# MONITORING AND PROMOTING PHYSICAL ACTIVITY AND PHYSICAL FITNESS IN CHILDREN

EDITED BY: Adilson Marques, Yolanda Demetriou, Stevo Popovic and Hugo Borges Sarmento

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# MONITORING AND PROMOTING PHYSICAL ACTIVITY AND PHYSICAL FITNESS IN CHILDREN

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EDITORIAL
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# Editorial: Monitoring and Promoting Physical Activity and Physical Fitness in Children

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**Keywords: sports, exercise, fitness, physical education, sedentary behavior**

**Editorial on the Research Topic**

**Monitoring and Promoting Physical Activity and Physical Fitness in Children**

## INTRODUCTION

Health is an important life resource that each person has. The preservation of a good state of health is important for the realization of the personal objective of life that each person defines for himself. Thus, from an early age, the determinants of health were identified. Among the various determinants of health, physical activity, and exercise stood out from an early age. It quickly became apparent that the most physically active people had better health indicators. Susruta (1500 BC), an Indian physician, was the first who prescribe daily exercise, while Hippocrates (460–370 BC) was the first one who provides a written exercise prescription for a patient suffering from consumption. On the other hand, the importance of physical fitness is recorded in the conversation between Socrates and one of Socrates' disciples named Epigenes. On noticing his companion was in poor condition for a young man, the philosopher admonished him by saying, "You look as if you need exercise, Epigenes." To which the young man replied, "Well, I'm not an athlete, Socrates." Socrates then offered an answer that was remembered as an anthology (1).

Physical inactivity is the fourth leading cause of premature death (2) since it can cause chronic diseases, such as obesity, type II diabetes, hypertension, cardiovascular diseases, or colon and breast cancers (3). However, a high percentage of children and adolescents in industrialized countries lead a sedentary lifestyle (4). A study by Cooper et al. (5) analyzing pooled accelerometer data from more than 27,000 children and adolescents (aged 3–18) shows that only 9% of the male and 2% of the female participants meet the WHO recommendation of daily 60 min of moderate-to-vigorous physical activity. Concerning the development throughout childhood and adolescence, physical activity decreases on average by about 4% with each year of age after the age of six. Additionally, sedentary behavior, which nowadays is considered not just as the opposite of physical activity but to have its independent negative influence on health, is increasing (5, 6). Physical fitness is a multi-component construct and a health biomarker highly correlated to physical activity (7, 8).

In addition to the impact on health, it has been shown that physical activity and physical fitness may significantly improve academic performance. There is a body of evidence to support this claim (9). In the first place, it is important to point out that mathematics and reading are academic topics that are most influenced by physical activity, but also the fact that basic cognitive functions that facilitate learning such as attention and memory can be improved by physical activity and greater aerobic fitness. Given the importance of monitoring and promoting physical activity and

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physical fitness in children, mostly due to the reason the single sessions of long-term participation in physical activity improve cognitive performance and brain health, as well as the reason the children who participate in vigorous- or moderate-intensity physical activity benefit the most, this Research Topic was created.

## CONTRIBUTION TO THE FIELD

The purpose of this Research Topic was to gather the latest knowledge in the field of monitoring and promoting physical activity and physical fitness in children. Several studies that emerged as the output of this special edition have pushed the boundaries of our knowledge, at least by so much that it is worth mentioning them and emphasizing that the whole work was meaningful and made a significant contribution to the scientific field.

Some interesting findings were reached in this Research Topic. First, an interesting finding regarding the evaluation of physical activity and physical fitness was that. Using physical fitness as a criterion to measure PA seems to be an effective option in terms of both the economic and organizational sense when reporting the monitoring, surveillance, and evaluation of PA interventions (Sember et al.). Additionally (Niessner et al.) presented a new LMS (least-mean-squares) coefficient to compare children's physical fitness levels and LMS curves that are available by year from age 4 to 17 years. A further significant contribution is the finding that shows growing inequality and polarization of the motor development of children (Potočnik et al.).

Some authors have confirmed that the declining trend of neuromotor fitness may have important implications for enjoyment and participation in physical activity, and thus for future health (Anselma et al.), which can significantly improve the participation of certain populations in daily physical activity, equally as an offer of extracurricular activities (Kuritz et al.). Another of the published articles in this special issue has a similar goal and emphasizes the importance of body image perception, anthropometric values, and physical condition to be physically active. Besides, it emphasizes the mediating role of physical self-perception for the development of physical activity (Sánchez-Miguel et al.). Kobel et al. confirm the positive impact of physical exercises on endurance performance in kindergarten children, but no other motor ability. Incorporating methods to develop agility and to improve resilience may lead to better outcomes when designing physical fitness programs to prevent or alleviate anxiety in children (Li et al.). Having siblings showed to be advantageous for general physical fitness in children (Rodrigues et al.) and standing desks provide an opportunity to reduce sedentary time during lessons and breaks at school (Sprengeler et al.). However, another studies raised several research questions such as if functionalized play can provide the pleasures of children's free play (Frahsa and Thiel), or school-based physical activity projects such as skipping hearts can have a long-term impact on health and health behavior (Baumgartner et al.). These issues will trigger a significant number of new clinical studies that should make new scientific progress toward new knowledge and new practices that will improve the field of monitoring and promotion of physical activity in children.

## CONCLUSION

Mounting research indicates that physical activity and physical fitness are associated with health benefits in children. High levels of physical activity and physical fitness, mainly cardiorespiratory fitness, are associated with better health-related biomarkers that may further influence adulthood health. In contrast, time spent in sedentary behavior is associated with negative health outcomes. Therefore, now, more than ever, understanding and developing strategies to promote physical activity behavior and to improve children's fitness levels are essential. These strategies can be developed in the school setting or indifferent contexts. For that reason, the purpose of this Research Topic was to collect high-quality research relating to the monitoring and promotion of physical activity and physical fitness in the pediatric population with special attention to novel intervention research in school, community-based, or sports settings to promote children's levels of physical activity and physical fitness, as well as the effects of physical activity on physical fitness in children and adolescents and correlational and survey studies examining these relationships.

## AUTHOR CONTRIBUTIONS

SP drafted the Editorial. HS, YD, and AM revised and approved the final version. All authors contributed to the article and approved the submitted version.

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ORIGINAL RESEARCH
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# The Mediating Role of the Self-Concept Between the Relationship of the Body Satisfaction and the Intention to Be Physically Active in Primary School Students

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The aim was to analyze the extent to which anthropometric values, in line with body image and physical ability, predict physical self-concept, and the latter, in turn, predicts the practice and intention to pursue physical activity. A total of 302 participants, 150 males and 152 females were recruited from different primary schools in Extremadura (Spain). The age of the participants ranges from 10 to 13 years old ($M = 11.74$; $SD = 0.86$). The indirect effects of the model showed significant relationship between physical condition ($p = 0.001$) and PA levels, according to the perception of self-concept [$\beta = 0.231$, 95% BcCI = (0.055, 0.212)]. However, anthropometric variables proved not to be related to any significant extent ($p < 0.05$). The second level covered the indirect effects between the intention to be physically active and self-concept, which showed a significant relationship between the perception of self-concept ($p = 0.000$) and the intention to be physically active. Last, the third level showed significant relationships between physical condition ($p = 0.001$) and the intention to pursue physical activity. The present investigation concluded that physical condition, anthropometric variables, and body image predict the perception of physical self-concept in adolescents. Finally, this article highlights the importance of body image perception, anthropometric values, and physical condition in the intention of being physically active. In addition, it highlights the mediating role of physical self-concept to develop physical activity.

**Keywords: body image, physical fitness, physical condition, youths, primary school**

## INTRODUCTION

Adolescence is characterized by being a stage in which major biological and psychological changes take place that define what a person will be like in adulthood (1). Studies show a decline in physical activity (PA) during this stage (2, 3), and this is a cause for concern given the physical and psychosocial benefits gained from doing PA (4), such as improvements in cardiovascular fitness, anthropometric values, bone structure, reduction in symptoms associated with depression and anxiety, and an improvement in psychological well-being. Along these lines, the adolescent stage is characterized by being a critical period in the development of the body image and one's perception of physical self-concept, whereby poor development of these constructs may give rise to problems linked to depression, anxiety, eating disorders, and imbalances in the perception of the body image and self-concept (5–7). In this respect, Casas et al. (8) stress the importance of detecting any factors that may contribute to an improvement in mental health in young people, drawing attention to the influence of body weight. With this in mind, Fernández-Bustos et al. (9) consider the body mass index (BMI) to be a major predictor of body image and self-esteem as well as body dissatisfaction in both men and women (10).

In keeping with the above, body image is a key element in the shaping of one's self-concept (11), and in this sense, body image reflects how individuals think, are viewed and act (12). Añez et al. (13) show its relationship with PA and draw attention to the fact that a poor body image may act as a barrier to pursuing physical activity. Moreover Neumark-Sztainer et al. (14), explain that adolescents with low body satisfaction are less likely to commit themselves to physical activity, instead of being more likely to spend their time indulging in sedentary activities such as watching TV, playing video games, or using the phone, etc. Likewise, attention is drawn to the moderating role of gender in associating body image with PA, by showing a positive association between the two in the case of the male gender (15). Conversely, there is no clear evidence of physical exercise in body image in the case of the female gender (16).

Additionally, body image is a factor that has a great impact on psychological well-being, which determines how self-concept is shaped, in particular, during adolescence (11). Numerous studies refer to a positive relationship between body satisfaction and self-concept (17, 18). Basing ourselves on the hierarchical and multidimensional model of general self-concept (19), physical self-concept (20) comprises the sum of specific domains: perceived competence, physical condition, physical appeal, and strength, while Sonstroem et al. (21) go on to add self-esteem. Previous studies have tended to relate physical self-concept to physical activity (9, 22, 23), the intention to pursue physical activity, social support (24), body image (25), physical condition (26), and anthropometric values such as BMI (27).

