightly clothed. The body mass index (BMI) was computed by dividing the body weight by the square of height (kg/m^2). To account for age and gender variations in growth patterns, the BMI was transformed into BMI z-scores using the LMS method [35].

Executive function

Child-friendly computerized behavioral tasks including the ‘animal Stroop’ task, ‘stop-signal’ task, and ‘safari training’ task, were used to assess different aspects of EF. Participants completed the tasks in the order of animal Stroop task, stop-signal task, and safari training task. To minimize fatigue, no time-limit breaks were provided between the tasks. This measurement took place individually in a quiet room within the kindergarten, supervised by a competent research assistant. The duration of the EF tasks and practice time was approximately 20 minutes.

The animal Stroop task is a nonverbal task to assess participants’ ability to flexibly inhibit a prepotent or habitual response [36]. During each trial, participants were presented with an image and a sound, both depicting animals. Participants were asked to determine whether the sound of the animal and the image of the animal were congruent or incongruent. Participants completed five warm-up trials to familiarize themselves with the task procedure and the requirement for rapid responses. The formal task included a total of 100 trials and lasted about 2 minutes. The Stroop effect is calculated as the average response time difference between incompatible and compatible trials.

The stop-signal task assesses response inhibition and control impulsivity. During the practice stage, participants were instructed to respond as quickly as possible to a series of arrows pointing either left or right, with the arrow circled in green. Children's understanding of the task requirements was checked, such as identifying the correct response key and the corresponding finger. Only when children answered all understanding checks correctly were they allowed to proceed to the testing phase; otherwise, they received further instruction and understanding checks. The practice block only included go trials to emphasize the importance of the go component for young children [37]. Feedback was provided after each trial, and the average reaction time was presented at the end of the practice to engage children's interest. The practice stage consists of 10 trials. In the formal task, participants were instructed not to respond to arrows circled in red. Performance feedback was given after each trial. The formal task comprised 100 trials and lasted around 2 minutes. The mean reaction time for go trials is used as an indicator of response inhibition ability.

The safari training task was used to assess working memory [38]. The working memory span task includes two stages. In the processing/encoding stage, participants were presented with various animal pictures and required to indicate the orientation of each picture. If participants' responses took longer than 3 seconds or if they incorrectly indicated the orientation, they received negative feedback. In the recall stage, participants were instructed to reproduce the sequence of animal pictures presented in the processing/encoding stage in the correct order, without any time limitation. To maintain engagement, feedback was provided after each trial. This task consists of a total of 90 trials and lasts for 6 minutes. The proportion of correct recall (i.e., accuracy) of each participant serves as the dependent variable.

FMS

The Test of Gross Motor Development Third Edition (TGMD-3) is used to assess FMS [39]. It is subdivided into locomotor and ball skills subscales. Six locomotors and seven ball skills were measured. Each skill was assessed twice. The sum of scores obtained from the two performance trials for each skill was used to calculate a raw score. Scoring and coding were completed by the research assistant and checked by a second research assistant familiar with the administration of the TGMD-3.

PA

A tri-axial accelerometry (Actigraph, model GT3-BT, Florida) was used to objectively monitor PA. The device initialization and data analysis were performed using the ActiLife software (version 6.13). The accelerometer was attached to the participant's right hip for 24 hours over seven consecutive days, during all activities except for sleeping and water-related activities. A recording epoch of 15 seconds was used, and valid wear time was defined as a minimum of 10 hours of wear time across at least three days (two weekdays and one weekend day). Non-wear time was determined by 20 consecutive minutes of zero count/minute. The accelerometers were initialized at a sampling rate of 30 Hz and then reintegrated into 60-second epochs for analysis. The activity counts recorded by the accelerometer were categorized into different intensity levels using the cut-off points [40]: sedentary (< 819 counts per minute (CPM)), light (820-3907 CPM), moderate (3908-6111 CPM), and vigorous (≥ 6112 CPM).

PF

Cardiorespiratory fitness was measured using the 20-meter shuttle run test. Participants ran back and forth between two tracks spaced 20 meters apart, starting at an initial speed of 6.5 km/h. The speed was subsequently increased by 0.5 km/h per minute. The test was performed once. Considering the young age of the children involved, the track was marked, and a research assistant was guided to help participants maintain the running pace.

The sit and reach test was used to assess flexibility. The participant sat on a mat with bare feet, legs straight, heels together, toes naturally apart, and palms resting on the test board. Then participant was instructed to gradually lean forward and extend their arms to push the edge of the mobile board in a maximal effort while maintaining their knees in a static position. The procedure was conducted twice, and the highest value was recorded.

Sit-ups were used to assess the muscular endurance of the trunk. Participants lay on their backs with their knees bent and arms crossed over the other shoulder. They sat up and returned to the starting position. The research assistant held the participant’s feet. The test was performed once. The number of lifts that correctly reached the sitting position within 30 seconds was recorded.

Muscular strength was tested with a WCS-100 electronic dynamometer (Shanghai Wanqing Electronics Co., LTD.). Participants stood in a quiet environment and were instructed to remain relaxed with their arms in a neutral position. They were prompted to hold the dynamometer and adjust the grip distance, subsequently using maximum force to grasp the dynamometer. Two measurements were taken for both the left and right hand, with the highest value being recorded.