In terms of theoretical models that attempt to provide an explanation about the determining factors that the pursuit of physical activity entails, Fernández-Bustos et al. (9) explain that both physical activity and BMI predict body image, physical self-concept, and general self-concept. In this regard, Garn et al. (28) and Zamani Sani et al. (29) draw attention, respectively, to reciprocity and direct and indirect links to physical and psychological mechanisms. Similarly, Jekauc et al. (30) focus on the importance of motor skills in predicting self-concept and, ultimately, PA, while Moreno et al. (24), Fernandez-Rio et al. (31), and Grao Cruces et al. (32) point out that it is physical self-concept that predicts the intention to be physically active. Last, Li et al. (33) propose a model in which social support (parents and peers) predicts physical self-concept, and the latter, in turn, predicts physical activity.

For all the aforementioned reasons, the present research tests a model based on four levels, in which anthropometric values, in line with body image and physical ability (level 1), predict self-concept (level 2), which will, in turn, predict physical activity (level 3), and this last-mentioned will predict the intention to pursue it (level 4). Some authors differ in how they test their models, drawing attention to distinct variables when predicting self-concept and the relationship this has to the previously mentioned variables.

Hence, this work constitutes an attempt to provide a new approach that may offer an explanation about the physical and psychological mechanisms associated with the practice of, and intention to, pursue PA. For this reason, the aim of this research is to analyze the extent to which anthropometric values, in line with body image and physical ability, predict physical self-concept, and the latter, in turn, predicts the practice and intention to pursue PA. To this end, anthropometric values, physical condition, and body image are thought to provide a positive prediction of the perception of self-concept, physical activity, and the intention to pursue the latter, while the perception of self-concept is likewise thought to act as mediator between anthropometric values, physical condition, body image, and the intention to pursue physical activity.

# MATERIALS AND METHODS

## Participants

A total number of 302 Spanish students from eight different primary schools in Extremadura, Spain, agreed to participate on a voluntary basis: males ($n = 150$) and females ($n = 152$), ranging in age from 10 to 13 years old ($M = 11.74$; $SD = 0.86$). All data was collected during normal school hours. The sample was selected according to the relevant research, respecting accessibility and involvement on the part of the schools. Moreover, taking into account that the highest levels of physical inactivity were evidenced in adolescents (7), we would like to cover school ages in order to test the relationships between the different variables. Data was collected from February 2018 to May 2018 in Cáceres. The sample was selected through hierarchical cluster sampling, considering the distance of the schools, whether the teaching staff was available, and the time required for the researcher to travel.

## Instruments

### Anthropometric Variables

#### *Body Mass Index*

The body mass index was established by obtaining weight and height, and by applying the following formula: weight (kg)/height $(m)^2$. Height and weight were established using the SECA 884 stadiometer model.

#### *Waist-to-Height Ratio (WHtR)*

The waist height perimeter was used, in which previous research has related to cardiometabolic markers (34). *WHtR* was calculated by dividing waist circumference (in cm) by height (in cm) (35).

### Physical Condition Variables

#### *Aerobic capacity*

This was assessed using the 6-min walk test (6MWT), which was standardized by the American Thorax Society (36). A single 6MWT was undertaken along a flat, straight corridor over a hard surface, and the stimulus was used during the test. The children were given instructions to stop if they felt upset or uncomfortable. The maximum recorded distance (6MWD) was determined at the end of the test in order to assess the children's cardiorespiratory level. With a view to establishing comparisons, raw data was used owing to a possible bias in obtaining an equation in order to estimate the mean peak VO2 from the mean 6MWD in the children who took part (37).

### Psychosocial Variables

#### *Body image*

The Stunkard Figure Rating Scale (**Figure 1**) was used to assess self and ideal body sizes. The Stunkard Scale consists of nine silhouette figures that increase in size from very thin (a value of 1) to very obese (a value of 9) (38). Self-body size refers to the number of the figure selected by participants in response to the prompt "Choose the figure that reflects how you think you look." Ideal body size refers to the number of the figure chosen in response to the prompt "Choose your ideal figure." For self-body size and ideal body size, dummy variables were created for the underweight, normal weight, overweight, and obese body size categories. This scale evidenced good validity and reliability (39), and body size satisfaction was subsequently calculated. The ensuing value is defined as the difference between one's perceived self-body size and perceived ideal body size. A body size satisfaction value was created for each participant by subtracting the number of the figure indicated as being the ideal body size from the number of the figure selected as the self-body size.

#### *Self-concept perception*

The Spanish version (40) of the Physical Self-Perception Profile (41) was used to assess physical self-concept. The complete instrument comprises 28 items that assess five factors: fitness (five items, e.g., "I feel very confident about continuously practicing and maintaining my physical form." $\alpha = 0.78$; $\Omega = 0.78$); perceived competence (four items, e.g., "I am very good at nearly all sports." $\alpha = 0.78$; $\Omega = 0.79$); physical strength (six items, e.g., "I am the first to put myself forward in situations that require strength." $\alpha = 0.68$; $\Omega = 0.65$); appearance (nine items, e.g., "I feel very satisfied with how I am physically." $\alpha = 0.72$; $\Omega = 0.74$); and self-esteem (four items, e.g., "I don't feel very self-confident in terms of physical appearance" $\alpha = 0.65$; $\Omega = 0.65$). Responses were rated on a Likert-type scale from 1 (*strongly disagree*) to 4 (*strongly agree*). The instrument evidenced acceptable internal consistency.

#### *Physical activity*

Physical activity was assessed using the Physical Activity Questionnaire for Adolescents: (PAQ-A) (42). This questionnaire comprises nine items that assess the physical activity pursued by the adolescent over the past 7 days, using a five-point Likert scale: during their free time, during physical education classes and also at different times during class days (lunchtime, afternoons, and evenings), and during the weekend. The result is a score from 1 to 5 that enables the level of physical activity to be graded (43), and their final score is obtained using the arithmetic mean of eight of the nine items, as the last item assesses whether the participant had been ill over the last week (43). Last, the Cronbach's alpha coefficient obtained for this sample was ($\alpha = 0.79$; $\Omega = 0.78$).

#### *Intention to be physically active*

This was assessed using an item in which the participant was asked: *Do you intend to practice sport in the future?* The response options were represented by a five-point Likert scale ranging from 1 (*totally disagree*) to 5 (*totally agree*).

## Procedure

Parents and school supervisors were informed by letter about the nature and purpose of the study, and written informed consent was provided. The study obtained permission from the University Ethics Committee, which adheres to the code of ethics established by the World Medical Association (Declaration of Helsinki), and the protocol was approved by the Ethics Committee of the University of Extremadura (89/2016). All participants were treated in accordance with guidelines set out by the American Psychological Association (APA), ensuring trust and anonymity in terms of student responses. Before commencing the data collection process, permission was requested via a letter of consent addressed to parents and teachers, in which the following were to be assessed: What the study consisted of, the anthropometric and psychometric variables that would be assessed and, last, an assurance that all responses would be anonymous and would not compromise the identity of the participants. The participants completed the questionnaires during physical education class in the presence of the teacher, who told them that it was not an assessment test, and that they should be sincere with their answers. While they were completing them, researchers called the students in order from the list to weigh and measure them, subsequently noting down the weight and height in the relevant space on the questionnaire. The results obtained from the tests were passed on to the teacher if they asked for them.

## Statistical Analysis

The SPSS 23.0 statistical package was used to carry out data analysis (see **Supplementary Material**). Likewise, different tests were used to determine the nature of this data—the Kolmogorov–Smirnov test and Levene's test—which provided scores over 0.05, whereby a decision was made to produce parametric statistics. Descriptive statistics were then provided together with a correlation analysis.

The MPLUS 7.0 statistical package was also used to ascertain predictive capacity (structural equation model) regarding the intention to pursue physical activity, and last, the indirect effects of the structural equations were then calculated.