Dynamic balance was tested using a balance beam. The participants stood on the platform behind the starting line, facing the balance beam (3 m in length, 10 cm in width, and 30 cm in height), with their arms held out horizontally. The tester gave instructions started the stopwatch when the participant began, and closely followed the participant until they crossed the finishing line. The stopwatch was stopped as soon as either the tiptoe or the participant crossed the finishing line. The trial was conducted twice, with the best value being recorded.

Speed-agility was assessed through the 4 × 10 meter shuttle run test. Upon hearing the start signal, participants sprinted and executed a sharp turn around the 10-meter track, exerting maximal effort over a total distance of 40 meters. At the end of each section of the track, participants were required to touch the outstretched hand of the tester, who had moved beyond the boundary, with their foot before swiftly returning to the starting line. The best of the two tests was recorded.

Procedure

Before the study, signed consent forms were obtained from the parents and kindergartens. The training session for research and workshop for the kindergarten teachers were conducted. FMS, PF, and EF tests were carried out within one day in the kindergarten for each participant. The demographic information questionnaires were taken home by children to be filled in by their parents and returned to teachers at the specified time. The day after the completion of FMS, PF, and EF tests, accelerometers were placed on children who wore the monitors for seven consecutive days.

Data analysis

Statistical analyses were conducted using IBM's Statistical Package for Social Sciences (SPSS) version 29. Invalid and abnormal values, i.e., z-scores≥±3 SD, were excluded. Descriptive statistics were used to analyze continuous variables. Independent sample t-tests were used to compare the means for demographic data, FMS, PA, PF, and EF between two participant cohorts. The generalized linear mixed models were applied to determine whether FMS, PA, and PF were associated with EFs after controlling for age, gender, BMI z-score, and SES during and post-pandemic, respectively. The significance level α was set at 0.05.

Results

Descriptive statistics

A total of 174 participants were included in the pandemic cohort and 189 participants were included in the post-pandemic cohort (Figure 1). The mean age of the pandemic cohort was 5.5 years and 42.5% were girls. The mean age of the post-pandemic cohort was 5.5 years and 46.0% were girls. There was no significant difference in characteristics between pandemic and post-pandemic cohorts.

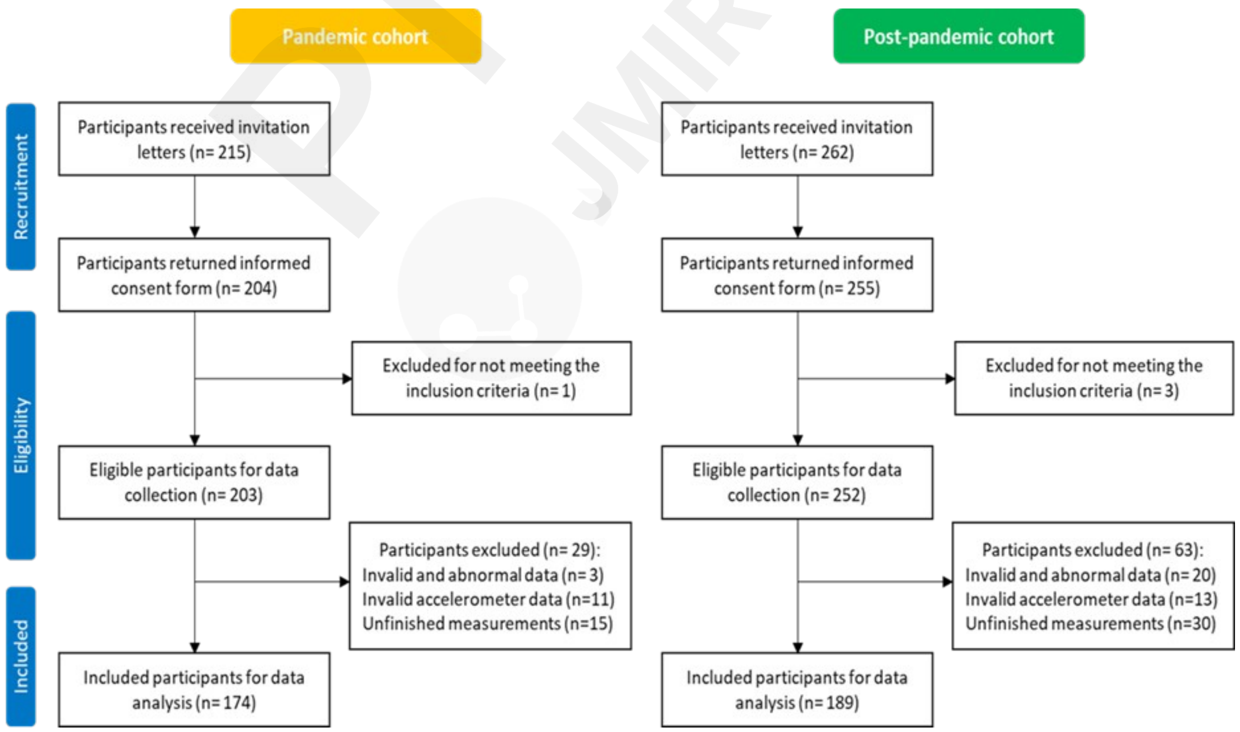

Figure 1. Flow chart of study

FMS, PA, PF, and EF during and post pandemic

The results showed that post-pandemic participants performed better in locomotor skills ($p< 0.001$), balance ($p< 0.001$), CRF ($p= 0.002$), flexibility ($p< 0.001$), muscular strength ($p< 0.001$), muscular endurance ($p= 0.019$), speed-agility ($p< 0.001$), inhibitory control ($p< 0.001$), and working memory ($p= 0.004$) than pandemic participants. Pandemic participants scored higher in ball skills than post-pandemic participants ($p< 0.001$). Compared to post-pandemic participants, pandemic participants spent more time in MVPA ($p= 0.002$). There was no significant difference in LPA and cognitive flexibility between pandemic and post-pandemic cohorts.

Association between FMS, PA, PF, and EF

For the pandemic cohort, higher ball skills score was associated with worse performance in cognitive flexibility ($\beta= -6.62$, 95% CI: -12.50, -0.74) and inhibitory control ($\beta= -2.90$, 95% CI: -5.64, -0.16). Spending more time in MVPA was associated with worse cognitive flexibility performance ($\beta= 1.33$, 95% CI: 0.15, 2.51). Spending more time in LPA had an association with worse inhibitory control skills ($\beta= 0.23$, 95% CI: 0.02, 0.44). Better flexibility was associated with better inhibitory control skills ($\beta= -2.58$, 95% CI: -4.27, -0.89). PF was not associated with cognitive flexibility. There was no association between FMS, PA, or PF, with working memory during the COVID-19 pandemic.

After the COVID-19 pandemic, better muscular strength performance was associated with better performance in cognitive flexibility ($\beta= -8.24$, 95% CI: -15.36, -1.13). Speed-agility was positively associated with inhibitory control ($\beta= 5.28$, 95% CI: 1.36, 9.20). FMS and PA were not associated with cognitive flexibility and inhibitory control. There was no association between FMS, PA, and PF, with working memory after the COVID-19 pandemic.

Discussion

This study compared the differences in FMS, PA, PF, and EF between two cohorts of preschool children and examined the association between FMS, PA, PF, and EF during and after the COVID-19 pandemic. Pandemic participants performed better in ball skills and MVPA time than post-pandemic participants. The post-pandemic cohort scored higher in locomotor skills, PF, inhibitory control, and working memory than the pandemic cohort. During the COVID-19 pandemic, certain EF components were negatively associated with ball skills and PA, and either positively associated with PF. After the COVID-19 pandemic, PF was associated with better EF components.

FMS, PA, PF, and EF during and post pandemic

The closure of schools and playgrounds during the early pandemic resulted in limited space, lack of sports instruction, and less time for children to move around, which further contributed to a decline in PA and related skills such as locomotor skills and PF [41] [42]. However, this study found that the pandemic cohort outperformed the post-pandemic cohort in ball skills and time spent engaged in MVPA, which is inconsistent with previous studies [27,43]. During COVID-19, lockdowns and social distancing measures drove children indoors for their play and recreation needs [44]. Preschool children may adopt new behavioral habits of play or PA in a more closed environment. This habit is extremely difficult to change after COVID-19 [41]. Preschool children have to re-adapt to more open spaces and freer activities, affecting their movement skills and activity intensity. In addition, parents were able to spend more time with their children during COVID-19, and parental support played a key role in promoting movement behaviors [45]. After COVID-19, parents may not be able to sustain the same amount of time and effort, resulting in a decreased willingness and ability of children to engage in PA and ball skills.

The post-pandemic cohort performed better in inhibitory control and working memory than the pandemic cohort, which is due to the change in preschool children’s screen exposure and social competence during the pandemic. Excessive screen exposure is positively associated with impaired

EF in preschool children [46]. The COVID-19 pandemic has forced children to use digital platforms and screen exposure has increased significantly [45]. Excessive screen use replaces activities that promote cognitive development, such as manipulative play and engaging in imaginative play [46]. Besides, social competence is critical to EF development, and play-based interactions in the classroom can enhance inhibition of impulsive responses and progress in self-regulation [47,48]. Changes in the physical context of education have limited preschool children's socialization [49], which may have inhibited the development of inhibitory control and working memory during the pandemic.

Association between FMS and EF

An interesting result of this study is that ball skills score was negatively associated with cognitive flexibility and inhibitory control during the COVID-19 pandemic, which is inconsistent with previous studies [50,51]. Notably, the ball skills were measured using easy motor tasks. These ball skills are familiar, frequent, and largely automated activities for preschool children [50]. EF-related brain regions, such as the dorsolateral prefrontal cortex, and brain regions required for motor planning and execution, such as the cerebellum and basal ganglia, are synergistically activated when the task is difficult, novel, and requires quick responses and concentration [52,53]. Preschool children learn ball skills better during the pandemic, and we assume that the more familiar the ball skills task, the higher automaticity, and the less EF involvement, leading to a negative association between ball skills and EF [54,55]. Besides, heterogeneity in methodology such as the choice of FMS assessment tool may result in the inconsistent findings with prior studies[51].

Association between PA and EF

Previous findings have been mixed regarding the associations between PA and EF. A cross-sectional study reported that PA was not related to inhibitory control in preschoolers from low-income families [19]. Vandenbroucke et al. (2016) found that PA was positively associated with working memory and cognitive flexibility [56]. Conversely, the results of this study suggested that MVPA was negatively associated with cognitive flexibility and LPA had a negative association with inhibitory control skills during the pandemic, which is consistent with the findings of Bezerra et al. (2021) and Willoughby et al. (2018). There are several explanations for the negative association. Hyperactive-impulsive behaviors may confound the association between PA and EF [21]. Preschool children with high levels of PA may exhibit EF deficits or be unable to engage in EF-promoting activities in the classroom [57,58], suggesting that their involvement in PA is more likely to be detrimental to EF development.