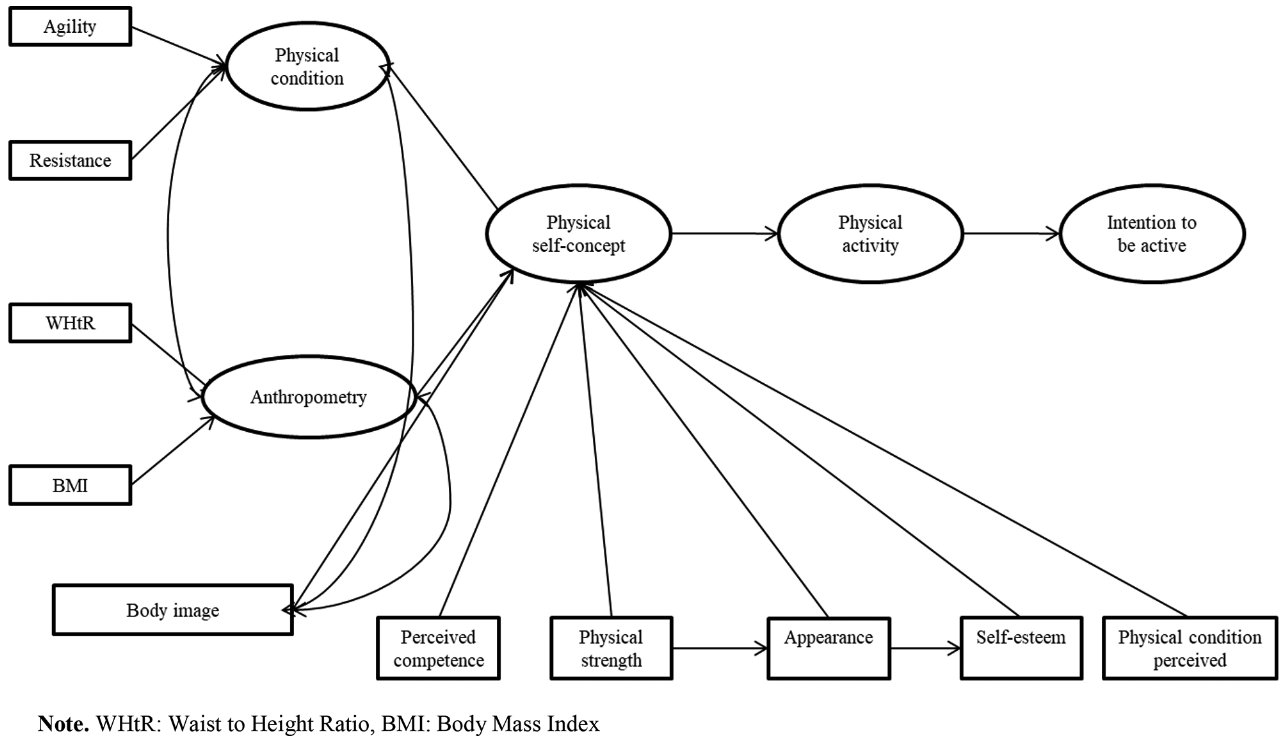


**FIGURE 1 |** Hypothesized model. WHtR, waist-to-height ratio; BMI, body mass index.

# RESULTS

**Table 1** shows the descriptive statistics and bivariate correlations of all the variables involved in the study, in which significant positive relationships between the intention to pursue physical activity, the time spent on extra-curricular activities, and the dimensions of perceived self-concept are provided. Likewise, it is shown how physical activity is positively related to the perception of self-concept and cardiovascular fitness, and negatively related to agility, anthropometric variables, and the perception of body image. The global score regarding the perception of self-concept also has a significant negative relationship with all those variables that refer to anthropometric values (BMI, waist–height perimeter), body image, and levels of physical condition (agility), except for resistance.

## Structural Equation Model

A structural equation model was hypothesized with the following structure (**Figure 1**). This model was formed from three latent variables: physical condition (agility and resistance), anthropometric variables (waist–height perimeter and body mass index), and self-concept (self-esteem, strength, and perceived competence). Variables pertaining to physical activity, extra-curricular time, and intention to be physically active were also used, with the last mentioned acting as a dependent variable of the model.

The initial model showed the following adjustment indexes—MRL$\chi^2$ = 372.295, $p < 0.05$, $df$ = 66, CFI = 0.74, TLI = 0.68, SRMR = 0.12, and RMSA = 0.12—whereby we decided to restructure the model in accordance with previous literature (9, 22, 24, 30, 33). Thus, the modification indexes suggest new forms of interaction to us: on the one hand, a correlation between body image and anthropometric variables, which provided us with the following adjustment indexes—MRL$\chi^2$ = 248.954, $p < 0.05$, $df$ = 66, CFI = 0.84, TLI = 0.80, SRMR = 0.084, and RMSA = 0.09—and, on the other, a regression in which perceived appearance would predict self-esteem, namely, MRL$\chi^2$ = 154.238, $p < 0.05$, $df$ = 66, CFI = 0.92, TLI = 0.89, SRMR = 0.072, and RMSA = 0.073. This last-mentioned modification provides us with nearly acceptable adjustment indexes, although a decision was made to make a final modification in which perceived appearance would predict strength. The final model (**Figure 2**) offered some good adjustment indexes: MRL$\chi^2$ = 125.535, $p < 0.05$, $df$ = 66, CFI = 0.94, TLI = 0.92, SRMR = 0.054, and RMSA = 0.059.

Invariance of the model was then tested in terms of gender. To do so, a first step was taken in which it was noted how the model adapted according to participants' gender. The results showed how the model is better explained in the female gender MRL$\chi^2$ = 64.433, $p < 0.05$, CFI = 0.98, TLI = 0.98, SRMR = 0.046, and RMSA = 0.027, than in the male gender MRL$\chi^2$ = 131.375, $p < 0.05$, CFI = 0.91, TLI = 0.88, SRMR = 0.072, and RMSA = 0.092. In this respect, the model explains how anthropometric variables, physical condition, and self-concept can be considered greater predictors of the intention to pursue physical activity in the male gender than in the female gender.

**TABLE 1 |** Descriptive statistics and correlation analysis.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. INPFA | – | 0.37** | 0.17** | 0.33** | 0.19** | 0.11 | 0.32** | 0.32** | −0.05 | 0.10 | −0.03 | −0.061 | −0.11* |
| 2. PPC | – | – | 0.41** | 0.69** | 0.43** | 0.22** | 0.53** | 0.75** | 0.30** | 0.26** | −0.24** | 0.38** | −0.26** |
| 3. PAP | – | – | – | 0.30** | 0.44** | 0.59** | 0.18* | 0.73** | −0.20** | 0.11* | −0.05 | −0.25** | −0.17** |
| 4. PC | – | – | – | – | 0.51** | 0.21** | 0.52** | 0.75** | −0.25** | 0.25** | −0.32** | −0.28** | −0.22** |
| 5. PS | – | – | – | – | – | 0.34** | 0.31** | 0.74** | 0.04 | 0.16** | −0.13** | −0.07 | −0.01 |
| 6. SEL | – | – | – | – | – | – | 0.12* | 0.66* | −0.10 | 0.06 | −03 | −0.13 | −0.10 |
| 7. PA | – | – | – | – | – | – | – | 0.46** | −0.11** | 0.21** | −0.16** | −0.19** | −0.12* |
| 8. GS_SC | – | – | – | – | – | – | – | – | −0.22** | 0.23** | −0.21** | −0.30** | −21** |
| 9. BMI | – | – | – | – | – | – | – | – | – | −0.17** | 0.25** | 0.58** | 0.73** |
| 10. TM6 | – | – | – | – | – | – | – | – | – | – | −0.46** | −0.13* | −0.09 |
| 11. Agil | – | – | – | – | – | – | – | – | – | – | – | 17** | 23** |
| 12. Body_I | – | – | – | – | – | – | – | – | – | – | – | – | 54** |
| 13. Wai_hei | – | – | – | – | – | – | – | – | – | – | – | – | – |
| M | 4.6 | 3.8 | 3.7 | 3.5 | 3.3 | 3.9 | 3.2 | 3.7 | 18.6 | 15.8 | 13.1 | 3.3 | 42.4 |
| SD | 0.69 | 0.84 | 0.70 | 0.86 | 0.84 | 0.96 | 0.67 | 0.61 | 3.00 | 3.93 | 1.69 | 1.13 | 4.64 |
| Ω | – | 0.78 | 0.72 | 0.78 | 0.68 | 0.65 | 0.79 | – | – | – | – | – | – |
| Ω | – | 0.78 | 0.74 | 0.79 | 0.65 | 0.65 | 0.78 | – | – | – | – | – | – |

*INPFA, intention to pursue physical activity; PPC, perceived physical condition; PAP, perceived appearance; PC, perceived competence; PS, perceived strength; SEL, self-esteem; PA, physical activity; GS_SC, self-concept global score; BMI, body mass index; TM6, 6-min test; Agil, agility; Body_I, body image; Wai_hei, waist–height perimeter. *p < 0.01, **p < 0.001.*