In addition, the intensity and duration of PA alone cannot explain the association between PA and EF [31]. During COVID-19, the most frequently reported PA was free play/unstructured PAs, with most preschool children staying at home all day with little opportunity to participate in structured activities [41]. Unstructured physical activity does not enhance EF development [19]. In contrast, cognitively engaged PA, such as team sports and structured PA games, may improve EF [59]. Willoughby et al. (2018) suggested that the context in which preschool children engage in MVPA is also important. The benefits of PA on EF skills may only exist in environments or activities with strong social and/or cognitive demands on children [60]. The restricted social environments during the pandemic may affect the development of PA and EF association in preschool children. After COVID-19, the reopening of schools, the resumption of team sports and activity sessions, and more time for preschool children to engage in free play/unstructured PA weakened the negative association between PA and EF. Therefore, there was no association between PA and EF after the pandemic.

Association between PF and EF

This study suggested that flexibility was positively associated with inhibitory control in the pandemic cohort. Flexibility reflects joint mobility and coordination of body movements in preschool children, coordinated movement enhances inhibitory control [11]. Neurologically, flexibility promotes the development of the sensory-motor cortex of the brain and improves perceptual-motor coordination, and the central cortex involved in motor and sensory systems matures the earliest, which in turn affects inhibitory control [61].

After the COVID-19 pandemic, muscular strength was positively associated with cognitive flexibility. Previous studies have shown that musculoskeletal fitness benefits children's health but is mainly associated with enhanced inhibitory control and working memory [62]. Skeletal muscle influences brain metabolism via muscle contraction-releasing peptides and cytokines, thus, preschool children with greater muscular strength may have better brain metabolism and cognitive flexibility [63]. This study found that speed-agility was positively associated with inhibitory control. Improved PF stimulates the growth of structural cells in the brain, contributing to EF development during early childhood. Specifically, increases in growth hormone and brain-derived neurotrophic factor (BDNF) are related to enhanced EF [64], and PF can stimulate the release the hormones and BDNF from the endocrine system and promote EF [65].

Strengths and limitations

The main strength of this study is the usage of objective measurement of PA, computerized assessment of EF, and internationally used tools of FMS and PF. Besides, this study examined the association between the specific components of FMS, PA, PF, and EF, which shows the associations more intuitively.

However, this study has some limitations. First, this study adopted a cross-sectional design. Longitudinal data will allow for more in-depth analyses of the associations and changes in FMS, PA, PF, and EF, providing complementary information for preschool children. Second, the relatively small sample size and lack of representativeness of this study may limit the generalization of our findings to the population. Third, this study only collected data on the duration and intensity of PA. Given that the type and context of PA may influence the association between PA and EF [21,31], future research should take PA type and context into account.

Implications

This study fills the research gap about the changes and associations between FMS, PA, PF, and EF components in Chinese preschoolers during and after the COVID-19 pandemic. The findings suggest that the MVPA level and ball skills of preschool children decreased after the pandemic, which reminds us that the short-term behavioral changes due to COVID-19 may persist over time. Actions need to be taken to improve PA levels and ball skills. Besides, different associations between FMS, PA, PF, and EF were found during and after the pandemic. The mechanisms behind these associations need to be further explored to inform theoretical models of early childhood development. In addition, the interrelationships among FMS, PA, PF, and EF suggest that multidimensional, integrated interventions and educational programs can be used to promote healthy cognitive and physical development in preschool children.

Conclusion

This study is the pioneer in investigating the differences in FMS, PA, PF, and EF between preschool children during and after the pandemic and examining their associations. Locomotor skills, PF, inhibitory control, and working memory increased, while MVPA level and ball skills decreased after the pandemic, suggesting that interventions need to be carried out to improve these changes. During the pandemic, certain EF components were negatively associated with ball skills and PA, and either positively associated with PF. After the pandemic, PF was positively associated with EF components. These findings highlight that integrated interventions and programs can promote cognitive and physical development during early childhood.

Acknowledgments

Not applicable.

Ethics approval

This study was approved by the Research Ethics Committee of Hong Kong Baptist University and the Research Ethics Committee of Beijing Normal University-Hong Kong Baptist University United International College.

Funding

Not applicable.

Authorship contributions

Conceptualization: Huiqi SONG, Jingjing WANG, Patrick W. C. LAU; Methodology: Huiqi SONG, Jingjing WANG; Formal Analysis: Huiqi SONG; Writing-Original Draft Preparation: Huiqi SONG; Writing-Review & Editing: Huiqi SONG, Jingjing WANG, Patrick W. C. LAU; Supervision: Jing LIU, Lei SHI.

Competing interests

Not applicable.

References

1. Diamond A. Executive Functions. *Annual Review of Psychology*. 2013;64(Volume 64, 2013):135-168. doi:https://doi.org/10.1146/annurev-psych-113011-143750
2. Blair C. Executive function and early childhood education. *Current Opinion in Behavioral Sciences*. 2016/08/01/ 2016;10:102-107. doi:https://doi.org/10.1016/j.cobeha.2016.05.009
3. Reilly SE, Downer JT, Grimm KJ. Developmental trajectories of executive functions from preschool to kindergarten. *Developmental Science*. 2022;25(5):e13236. doi:https://doi.org/10.1111/desc.13236
4. Zelazo PD, Carlson SM. The neurodevelopment of executive function skills: Implications for academic achievement gaps. *Psychology & Neuroscience*. 2020;13(3):273-298. doi:10.1037/pne0000208
5. Logan SW, Ross SM, Chee K, Stodden DF, Robinson LE. Fundamental motor skills: A systematic review of terminology. *Journal of Sports Sciences*. 2018/04/03 2018;36(7):781-796. doi:10.1080/02640414.2017.1340660
6. Organization WH. *WHO guidelines on physical activity and sedentary behaviour*. World Health Organization; 2020.
7. Ortega FB, Ruiz JR, Castillo MJ, Sjöström M. Physical fitness in childhood and adolescence: a powerful marker of health. *International Journal of Obesity*. 2008/01/01 2008;32(1):1-11. doi:10.1038/sj.ijo.0803774
8. Klingberg B, Schranz N, Barnett LM, Booth V, Ferrar K. The feasibility of fundamental movement skill assessments for pre-school aged children. *Journal of Sports Sciences*. 2019/02/16 2019;37(4):378-386. doi:10.1080/02640414.2018.1504603
9. Carson V, Lee E-Y, Hewitt L, et al. Systematic review of the relationships between physical activity and health indicators in the early years (0-4 years). *BMC Public Health*. 2017/11/20 2017;17(5):854. doi:10.1186/s12889-017-4860-0
10. Ortega FB, Cadenas-Sanchez C, Lee D-c, Ruiz JR, Blair SN, Sui X. Fitness and Fatness as Health Markers through the Lifespan: An Overview of Current Knowledge. *Progress in Preventive Medicine*. 2018;3(2)
11. Stein M, Auerswald M, Ebersbach M. Relationships between Motor and Executive Functions and the Effect of an Acute Coordinative Intervention on Executive Functions in Kindergartners. Original Research. *Frontiers in Psychology*. 2017;8

12. Han X, Zhao M, Kong Z, Xie J. Association between fundamental motor skills and executive function in preschool children: A cross-sectional study. Original Research. *Frontiers in Psychology*. 2022-August-25 2022;13doi:10.3389/fpsyg.2022.978994
13. Roebers CM, Kauer M. Motor and cognitive control in a normative sample of 7-year-olds. *Developmental Science*. 2009;12(1):175-181. doi:https://doi.org/10.1111/j.1467-7687.2008.00755.x
14. Stöckel T, Hughes CML. The relation between measures of cognitive and motor functioning in 5- to 6-year-old children. *Psychological Research*. 2016/07/01 2016;80(4):543-554. doi:10.1007/s00426-015-0662-0
15. Rosenbaum DA, Carlson RA, Gilmore RO. Acquisition of Intellectual and Perceptual-Motor Skills. *Annual Review of Psychology*. 2001;52(Volume 52, 2001):453-470. doi:https://doi.org/10.1146/annurev.psych.52.1.453
16. Kirk D. Physical education, youth sport and lifelong participation: the importance of early learning experiences. *European Physical Education Review*. 2005;11(3):239-255. doi:10.1177/1356336x05056649
17. Howie EK, Pate RR. Physical activity and academic achievement in children: A historical perspective. *Journal of Sport and Health Science*. 2012/12/01/ 2012;1(3):160-169. doi:https://doi.org/10.1016/j.jshs.2012.09.003
18. Robbins TW, Arnsten AFT. The Neuropsychopharmacology of Fronto-Executive Function: Monoaminergic Modulation. *Annual Review of Neuroscience*. 2009;32(Volume 32, 2009):267-287. doi:https://doi.org/10.1146/annurev.neuro.051508.135535
19. Cook CJ, Howard SJ, Scerif G, et al. Associations of physical activity and gross motor skills with executive function in preschool children from low-income South African settings. *Developmental Science*. 2019;22(5):e12820. doi:https://doi.org/10.1111/desc.12820
20. McNeill J, Howard SJ, Vella SA, Santos R, Cliff DP. Physical activity and modified organized sport among preschool children: Associations with cognitive and psychosocial health. *Mental Health and Physical Activity*. 2018/10/01/ 2018;15:45-52. doi:https://doi.org/10.1016/j.mhpa.2018.07.001
21. Willoughby MT, Wylie AC, Catellier DJ. Testing the association between physical activity and executive function skills in early childhood. *Early Childhood Research Quarterly*. 2018/07/01/ 2018;44:82-89. doi:https://doi.org/10.1016/j.ecresq.2018.03.004
22. Oberer N, Gashaj V, Roebers CM. Motor skills in kindergarten: Internal structure, cognitive correlates and relationships to background variables. *Human Movement Science*. 2017/04/01/ 2017;52:170-180. doi:https://doi.org/10.1016/j.humov.2017.02.002
23. Tomporowski PD. Cognitive and Behavioral Responses to Acute Exercise in Youths: A Review. *Pediatric Exercise Science*. 01 Nov. 2003 2003;15(4):348-359. doi:10.1123/pes.15.4.348
24. Hermahayu H, Wimbarti S, Paramastri I, Lumintuarso R. Physical Fitness and Executive Functions in Preschool Children. *ACTIVE: Journal of Physical Education, Sport, Health and Recreation*. 2019;8(3):113-123.
25. Li Y, Zhou T, Lu Y, et al. The association between the health-related physical fitness and inhibitory control in preschool children. *BMC Pediatrics*. 2022/02/24 2022;22(1):106. doi:10.1186/s12887-022-03163-y
26. Latorre-Román PA, Lloris-Ogallar E, Salas-Sánchez J, García-Pinillos F. ASSOCIATION BETWEEN EXECUTIVE FUNCTION, INTELLECTUAL MATURITY AND PHYSICAL FITNESS IN PRESCHOOLCHILDREN. Article. *International Journal of Medicine & Science of Physical Activity & Sport / Revista Internacional de Medicina y Ciencias de la Actividad Física y del Deporte*. 2020;20(79):471-485. doi:10.15366/rimcafd2020.79.006
27. Abe T, Kitayuguchi J, Fukushima N, et al. Fundamental movement skills in preschoolers before and during the COVID-19 pandemic in Japan: a serial cross-sectional study. *Environmental Health and Preventive Medicine*. 2022;27:26-26. doi:10.1265/ehpm.22-00049
28. Hashimoto M, Shishido T, Kowa S. Physical activity of preschool children in COVID-19