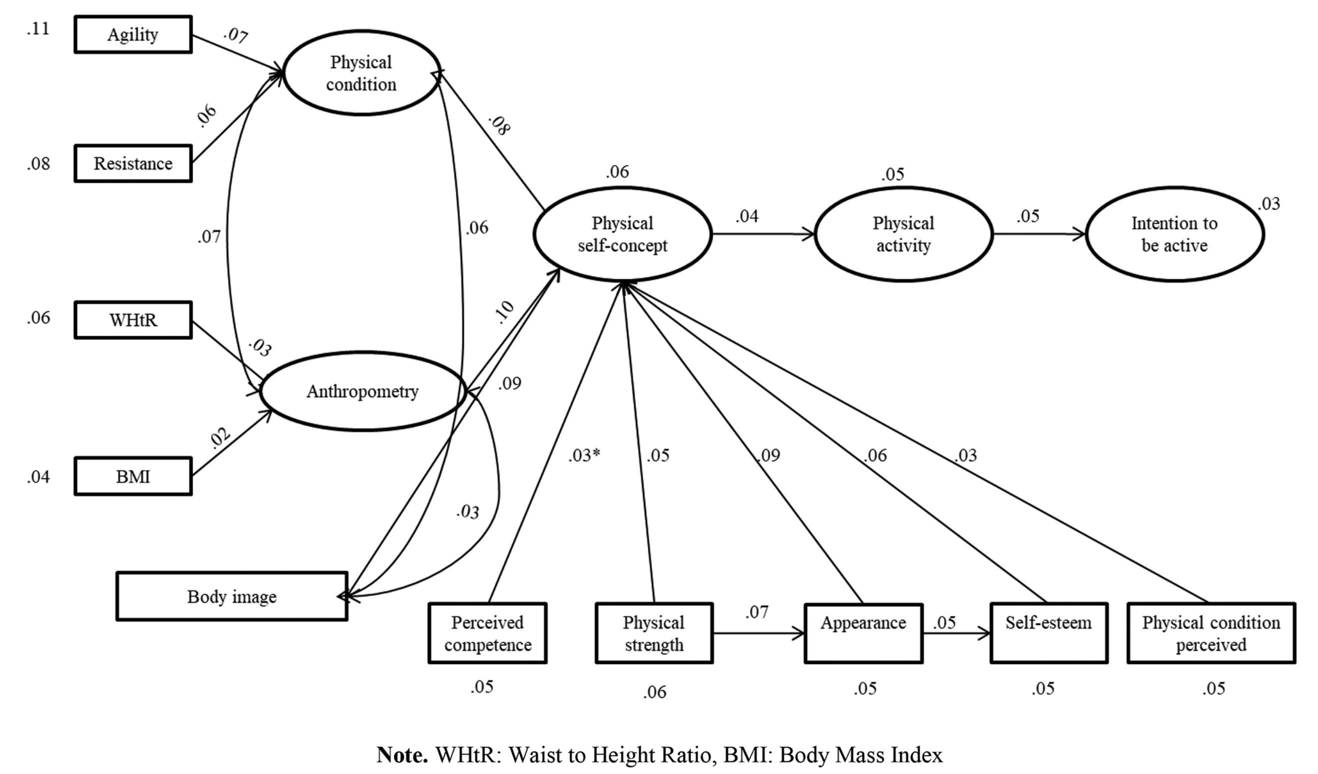


**FIGURE 2 |** Final model. WHtR, waist-to-height ratio; BMI, body mass index.

Indirect effects among variables were calculated on several levels according to the hypothesized model. The first level showed the indirect effects among all the variables situated between the pursuit of physical activity and physical condition, anthropometric variables, and body image. In this sense, the analysis of indirect effects evidenced significant relationships between physical condition ($p = 0.001$) and PA levels, according to the perception of self-concept [β = 0.231, 95% BcCI = (0.055, 0.212)], in a similar way to how body image showed significant relationships between physical condition ($p = 0.003$) and levels of physical activity, according to the perception of self-concept [β = 0.172, 95% BcCI = (0.058, −0.295)]. However, anthropometric variables proved not to be related to any significant extent ($p < 0.05$) to physical activity, according to the perception of self-concept. The second level covered the indirect effects between the intention to be physically active and self-concept, which showed a significant relationship between the perception of self-concept ($p = 0.000$) and the intention to be physically active, according to physical activity [β = 0.196, 95% BcCI = (0.036, −0.543)]. Last, the third level showed significant relationships between physical condition ($p = 0.001$) and the intention to pursue physical activity, according to the level of that activity [β = 0.074, 95% BcCI = (0.022, −0.362)], in the same way that body image proved to be significantly related ($p = 0.007$) to the intention to be physically active, according to the level of physical activity [β = −0.055, 95% BcCI = (0.020, −0.708)]. For their part, anthropometric variables proved not to be significantly related to the intention to pursue physical activity ($p < 0.05$).

## DISCUSSION

The main purpose of this study was to analyze the relationships established between anthropometric values, body image, physical ability, and the intention to be physically active. A further objective was to test a structural equation model in which physical conditions, anthropometric values, body image, self-concept, and physical activity explain the intention to be physically active.

In terms of the relationships established, a significant positive relationship between the intention to be physically active, physical activity, and the perception of self-concept was shown, and to this end, Zamani Sani et al. (29) showed positive associations between physical activity and self-concept, also drawing attention to the fact that this association is influenced by different key factors such as body image, body mass index, and physical form. In terms of the relationships established between self-concept and the intention to be physically active, the study carried out by Moreno et al. (24) showed significant relationships between the two. Conversely, our study revealed that the intention to pursue physical activity is negatively—albeit not significantly—related to anthropometric values, and to physical form in terms of agility, unlike physical resistance, with which a positive relationship was found. This is in line with previous studies in which attention was drawn to the perception of physical condition as being the most determining factor in being active (44, 45). As for the negative relationship with anthropometric values, our results are in line with those found by Centeio et al. (46), in which physical ability acted as a mediator with the intention to be physically active, although the intention to pursue physical activity may vary depending on the strategies we implement. In this respect, García-Hermoso et al. (47) point out that the intention to be physically active might be improved by activities such as walking or cycling to school. Likewise, the overall perception of self-concept was negatively and significantly related to anthropometric values, and agility to physical form, although this proved not to be the case with resistance. In this sense, Reigal-Garrido et al. (48) draw attention to the fact that the study of aerobic capacity is a determining factor in the perception of self-concept.

In terms of the structural equation model, our model showed that physical condition, anthropometric variables, and body image predict the perception of physical self-concept as backed up by previous literature on the subject. As for the predictive role of physical condition, Garn et al. (23) draw attention to the fact that overall physical self-concept is predicted by multiple improvements that take place in physical condition. Thus, the fact might be interpreted that improvements taking place via specific exercises involving speed, strength, and resistance would have a direct influence on self-concept, as shown by Lemoyne et al. (49) in university students. On the other hand, and in terms of the predictive role of anthropometric values (BMI and waist–height perimeter), our results are in keeping with those found in the study by Fernández-Bustos et al. (9), where a model was shown in which BMI predicted physical activity and self-concept. A difference should also be highlighted in the role taken on by body image in the model put forward by Fernández-Bustos et al. (9) and ours. In this respect, they provided body image with a mediating role between BMI and physical activity (50), whereas our study showed body image to be an independent construct which, alongside anthropometric values and variables associated with physical ability, predict self-concept. Therefore, it should be noted that anthropometric variables such as BMI are associated with body dissatisfaction in both men and women (10).

Last, our model showed the role played by self-concept in pursuing or intending to pursue physical activity. These findings are in keeping with those made by Moreno et al. (24), in which it was shown that physical self-concept predicted the intention to pursue physical activity, although the intention that a subject should remain physically active is influenced by the perception of physical self-concept, as this is positively modified via physical activity (51), and also with the findings made by Fernandez-Rio et al. (31), in which the pursuit of physical activity predicted intention. To this, we should also add the importance of other variables such as motivation and enjoyment that will influence the intention to pursue such activity (52).

Nonetheless, the results obtained should be treated with caution, as the present research is subject to certain limitations such as its transversal design, which does not enable cause–effect relationships to be established, and the small number of participants, whereby these conclusions are not able to be transferred to a different population. Thus, this research draws the conclusion that the intention to pursue and practice physical activity is predicted by body image, anthropometric values, physical condition, and the perception of physical self-concept. In this respect, those individuals who evidence having a healthy body image accompanied by suitable anthropometric values and physical condition will be more likely to have a perception of self-concept and, therefore, be more inclined to pursue physical activity. Future studies should replicate this same hypothesized model, increasing the sample size. On another hand, it should focus on stipulating profiles of physical self-concept and being more specific about these relationships, rather than referring to a high or low degree of self-concept, as this might give rise to incongruences when establishing such relationships. In this regard, there may, on the one hand, be individuals who have a great perception of strength and physical competence, who maintain more significant relationships with tests associated with physical ability, while on the other, other types of individual may have a better self-esteem and perception of themselves and be more closely related to variables such as body image.

## DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

## ETHICS STATEMENT

This study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of the University of Extremadura (89/2016). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

## AUTHOR CONTRIBUTIONS

PS-M, PL-G, ML-G, and MT-S contributed conception and design of the study. DH-A and MV-S organized the database. PS-M and MV-S performed the statistical analysis and wrote the first draft of the manuscript. PS-M, MT-S, and MV-S wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2020.00113/full#supplementary-material

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# Physical Fitness and Somatic Characteristics of the Only Child

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The purpose of this study was to examine if only child show differences on somatic growth and physical fitness compared to be a child with siblings. The participants included 542 children (boys: $N = 270$; girls: $N = 270$) between 7 and 15 years of age. Somatic growth (height, weight, body mass index) and physical fitness (handgrip strength; flexed harm hang; 60-s sit-ups; standing long jump; 10-m shuttle run and PACER test) were assessed. Variance analysis revealed significant advantages for children with siblings in the flexed arm hang ($p = 0.046$), 60-s sit-ups ($p = 0.002$), 10-m shuttle run ($p = 0.013$) and PACER ($p = 0.032$). An examination of the possible differential effect of sex on the results revealed no significance for physical fitness variables, but significant interaction were found for weight ($p = 0.004$) and body mass index ($p = 0.005$). Despite a lack of interactions between offspring and sex in physical fitness, significant differences between sexes were found in all fitness variables. In conclusion, having siblings showed to be advantageous for general physical fitness in children. This evidence may be used for future analysis and interventions in motor competence, namely considering the growing number of only children in some regions of the world.

**Keywords: only child, motor competence, motor performance, human development, children**



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## INTRODUCTION

In the European Union in 2016, almost half (47% or 31 million) of all households with children had only one child. In Portugal, there was also a tendency for single-child families to increase over the last few decades. In 1991, 44% of Portuguese households with children had only one child. This number rose to 51% in 2001, and to 55% in the last 2011 census. At the same time, the percentage of couples with three or more children has decreased (17, 11, and 8% in 1991, 2001, and 2011 respectively), and the number of couples with two children has remained at 38% (1). Surely this phenomenon of the only child, associated with the diminishing autonomy of children and young people (2), has an effect on the opportunities (affordances) for motor stimulation in these children and, consequently, on the development of their motor competence and physical fitness. For instance, solitary play, without a brother or sister, will be more sedentary, focused on individual play without movement, while the lack of autonomy will hamper children from experiencing new environments and motor challenges, with evident implications on his(her) perceive motor competence and self-confidence.

The only-child condition was widely examined in the literature throughout the 20th century and was particularly boosted by the single child policy imposed in China and by the general concern that the development of only children could be impaired by a lack of stimulation from siblings (3).

On the contrary, the expectation of an enriched family-child involvement and investment (4) within the context of only-child education and development conflicts with previously stated ideas. In an extended review from 1986, Fabo and Polit showed that English-speaking only children had more positive developmental outcomes (achievement, character, and intelligence) than their peers with siblings.

Urban Korean only children showed a greater tendency for depression (5), while Brazilian only sons were less likely to have an alcohol intoxication episode during adolescence (6).

In a recent study with 20,592 adult subjects in New Zealand, Stronge et al. (3) tested for differences in Big Six personality traits in adults and found that the ones with no siblings showed lower average levels of honesty-humility and conscientiousness and higher levels of neuroticism and openness. However, while statistically significant, these differences did not rise to the level of practical effects (3).