pandemic: Focusing on activity content and exercise intensity during childcare. *Creative Education*. 2021;12(5):999-1010.
29. Guo H, Kim H. Longitudinal changes in lifestyle behaviors and physical fitness of Japanese preschoolers during the COVID-19 pandemic: Results from a 7-year longitudinal study. Research Square; 2022.
30. Chichinina EA, Gavrilova MN. Growth of Executive Functions in Preschool-Age Children During the COVID-19 Lockdown: Empirical Evidence. *Psychol Russ*. 2022;15(2):124-136. doi:10.11621/pir.2022.0209
31. Malambo C, Nová A, Clark C, Musálek M. Associations between Fundamental Movement Skills, Physical Fitness, Motor Competency, Physical Activity, and Executive Functions in Pre-School Age Children: A Systematic Review. *Children*. 2022;9(7):1059.
32. Zhang T, Hong J, Yu X, et al. Association between socioeconomic status and dental caries among Chinese preschool children: a cross-sectional national study. *BMJ Open*. 2021;11(5):e042908. doi:10.1136/bmjopen-2020-042908
33. Cohen S, Doyle WJ, Baum A. Socioeconomic Status Is Associated With Stress Hormones. *Psychosomatic Medicine*. 2006;68(3)
34. Zhang X, Hu BY, Ren L, Zhang L. Family socioeconomic status and Chinese children's early academic development: Examining child-level mechanisms. *Contemporary Educational Psychology*. 2019/10/01/ 2019;59:101792. doi:https://doi.org/10.1016/j.cedpsych.2019.101792
35. Organization WH. *WHO child growth standards: length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age: methods and development*. World Health Organization; 2006.
36. Nayak S, Salem HZ, Tarullo AR. Neural mechanisms of response-preparation and inhibition in bilingual and monolingual children: Lateralized Readiness Potentials (LRPs) during a nonverbal Stroop task. *Developmental Cognitive Neuroscience*. 2020/02/01/ 2020;41:100740. doi:https://doi.org/10.1016/j.dcn.2019.100740
37. Verbruggen F, Aron AR, Band GPH, et al. A consensus guide to capturing the ability to inhibit actions and impulsive behaviors in the stop-signal task. *eLife*. 2019/04/29 2019;8:e46323. doi:10.7554/eLife.46323
38. Loosli SV, Buschkuehl M, Perrig WJ, Jaeggi SM. Working memory training improves reading processes in typically developing children. *Child Neuropsychology*. 2012/01/01 2012;18(1):62-78. doi:10.1080/09297049.2011.575772
39. Ulrich DA. Introduction to the special section: Evaluation of the psychometric properties of the TGMD-3. *Journal of Motor Learning and Development*. 2017;5(1):1-4.
40. Butte NF, Wong WW, Lee JS, Adolph AL, Puyau MR, Zakeri IF. Prediction of energy expenditure and physical activity in preschoolers. *Med Sci Sports Exerc*. Jun 2014;46(6):1216-26. doi:10.1249/mss.0000000000000209
41. Dunton GF, Do B, Wang SD. Early effects of the COVID-19 pandemic on physical activity and sedentary behavior in children living in the U.S. *BMC Public Health*. 2020/09/04 2020;20(1):1351. doi:10.1186/s12889-020-09429-3
42. Tulchin-Francis K, Stevens W, Gu X, et al. The impact of the coronavirus disease 2019 pandemic on physical activity in U.S. children. *Journal of Sport and Health Science*. 2021/05/01/ 2021;10(3):323-332. doi:https://doi.org/10.1016/j.jshs.2021.02.005
43. Jáuregui A, Argumedo G, Medina C, Bonvecchio-Arenas A, Romero-Martínez M, Okely AD. Factors associated with changes in movement behaviors in toddlers and preschoolers during the COVID-19 pandemic: A national cross-sectional study in Mexico. *Preventive Medicine Reports*. 2021/12/01/ 2021;24:101552. doi:https://doi.org/10.1016/j.pmedr.2021.101552
44. Barron C, Emmett MJ, Patte MM, Higham S, Bulgarelli D. Indoor play during a global pandemic: commonalities and diversities during a unique snapshot in time. *International Journal of Play*. 2021/10/02 2021;10(4):365-386. doi:10.1080/21594937.2021.2005396