Physical fitness is a determinant of healthy child development, as it is related to several health outcomes and is a good summative measure of the body's ability to perform physical activity and exercise (7, 8).

Children with low levels of physical fitness (9) and motor competence are at greater risk for obesity (10).

A significantly higher likelihood of being overweight and obese has been found in only children, both in a recent systematic review and meta-analysis (11) and amongst a national sample of 43,046 children born in 2001 in Japan (12). Children with no siblings also had significantly lower levels of moderate-to-vigorous physical activity than children with siblings (13).

It is largely reported in research that environmental variables are important in influencing positive health behaviors and improving physical fitness. Several studies have revealed that birth weight, the mother's lifestyle during her pregnancy, the father's health, and the presence of siblings had the strongest influence on children's fitness (14–18). Regarding the birth order of siblings, the literature shows differences in motor development between older and younger siblings (15). These differences are probably due to the influence of older siblings on younger ones, although the authors conclude that this relationship may depend on biological characteristics.

The presence of siblings and peers seems to be a predictor of enriched motor development (19, 20). When the sibling influence is compared for sportsmen, elite athletes are more likely to be later-born children, while non-elite athletes are more likely to be the firstborn (21).

Although the number of single-child households is increasing, the consequences for child motor development have not been fully addressed in the literature. Individual pathways of change in physical fitness and growth are expected to be influenced by children's immediate environments and the presence or absence of other children in the family.

Consequently, the aim of this study is 2-fold: (i) to examine if being an only child is associated with negative differences on somatic growth and physical fitness compared to being a child with siblings and (ii) to analyze whether these differences are influenced by the child's sex. Our specific hypothesis is that only child will show detrimental differences in physical fitness and weight status.

# MATERIALS AND METHODS

## Sample

Participants in this study belong to the Melgaço Youth Observatory (MYO), a mixed-longitudinal growth and development project that is currently taking place at this location in the north of Portugal. A convenience sample that included all participants who entered the study between 2015 and 2019 was selected. A database was organized with data from the first year of assessment of each MYO participant, resulting in a total of 542 children (270 boys; 270 girls), aged from seven to 15 years of age (boys mean age= $10.47 \pm 2.67$; girls mean age=$10.44 \pm 2.64$). Within the sample, 141 children were only child (71 boys; 70 girls) and 399 children had brothers or sisters (197 boys, 202 girls).

## Procedures

The study was approved by the Scientific Council of the Polytechnic Institute of Viana do Castelo with the reference CTC-ESDL-001-2014. School directors approved the study, adult participants and the parents or tutors of underage children gave their informed consent. Children also gave verbal assent prior to data collection. All procedures were carried out in accordance with the 1964 Helsinki declaration and its later amendments.

Participants were individually interviewed by a research assistant to fill a sociodemographic questionnaire containing information about the family (parent's professional occupation, number of brothers and sisters and respective age). All somatic characteristics and physical fitness assessments were done in the same order at the laboratories of the Melgaço School of Sports and Leisure. Observers were trained in the assessment's protocols and its specifications, and each observer was responsible for only one test or measure. At least two of the three first authors of this study personally supervised all data collection.

## Assessments Protocols

### Somatic Measures

Somatic measurements included height and weight, which were measured with a SECA 217 stadiometer and a SECA 762 weight scale. All measurements were taken according to the International Society for the Advancement of Kinanthropometry's (22) standardized protocol.

Body mass index (BMI) was calculated using by dividing body weight (in kilograms) by height (in square meters).

### Physical Fitness

Handgrip strength (HS) was tested using the handgrip dynamometer (SAEHAN, model SH5001), with individuals seated with their shoulders adducted, their elbows flexed at

90°, and their forearms in a neutral position, according to the American Society of Hand Therapists (23). In this analysis, we reported data only for the right hand, as some children of younger ages were not fully able to report their preferred hand.

Flexed arm hang (FAH) performances were assessed by noting the time the participant could hold herself with the chin above the bar, arms flexed, and using a supine grasp position. Two observers helped the child to assume the initial position, and the stopwatch counted the time between this moment and the moment the child's chin touched the bar or fell below the level of the bar. Results are recorded in tenths of seconds.

The maximum number of correct sit-ups (SU) performed in 60 s was counted. The participant started by lying down on a mat with their arms crossed across the chest and legs flexed at ∼45°. An observer secured the participant's feet using two hands throughout the test. A correct sit-up was counted when the participant touched their knees with their arms kept close to the chest. The total number of correct SU is the result of the test.

Standing long jump (SLJ) performances were assessed by recording the length of a landing horizontal jump, with the participant departing from a line in the ground at a two-foot-long take-off. The result of the test was the best result of three trials. The length of the jump was measured from the departing line to the nearest point where the heels touch the ground. The results were recorded in cm.

Performances in a 10-m shuttle run (SHR) were recorded using the following protocol. Two parallel lines were marked on the floor 10 meters apart. Two blocks of wood were placed behind one of the lines opposite the starting line. On the signal "Ready? Go!" the child ran to the blocks, picked one up, ran back to the starting line, and placed the block behind the line; he then ran back and picked up the second block, which he carried back across the starting line. Two attempts were allowed, with the best time used as the result of the test.

The PACER test is a widely used progressive test where participants run back and forth at a specified pace from two lines that are 20 meters apart. The pace is externally regulated by an auditory sign (a beep) that marks the moment participants should be at each end of the course (a lap). The pace is increased every minute, and participants remain in the test until they can no longer keep up with the pace at the end of two consecutive laps. Participants were encouraged to achieve their maximal performance. When they did not, according to the observer's judgment (e.g., when showing a lack of motivation to complete the task, stopping due to injury or pain, or not showing facial flushing, sweating, hyperpnoea, or an unsteady gait), the result was not included. For children below 10 years of age, a pacing light apparatus was used throughout the testing time to assure full participation and motivation in the 20-m SRT test. The number of completed laps was recorded as the result of the test.

### Maturation

Time to Peak Height Velocity (PHV) was used as a maturational index assessed according to the following equations for each sex (24):

Time to PHV Boys $= -8.3971103 + (0.0070346 * \text{decimal age} * \text{sitting height})$.

Time to PHV Girls $= = -7.709133 + (0.0042232 * \text{decimal age} * \text{height})$.

### Statistics

Descriptive statistics for age groups (7–9, 10–12, 13–15 years-of-age) according to the sex and offspring condition are presented for all variables. A two factor ANCOVA full factorial model was used to test for the effects of Sex (boy or girl) and Offspring (only child or sibling) on each somatic and physical fitness variable, while adjusting for decimal age (covariate). All variables were previously tested for normality and homoscedasticity and, in accordance, the FAH and PACER data were logarithmic transformed. Residuals configurations from of the ANCOVAs were scrutinized for possible non-normal or biased configurations.

## RESULTS

Descriptive results according to sex, age, and existence of siblings in the family can be found in **Table 1**.

Although no differences were found between decimal ages of boys and girls ($p = 0.521$), girls proved to be maturational advanced relative to boys (time PHV $= -1.37 \pm 2.19$ and $-2.78 \pm 1.97$ respectively for girls and boys; $p < 0.001$). Nonetheless no differences were found in the time to PHV between the only child and the siblings' groups ($p = 0.500$). The correlation between decimal age and maturational time to PHV was of 0.98 for boys and 0.99 for girls showing that decimal age is also a very good indicative of both chronological and biological age of the participants.

In order to understand if being an only child can result on deleterious differences on the somatic growth and physical fitness of children, a two-way ANCOVA was run for each collected variable. The main effect of interest was related to the offspring condition of being an only child compared with having other siblings in the house, but we were also interested in understanding if being a boy or a girl can affect this possible offspring effect. Since different ages were present in the sample, we used decimal age as a covariate in order to control for the age and maturation effect in the variables. The results are shown in **Table 2** below.

For all tested variables, except for BMI, Sex has proved to have a significant effect on the outcome value, as expected. Similar thing happened with Decimal Age entering as a covariate in the models, but in this case the effect was significant for all variables ($p < 0.001$ for all models).

Interaction between Offspring conditions and Sex was never significant for all physical fitness variables tested but turned out as significant for Weight and BMI, meaning that the Offspring effect on weight and BMI can be different depending on the sex of the child.

Finally, and looking for our condition of interest in this study, the Offspring condition, we can see that significant differences were found between children that are the only child in the family and the ones that have brothers and/or sisters (siblings) for most of the physical fitness variables (FAH, SU, SHR, and PACER), and for height and weight. In general, the difference found was

**TABLE 1 |** Number of subjects, mean, and standard deviation values for all variables according to age group, sex, and the existence of siblings in the family.