45. Beck F, Schmidt SCE, Woll A, Reimers AK. Family predictors of physical activity change during the COVID-19 lockdown in preschool children in Germany. *Journal of Behavioral Medicine*. 2023/08/01 2023;46(4):609-621. doi:10.1007/s10865-022-00382-7
46. Likhitweerawong N, Khorana J, Boonchooduang N, Phinyo P, Patumanond J, Louthrenoo O. Associated biological and environmental factors of impaired executive function in preschool-aged children: A population-based study. *Infant and Child Development*. 2023;32(3):e2404. doi:https://doi.org/10.1002/icd.2404
47. Benavides-Nieto A, Romero-López M, Quesada-Conde AB, Corredor GA. Basic Executive Functions in Early Childhood Education and their Relationship with Social Competence. *Procedia - Social and Behavioral Sciences*. 2017/02/21/ 2017;237:471-478. doi:https://doi.org/10.1016/j.sbspro.2017.02.092
48. Peterson J, Flanders J. Play and the regulation of aggression. Developmental origins of aggression. New York: Guilford Press; 2005.
49. Luo W, Berson IR, Berson MJ, Han S. Young chinese children's remote peer interactions and social competence development during the COVID-19 pandemic. *Journal of Research on Technology in Education*. 2022/01/31 2022;54(sup1):S48-S64. doi:10.1080/15391523.2021.1906361
50. Maurer MN, Roebers CM. Towards a better understanding of the association between motor skills and executive functions in 5- to 6-year-olds: The impact of motor task difficulty. *Human Movement Science*. 2019/08/01/ 2019;66:607-620. doi:https://doi.org/10.1016/j.humov.2019.06.010
51. Stuhr C, Hughes CML, Stöckel T. The Role of Executive Functions for Motor Performance in Preschool Children as Compared to Young Adults. Original Research. *Frontiers in Psychology*. 2020-July-07 2020;11doi:10.3389/fpsyg.2020.01552
52. Abe M, Hanakawa T. Functional coupling underlying motor and cognitive functions of the dorsal premotor cortex. *Behavioural Brain Research*. 2009/03/02/ 2009;198(1):13-23. doi:https://doi.org/10.1016/j.bbr.2008.10.046
53. Hanakawa T. Rostral premotor cortex as a gateway between motor and cognitive networks. *Neuroscience Research*. 2011/06/01/ 2011;70(2):144-154. doi:https://doi.org/10.1016/j.neures.2011.02.010
54. Seger CA, Spiering BJ. A Critical Review of Habit Learning and the Basal Ganglia. Hypothesis and Theory. *Frontiers in Systems Neuroscience*. 2011-August-30 2011;5doi:10.3389/fnsys.2011.00066
55. Carlson AG, Rowe E, Curby TW. Disentangling Fine Motor Skills' Relations to Academic Achievement: The Relative Contributions of Visual-Spatial Integration and Visual-Motor Coordination. *The Journal of Genetic Psychology*. 2013/09/01 2013;174(5):514-533. doi:10.1080/00221325.2012.717122
56. Vandenbroucke L, Seghers J, Verschueren K, Wijtzes AI, Baeyens D. Longitudinal Associations Between Objectively Measured Physical Activity and Development of Executive Functioning Across the Transition to First Grade. *Journal of Physical Activity and Health*. 01 Aug. 2016 2016;13(8):895-902. doi:10.1123/jpah.2015-0708
57. Schoemaker K, Bunte T, Espy KA, Deković M, Matthys W. Executive Functions in Preschool Children With ADHD and DBD: An 18-Month Longitudinal Study. *Developmental Neuropsychology*. 2014/05/19 2014;39(4):302-315. doi:10.1080/87565641.2014.911875
58. Howie EK, Brown WH, Dowda M, McIver KL, Pate RR. Physical activity behaviours of highly active preschoolers. *Pediatric Obesity*. 2013;8(2):142-149. doi:https://doi.org/10.1111/j.2047-6310.2012.00099.x
59. Diamond A, Ling DS. Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental Cognitive Neuroscience*. 2016/04/01/ 2016;18:34-48. doi:https://doi.org/10.1016/j.dcn.2015.11.005
60. Tomporowski PD, McCullick B, Pendleton DM, Pesce C. Exercise and children's cognition:

The role of exercise characteristics and a place for metacognition. *Journal of Sport and Health Science*. 2015/03/01/ 2015;4(1):47-55. doi:https://doi.org/10.1016/j.jshs.2014.09.003
61. Chang Y-K, Tsai Y-J, Chen T-T, Hung T-M. The impacts of coordinative exercise on executive function in kindergarten children: an ERP study. *Experimental Brain Research*. 2013/03/01 2013;225(2):187-196. doi:10.1007/s00221-012-3360-9
62. Pearson DG, Craig T. The great outdoors? Exploring the mental health benefits of natural environments. Opinion. *Frontiers in Psychology*. 2014;5
63. Pedersen BK, Febbraio MA. Muscles, exercise and obesity: skeletal muscle as a secretory organ. *Nature Reviews Endocrinology*. 2012/08/01 2012;8(8):457-465. doi:10.1038/nrendo.2012.49
64. Nyberg F, Hallberg M. Growth hormone and cognitive function. *Nature Reviews Endocrinology*. 2013/06/01 2013;9(6):357-365. doi:10.1038/nrendo.2013.78
65. Chaddock L, Erickson KI, Prakash RS, et al. Basal Ganglia Volume Is Associated with Aerobic Fitness in Preadolescent Children. *Developmental Neuroscience*. 2010;32(3):249-256. doi:10.1159/000316648

Table 1. Descriptive characteristics of the included participants

	Pandemic cohort (n=174)	Post-pandemic cohort (n=189)	P value
Age (year)	5.5 (0.4)	5.5 (0.3)	*0.820*
Gender			
Female	74 (42.5%)	87 (46.0%)	*0.286*
Male	100 (57.5%)	102 (54.0%)	
Height (cm)	115.5 (5.1)	115.5 (5.3)	*0.994*
Weight (kg)	21.0 (3.0)	20.7 (3.4)	*0.403*
BMI z-score	0.062 (1.034)	-0.118 (1.093)	*0.111*
SES	-0.005 (0.681)	-0.012 (0.625)	*0.919*

Note: Data are presented as mean (standard deviation) or number (percentage).