| | | Girls | | | | Boys | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Only child | | Sibling | | Only child | | Sibling | |
| Variable | Age | *n* | Mean SD | *n* | Mean SD | *n* | Mean SD | *n* | Mean SD |
| Height | 7–9 | 36 | 129.8 ± 6.7 | 110 | 130.3 ± 6.6 | 32 | 133.0 ± 7.3 | 107 | 130.3 ± 7.4 |
| | 10–12 | 19 | 150.6 ± 10.5 | 46 | 148.8 ± 9.4 | 23 | 147.4 ± 8.7 | 45 | 143.9 ± 6.7 |
| | 13–15 | 15 | 158.4 ± 5.5 | 46 | 158.1 ± 6.3 | 16 | 165.4 ± 5.9 | 45 | 165.6 ± 10.0 |
| Weight | 7–9 | 36 | 29.8 ± 6.9 | 110 | 30.3 ± 6.9 | 32 | 34.1 ± 10.8 | 107 | 30.5 ± 8.4 |
| | 10–12 | 19 | 43.9 ± 11.4 | 46 | 42.6 ± 9.2 | 23 | 45.0 ± 12.0 | 45 | 40.4 ± 9.9 |
| | 13–15 | 15 | 53.2 ± 8.9 | 46 | 56.8 ± 10.2 | 16 | 61.3 ± 11.3 | 45 | 55.9 ± 13.5 |
| BMI | 7–9 | 36 | 17.6 ± 3.2 | 110 | 17.7 ± 3.0 | 32 | 18.9 ± 4.3 | 107 | 17.7 ± 3.4 |
| | 10–12 | 19 | 19.1 ± 3.4 | 46 | 19.1 ± 2.8 | 23 | 20.4 ± 3.9 | 45 | 19.3 ± 3.4 |
| | 13–15 | 15 | 21.2 ± 3.4 | 46 | 22.8 ± 4.3 | 16 | 22.3 ± 3.5 | 45 | 20.2 ± 3.2 |
| HG | 7–9 | 36 | 12.3 ± 2.5 | 110 | 12.3 ± 3.0 | 32 | 13.2 ± 3.4 | 107 | 13.0 ± 3.1 |
| | 10–12 | 19 | 21.1 ± 6.0 | 46 | 19.9 ± 5.0 | 23 | 18.9 ± 6.0 | 45 | 20.5 ± 5.1 |
| | 13–15 | 15 | 24.2 ± 4.5 | 46 | 25.2 ± 3.8 | 16 | 32.6 ± 6.2 | 45 | 31.8 ± 7.4 |
| FAH | 7–9 | 36 | 7.8 ± 6.3 | 110 | 11.0 ± 10.8 | 32 | 9.0 ± 11.2 | 107 | 10.9 ± 8.3 |
| | 10–12 | 19 | 8.2 ± 8.6 | 46 | 7.3 ± 9.4 | 23 | 9.0 ± 9.2 | 45 | 16.5 ± 17.4 |
| | 13–15 | 15 | 14.1 ± 10.9 | 46 | 12.8 ± 10.2 | 16 | 37.0 ± 21.3 | 45 | 43.2 ± 24.4 |
| SU | 7–9 | 36 | 23.0 ± 9.7 | 110 | 25.2 ± 8.1 | 32 | 24.3 ± 9.0 | 107 | 26.4 ± 7.2 |
| | 10–12 | 19 | 27.9 ± 6.8 | 46 | 30.5 ± 6.8 | 23 | 29.4 ± 9.8 | 45 | 34.4 ± 8.2 |
| | 13–15 | 15 | 32.7 ± 4.0 | 46 | 33.1 ± 7.0 | 16 | 40.9 ± 8.7 | 45 | 43.5 ± 8.9 |
| SLJ | 7–9 | 36 | 108.6 ± 15.6 | 110 | 113.3 ± 17.9 | 32 | 114.7 ± 20.3 | 107 | 117.6 ± 19.0 |
| | 10–12 | 19 | 133.6 ± 23.5 | 46 | 128.6 ± 18.6 | 23 | 125.9 ± 22.2 | 45 | 139.4 ± 20.1 |
| | 13–15 | 15 | 135.5 ± 20.2 | 46 | 130.4 ± 21.3 | 16 | 179.9 ± 27.9 | 45 | 176.0 ± 24.4 |
| SHR | 7–9 | 36 | 14.5 ± 1.2 | 110 | 14.2 ± 1.2 | 32 | 14.1 ± 1.4 | 107 | 13.8 ± 1.4 |
| | 10–12 | 19 | 12.7 ± 1.0 | 46 | 12.7 ± 0.9 | 23 | 13.0 ± 1.5 | 45 | 12.2 ± 1.2 |
| | 13–15 | 15 | 12.4 ± 0.7 | 46 | 12.5 ± 1.0 | 16 | 10.7 ± 0.9 | 45 | 10.8 ± 0.8 |
| PACER | 7–9 | 36 | 22.7 ± 8.4 | 110 | 25.3 ± 9.8 | 32 | 25.8 ± 12.5 | 107 | 30.2 ± 16.0 |
| | 10–12 | 19 | 28.5 ± 12.6 | 46 | 36.6 ± 16.1 | 23 | 37.0 ± 18.8 | 45 | 41.2 ± 18.6 |
| | 13–15 | 15 | 29.6 ± 10.0 | 46 | 30.3 ± 11.4 | 16 | 66.1 ± 20.8 | 45 | 61.7 ± 18.5 |

**TABLE 2 |** Main effects for Offspring condition, Sex, and interaction between them, controlling for decimal age, for each somatic and physical variable.

| | Offspring | | Sex | | Interaction | |
|---|---|---|---|---|---|---|
| | Only child (yes or no) | | (boy or girl) | | Sex x Offspring | |
| | *F* | *sig* | *F* | *sig* | *F* | *sig* |
| **Somatic growth** | | | | | | |
| Height | 4.062 | $\mathbf{p = 0.044}$ | 7.578 | $\mathbf{p = 0.006}$ | 1.897 | $p = 0.169$ |
| Weight | 4.316 | $\mathbf{p = 0.038}$ | 6.006 | $\mathbf{p = 0.001}$ | 8.251 | $\mathbf{p = 0.004}$ |
| BMI | 2.414 | $p = 0.121$ | 1.832 | $p = 0.177$ | 7.896 | $\mathbf{p = 0.005}$ |
| **Physical Fitness** | | | | | | |
| Handgrip | 0.025 | $p = 0.873$ | 19.636 | $\mathbf{P < 0.001}$ | 0.178 | $p = 0.673$ |
| Flexed arm hang | 3.989 | $\mathbf{p = 0.046}$ | 9.145 | $\mathbf{p = 0.001}$ | 1.579 | $p = 0.209$ |
| 60 s Sit-ups | 9.355 | $\mathbf{p = 0.002}$ | 21.714 | $\mathbf{P < 0.001}$ | 0.379 | $p = 0.539$ |
| Standing Long Jump | 1.265 | $p = 0.261$ | 40.907 | $\mathbf{P < 0.001}$ | 1.399 | $p = 0.237$ |
| 10 m SHR | 6.166 | $\mathbf{p = 0.013}$ | 35.809 | $\mathbf{P < 0.001}$ | 0.910 | $p = 0.340$ |
| PACER | 4.636 | $\mathbf{p = 0.032}$ | 33.958 | $\mathbf{P < 0.001}$ | 0.075 | $p = 0.784$ |

*Decimal age was a covariate present in all statistical tests reported in the table, and showed a significant effect for all models ($p < 0.001$). Significant values ($p < 0.05$) are showed in bold.*

deleterious for the only child group that always showed a worst average performance in the physical fitness tests but tend to be taller and heavier than the sibling's group (see **Figure 1**).

## DISCUSSION

The aim of the present study was to understand whether being an only child can be associated with a deleterious difference on somatic growth and physical fitness between the ages of seven and fifteen, our hypothesis being that those differences will be identified in physical fitness and weight status.

Our results showed that only children were taller ($p = 0.044$) and heavier ($p = 0.038$) than children with siblings, although no differences were found in BMI ($p = 0.121$). The growth and maturity features of a child (morphological, physiological, and neuromuscular) have an important role in the development of motor performance during infancy and childhood (25). Differences in height and weight during late childhood and adolescence can be due to differences in maturational status (25–28). However, in the present case, no differences were found in maturational time at PHV (peak height velocity) between these two groups. Genetics and nutritional or environmental conditions are possible explanations for this phenomenon, but more information is needed to substantiate these allegations.

Considering weight, different profiles were observed between sexes regarding each child's condition, with boys achieving higher results in the only-child group and girls achieving higher scores in the children with siblings group. The boys' results were in line with a study conducted with Chinese children aged six to eighteen, which showed that only children were about four times more likely to be obese than children with siblings, even after controlling for sex, age, parental weight status, parental education level, household income, and urban/rural residence (29). Also, Bagley et al. (30) found that boys without siblings spent more time watching television than boys with siblings. The consequence of this was an increase in sedentary time and, in turn, an increase in body weight. On the other hand, the girls' results could be related to the fact that having a sibling has been associated with a 2-fold increase in the likelihood of adolescents viewing $\geq$ 2 h of television per day (31). Nevertheless, contradictory results were found in the same study that registered less time spent viewing television in girls with siblings compared to girls without siblings. In the same vein, the BMI results displayed a different profile regarding sex and offspring conditions, although any sex differences were registered.

After removing the effect of age, children with siblings showed better results in four of the six tested items (FAH, 60 s sit-ups, 10 m SHR, and PACER), with no differences found for the other two items (handgrip and SLJ).

Consistent with the literature [e.g., (19, 32–35)], boys performed better than girls in all physical fitness tests across all ages. In fact, studies have shown that girls outperform boys only in tasks that include mainly balancing, hopping (19, 32), and flexibility (36). Such results have been interpreted as a social rather than genetic influence in childhood, as the physical characteristics of girls and boys are very similar (37–39). During pubertal age, sexual dimorphism explains the male's advantages in most physical fitness tasks (37).

Age of the study participants ranged from pre-pubertal to pubertal ages, surely living in different motor skill development periods and maturational levels, both wich can influence physical fitness performance and be associated with sex differences. Trying to account for this question we had sex groups with similar age (10.47 $\pm$ 2.67 and 10.44 $\pm$ 2.64, respectively, for mean and standard deviation of boys and girls) in the sample. Furthermore, age groups within sexes also showed similar decimal ages (see **Table 1**) reducing the chance for impacting the main effect of interest in the study. Maturation is expected to influence physical fitness performance but, in this case, decimal age and maturational age (age at peak of height velocity) was found to be highly correlated (0.98 and 0.99, respectively, for boys and girls). Because decimal age was used as a covariate in the analysis, the results are independent for both age and maturation level. Boys and girls had the same decimal age.

Relative age or season of birth, is another known variable that seems to be associated with differences in motor competence specifically in sports, with athletes born in the first months of the year showing advantages on the long term sport's career (40). Our sample showed similar distribution of birth month between only child and non-only child by sex (Boys $\chi^2(268,11) = 10.86$, $p = 0.455$; Girls $\chi^2(272,11) = 10.65$, $p = 0.473$), showing that this characteristic did not affect our results.

Muscular fitness is an important marker of health that has been inversely and independently associated with insulin resistance, clustered cardiometabolic risk, and inflammatory proteins during childhood and adolescence (41–43). Considering the strength-related tests conducted in this study, it seems that maximal force (expressed in the HG test) showed no differences between offspring conditions, as well as the leg power test (expressed in the SLJ), in each sex. Nevertheless, in the resistance strength tests (SU and FAH), different profiles were expressed when comparing offspring conditions. In boys, those with siblings clearly demonstrated an advantage, presenting consistently higher values than only-child boys. In fact, other studies suggest that children may benefit from having siblings, especially older siblings who serve as role models, as parents tend to be over-protective of only or firstborn children (19). The same pattern was clearly observed in girls in the SU test, but in FAH, a mixed profile was expressed, with sibling girls showing higher values between 7 and 9 years of age while only child girls outperformed those with siblings in terms of physical growth. Indeed, Wrotniak et al. (44) also concluded that motor proficiency was not related among siblings, while Costa et al. (45) and Pereira et al. (46) observed that only children and firstborn siblings showed greater strength values while exhibiting worse velocity and flexibility results. Such contradictory results confirm the need to conduct more studies in this field.

SHR is commonly used to measure agility (47). In our sample, this capacity differed based on offspring conditions; however, it led to a clear difference between boys and girls. In only-child boys, the 10-m SHR times were slower, especially for those between 7 and 12 years of age. However, in children between 13 and 15 years old, this difference seemed to disappear. It should be noted that the participants in our sample live in a

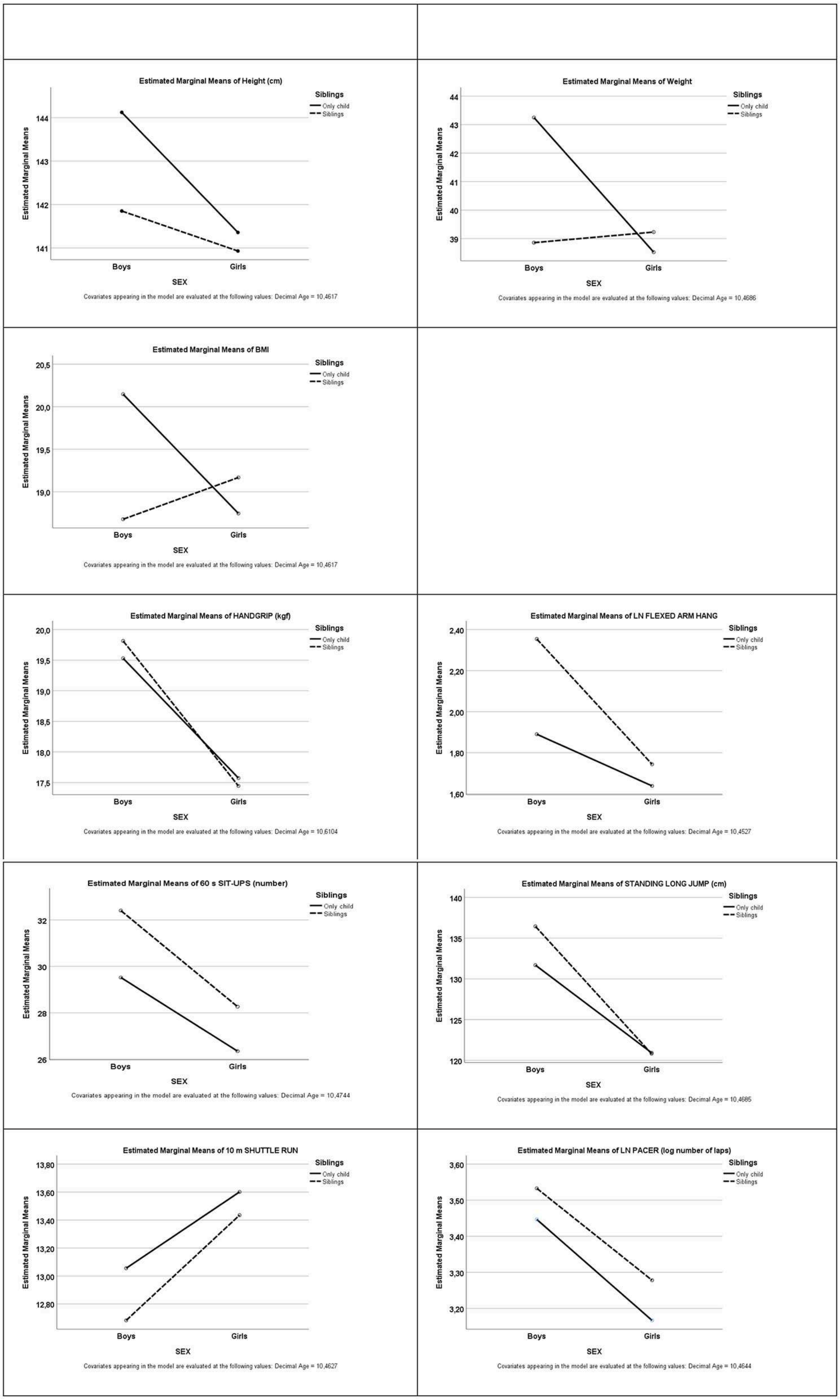


**FIGURE 1 |** Representation of the estimated marginal mean for somatic measures and physical fitness tests according to the number of siblings (only child or with siblings) by sex.

rural environment, which could lead only children to explore the surrounding spaces to a greater extent as they become older and more autonomous. Nevertheless, in girls, this same pattern was observed as being smoother. Only slight differences were observed for girls between 7 and 9 years of age, with the same values maintained in the older ages. Earlier stabilization in girls could be related to the maturation process, which also happens earlier in girls (generally, when they are 10–12 years old) (48).

The PACER, which is strongly associated with health, was developed as a field-based measure for estimating cardiovascular fitness (7, 49). This capacity seems to be developed further in children with siblings than in only children—for both sexes, only children showed poorer results for all age groups, except for boys between 13 and 15 years old. In fact, (50) have suggested that siblings have an unequivocal advantage in motor competence and physical fitness independent of age, sex, or birth order. This phenomenon was observed in children of both sexes of 7 to 15 years of age.

This was the first study that looked at the condition of being an only child in relation to physical fitness. In summary, our results suggest that not having brothers or sisters to play with in the family is a clear disadvantage for the development of physical fitness and highlights the need to conduct more studies in this field, especially because Portuguese statistics show that only-child families are increasing (1).

Although siblings share, on average, 50% of their genes identical-by-descent and a common family environment, they differ in their chronological age, sex, and health behaviors as well as in their physical growth, biological maturation, and motor development trajectories (28). The literature is not consistent when considering who has the advantage between the firstborn [e.g., (17, 51, 52)] or the later-born child [e.g., (15, 19, 53)], suggesting that differences in motor competence and physical fitness exist between siblings depending on birth order and sex.

Very young (preschool age and younger) siblings can spend more time interacting with each other than with any other person, including their parents (54–56). Normally, parents are more protective of an only child, which can result in restrained autonomy and less moving around physically. The only child has the parents' attention for a longer time. In this sense, the family environment seems to play an important role in the development of physical fitness.

In this study, we did not account for the sex, age difference, or the number of siblings in the household. Although including participants from different growing ages, we should keep in mind the cross-sectional nature of the study, so caution should be used when longitudinal inferences are made. Future studies should include these questions and attempt to further disentangle possible causes for the differences found. Age difference and sex of the sibling(s) relative to the child can be variables of interest to analyze in next studies with larger samples. Parenting styles can be of importance, along with the socioeconomic background of the family since there is a known association with the number of siblings. Motor competence as a foundational cornerstone for movement abilities should also be examined within the scope of only children. Longitudinal follow-ups of children, or simply to look for the association of adult's level of motor competence with their offspring condition can probably bring us a better understanding of the only-child motor development phenomena.

Our findings give support to the need for special attention of parents, educators and coaches to the only child physical fitness and somatic development. Parents should try to compensate for the lack of peers in the household by organizing more shared time with friends at home and out of it. Educators should be aware of these potential characteristics of the only child and its consequences within the children's group relationships, and act accordingly. Coaches are to understand the uniqueness of the only child to give them the opportunity to catch up on their specific motor competence whenever the case.

In this study we conclude that children with siblings show positive differences on somatic growth and physical fitness compared to the only child. This conclusion holds for both sexes and for all ages between 7 and 15 years of age.

## CONCLUSIONS

The present study compared the somatic characteristics and physical fitness of only children with those of children with siblings. It revealed significantly better levels of flexed arm hang, 60-s sit-ups, 10-m shuttle run, and PACER results in children with siblings despite only children having significantly greater values of height and weight. No significant interaction was found between offspring and sex, considering physical fitness. Comparisons between sexes revealed that boys had significantly better results than girls for the handgrip strength, flexed arm hang, 60-s sit-ups, standing long jump, 10-m shuttle run, and PACER tests. Generally, our results highlight the importance of offspring in the physical fitness of children. This should be carefully considered by parents, educators and specialists who aim to analyze the contexts that may influence motor competence in the future.