Table 2. Cohort comparison in FMS, PA, PF, and EF

	Pandemic cohort (n=174)	Post-pandemic cohort (n=189)	P value
FMS			
Locomotor skills (score)	42.9 (3.4)	45.4 (0.9)	***<0.001***
Ball skills (score)	48.7 (3.4)	44.8 (3.4)	***<0.001***
PA			
MVPA (min/day)	56.5 (17.3)	50.2 (22.8)	***0.002***
LPA (min/day)	251.0 (42.2)	256.8 (40.7)	*0.092*
PF			
Balance (s)[a]	9.2 (3.6)	6.7 (3.2)	***<0.001***
CRF (laps)	16.4 (11.3)	19.1 (6.5)	***0.002***
Flexibility (cm)	8.9 (5.4)	10.6 (4.4)	***<0.001***
Muscular strength (kg)	6.9 (2.7)	7.7 (2.1)	***<0.001***
Muscular endurance (number)	10.3 (3.0)	10.9 (2.5)	***0.019***
Speed-agility (s)[a]	16.0 (1.8)	14.9 (2.1)	***<0.001***
EF			
Cognitive flexibility (ms)[a]	150.7 (117.9)	133.7 (96.2)	*0.066*
Inhibitory control (ms)[a]	731.8 (57.2)	695.6 (59.4)	***<0.001***
Working memory (%)	83.8 (10.9)	86.7 (9.3)	***0.004***

Abbreviation: CRF, cardiorespiratory fitness; EF, executive function; FMS, fundamental movement skills; LPA, light physical activity; MVPA, moderate-to-vigorous physical activity; PA, physical activity.

Note: Data are presented as mean (standard deviation).

[a]A higher score indicates worse performance.

Table 3. Association between FMS, PA, PF, and EF during and post-pandemic

	Pandemic cohort (n=174)			Post-pandemic cohort (n=189)		
	Cognitive flexibility[a]	Inhibitory control[a]	Working memory	Cognitive flexibility[a]	Inhibitory control[a]	Working memory
FMS						
Locomotor skills	4.09 (-3.38, 11.57)	-0.75 (-4.23, 2.74)	0.32 (-0.39, 1.02)	8.87 (-6.29, 24.03)	-1.12 (-10.14, 7.90)	-1.14 (-2.63, 0.35)
Ball skills	-6.62 (-12.50, -0.74)*	-2.90 (-5.64, -0.16)*	-0.04 (-0.59, 0.51)	-1.10 (-5.23, 3.03)	-2.44 (-4.90, 0.01)	0.05 (-0.35, 0.46)
PA						
MVPA	1.33 (0.15, 2.51)*	-0.37 (-0.92, 0.18)	-0.04 (-0.15, 0.07)	0.11 (-0.53, 0.74)	-0.08 (-0.30, 0.45)	-0.02 (-0.08, 0.05)
LPA	-0.41 (-0.87, 0.05)	0.23 (0.02, 0.44)*	0.02 (-0.03, 0.06)	-0.16 (-0.50, 0.19)	0.11 (-0.10, 0.31)	0.01 (-0.02, 0.05)
PF						
Balance[a]	4.15 (-0.96, 9.27)	-0.68 (-3.06, 1.70)	0.09 (-0.39, 0.57)	0.29 (-4.21, 4.79)	-1.75 (-4.43, 0.92)	-0.05 (-0.49, 0.39)
CRF	-0.25 (-1.83, 1.33)	0.45 (-0.29, 1.18)	0.07 (-0.08, 0.22)	-1.64 (-3.81, 0.53)	0.08 (-1.21, 1.37)	0.07 (-0.15, 0.28)
Flexibility	-0.78 (-4.41, 2.86)	-2.58 (-4.27, -0.89)**	0.27 (-0.07, 0.61)	-0.06 (-3.29, 3.17)	0.38 (-1.54, 2.30)	-0.26 (-0.96, 0.44)
Muscular strength	-0.40 (-7.53, 6.73)	-2.30 (-5.62, 1.02)	0.52 (-0.15, 1.19)	-8.24 (-15.36, -1.13)*	0.67 (-3.56, 4.91)	-0.26 (-0.96, 0.44)
Muscular endurance	-4.49 (-10.92, 1.93)	-1.41 (-4.40, 1.59)	0.04 (-0.56, 0.64)	-1.05 (-6.79, 4.70)	0.69 (-2.72, 4.11)	0.02 (-0.54, 0.59)
Speed-agility[a]	3.12 (-7.82, 14.05)	-3.69 (-8.79, 1.40)	-0.66 (-1.69, 0.37)	3.71 (-2.88, 10.30)	5.28 (1.36, 9.20)**	-0.12 (-0.08, 0.05)

Abbreviation: CRF, cardiorespiratory fitness; EF, executive function; FMS, fundamental movement skills; LPA, light physical activity; MVPA, moderate-to-vigorous physical activity; PA, physical activity.

Note: Data are presented as β (95% confidence interval)

Adjusted for age, gender, BMI z-score, and SES.

*$p < 0.05$, **$p < 0.01$.

[a]A higher score indicates worse performance.