## DATA AVAILABILITY STATEMENT

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

## ETHICS STATEMENT

The study was approved by the Scientific Council of the Polytechnic Institute of Viana do Castelo. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

## AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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# Intervention Effects of a Kindergarten-Based Health Promotion Programme on Motor Abilities in Early Childhood

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**Background:** Physical activity is positively related to motor abilities. Especially in childhood, an active lifestyle is important to support healthy motor development. The low-threshold health promotion programme "Join the Healthy Boat" in kindergartens promotes physical activity in order to also improve motor abilities. Here, effects of the programme on children's motor abilities after 1 year were investigated.

**Materials and Methods:** The longitudinal study included 419 children (3.7 ± 0.6 years) from 58 kindergartens throughout south-west Germany (intervention: 254, control: 165). Children in the intervention group received physical activity promotion with a focus on motor ability development, led by teachers, through one kindergarten year; children in the control group followed the normal kindergarten routine. At baseline and follow-up, motor tests (3-min-run, one-leg-stand, standing long jump, sit-and-reach-test) were performed, anthropometric measures (body weight and height) were taken and a parental questionnaire was issued. Intervention effects were assessed using differential measures (follow-up – baseline) adjusted for gender, age, socioeconomic status (SES) and baseline values, with covariance analyses.

**Results:** Children in the intervention group showed a significant improvement in endurance performance ($F\,(1.329) = 20.95,\ p < 0.000,\ \eta_P^2 = 0.060$), which applies to boys $\left(F\,(1,172) = 13,66,\ p \leq 0.000,\ \eta_P^2 = 0,074\right)$ and girls $\left(F\,(1,152) = 7,48,\ p \leq 0.007, \eta_P^2 = 0,047\right)$. No significant intervention effects on endurance performance were found for children with low baseline values, children with a low SES, and children aged 5 years, nor for any other assessed motor ability.

**Conclusions:** The theory-based, teacher-centered intervention promoting physical activity in order to also improve motor abilities has shown a positive effect on endurance performance in kindergarten children, but no other motor ability. Future interventions should therefore be either longer, more intense and take into account children's age, initial level of performance and their SES. In addition, the influence of teachers should be considered more closely in future research.

**Keywords: physical activity, children, preschool, endurance performance, socio-economic status**

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## INTRODUCTION

From an early age, physical activity supports a healthy growing-up as well-children's development of their motor abilities (1, 2). However, research shows that physical activity levels of children have declined in recent years, and that only half of kindergarten-aged children are sufficiently physically active (3–5). In Germany, 43% of 3–6-year-old girls and 49% of the boys are moderately to vigorously physically active for at least 1 h per day (4). These global recommendations [moderate to vigorous physical activity for at least 1 h per day (6)] can only be seen as a minimum of daily physical activity (6). Children between the ages of three and four (6) and 4 and 6 years of age (7) are encouraged to engage in a minimum of 180 min of physical activity per day, respectively, which includes structured and unstructured activities (7). In general, it is advised to reduce periods of inactivity and increased levels of physical activity have shown to result in greater health benefits such as prevention of obesity, developing an active lifestyle throughout childhood, adolescence and into adulthood, as well as greater cognitive and academic achievements (4, 8).

It is undisputed that physical activity and motor abilities are interrelated (9). Developing adequate motor abilities is considered as one of the key developmental tasks in early childhood (10), for health-related fitness, the promotion of physical activity as well as the prevention of overweight and sedentary behavior (11–13). In addition, studies were able to show that the level of motor abilities during childhood is positively associated with later physical activity behavior (14). Furthermore, a positive correlation between motor abilities and various developmental areas, such as cognitive abilities and language acquisition have been suggested (15–17).

Along with the decline in physical activity in recent decades, various studies also indicate a change in motor abilities in childhood and adolescence (12, 18, 19). For children at kindergarten age, there are only very few evidence-based studies that have addressed changes in motor abilities over recent years. Overall, the results available to date do not show a uniform picture; compared to previous generations, significant changes can only be seen in individual motor abilities, especially in the energetic-conditional area and flexibility (10, 20, 21).

The positive impact of physical activity on children's motor abilities, health and health behaviors is subject of ongoing health research. Findings of various evaluation studies of physical activity promotion measures suggest that targeted promotion of physical activity can positively support the development of motor abilities even at kindergarten age (22–27). Therefore, it is recommended to integrate physical activity promotion into children's everyday lives from an early age on in order to promote a physically active lifestyle and encourage more movement experiences so motor abilities can be developed (4, 28–31).

Since it is one of the first educational institutions children enter, kindergarten is ideally suited for early support of health resources, as it is possible to realize behavior as well as environmental change. In Germany, visiting a kindergarten is voluntary, still, almost all children – independent of their social background – between the ages of three and six can be reached here (32, 33). It is primarily used as a child care offer, not comparable with school, i.e., without fixed curriculum but some recommendations of promoting certain developmental areas during the time children are at kindergarten (e.g., knowledge, creativity, motor skills etc.). The theory-guided health promotion programme "Join in the Healthy Boat" aims to intervene in that setting and offers kindergarten teachers materials to realize bespoke recommendations in health-related areas. The intention of this low-threshold behavioral and preventive intervention is to promote children's health behaviors in kindergartens (34) with the focus on physical activity, nutrition and leisure time activities in order to inter alia improve children's motor abilities. Without adding extra lessons or interfering too much, the teacher-based programme supports and structures already present elements of the daily kindergarten routine such as educational lessons, physical activity sessions, and trips into more health promoting ones. Against the background of the already identified need for early promotion of physical activity and motor abilities, this study investigated intervention effects of the health promotion programme on kindergarten children's motor abilities.

## MATERIALS AND METHODS

### Study Design

For this cluster randomized longitudinal study, nearly 8,000 kindergartens in south-west Germany were contacted by mail. 398 kindergarten teachers of 66 kindergartens provided written, informed consent for participation in the study. After that, a three-stage randomization on the basis of kindergarten size [see (34)] was performed to assign kindergarten children to intervention or control group, which resulted in a drop-out of 22 kindergarten teachers and therefore eight kindergartens. More detailed information can be found elsewhere (34).

The framework-guided (35) study was conducted in kindergartens throughout south-west Germany. Before and after the intervention period of 1 year, age-appropriate tests and measurements were carried out in the kindergartens of all participating children whose parents had given their written informed consent and children their assent. After those examinations, a parental questionnaire was issued. After baseline measurements were completed, the kindergartens were divided into intervention and control group. Kindergartens in the intervention group implemented the "Healthy Boat" programme during one kindergarten year; the control group carried on with their normal kindergarten routine (starting with the programme after follow-up measurements were completed). However, it has to be assumed that children in the control group also received some kind of health-promotion since the Ministry of Culture, Youth and Sport recommends health promotion at kindergartens, however does not give any guidance on how to implement it (32).

The theory-based intervention (36, 37) consists of weekly exercises and games lessons with the focus to improve children's motor abilities, also includes ready-to-use ideas, action alternatives, and instructions to get children to be more physically active and gain knowledge about their body and health, as well as eat more healthily (38). Additionally, ideas on how to re-arrange rooms and outdoor spaces for more opportunities to be physically active as well as helpful structures and norms were presented to enable the development of healthy eating habits. Further, short activity games (5–7 min each) designed to promote children's physical activity and motor abilities were incorporated into the daily kindergarten routine and delivered by the kindergarten teachers (more details: 34).

The here reported results were assessed as a secondary outcome of the programme. Primary outcomes as well as other secondary aspects of the programme are reported elsewhere (39–42).

## Instruments

Children's flexibility (sit-and-reach), balance (one-legged stand), and speed strength (standing long jump) were assessed using the KiMo-Test (43), children's endurance performance was assessed during a 3-min run (44). Skilled examiners carried out the tests on a one-to-one basis, including trained students who recorded the results.

During a kindergarten visit, children's height (m) and body weight (kg) were measured to ISAK standards (45) by trained staffed using a stadiometer and calibrated electronic scales (Seca 213 and Seca 826, respectively, Seca Weighing and Measuring Systems, Hamburg, Germany). Based on height and weight, children's body mass index (BMI; kg/m$^2$) was calculated and subsequently converted to BMI percentiles based on German reference data (46). Children thereafter were classified into under-/normal weight (percentiles $< 90$), overweight (percentiles $\geq 90$) and obese (percentiles $\geq 97$).

Socio-demographic information as well as children's and parental health behaviors were collected via parental questionnaire. For the present study, data on children's physical activity behavior {"On how many days of a normal week is your child physically active for a total of at least 60 min a day?" [WHO guideline (6)]} was derived from bespoke questionnaire, as well as their leisure time activities ("Is your child physically active in/out of a sports club?"). In order to calculate children's socioeconomic status (SES), based on the so-called Winkler index (47), highest parental education level, their occupation and the household income were used. This was followed by a division into a low, medium and high SES.

## Statistical Analyses

For the performed analyses, a significance level of $\alpha \leq 5\%$ was defined; data were calculated using SPSS Statistics 25 (SPSS Inc., Chicago, IL, US). Effect strength was evaluated using the partial eta square ($\eta^2_P$) $\geq$ 0.059. To check randomization, the two groups were screened for possible differences based on various characteristics. For nominally scaled variables chi-square tests; for ordinal scaled variables, Mann-Whitney *U*-tests, and for metric variables, *t*-tests for independent samples were used. In addition, *t*-tests for dependent samples were used to analyse within group effects. The differential measures (follow-up - baseline) of all dependent variables (motor tests) were checked for existing differences and analyzed by covariance analyses (ANCOVA). Based on the current state of research, the factors intervention/control group, gender, age, and SES were included in the statistical model in order to examine intervention effects; participation in organized sports was originally planned to be included as well but showed no effect in any models, so it was disregarded. In the case of intervention effects, the results were stratified for different characteristics.

# RESULTS

## Sample Descriptives

After plausibility checks, the valid sample included 558 children from 58 kindergartens. Since only children who had completed the full motor test battery at baseline and follow-up were included, 139 children were excluded from the dataset and the thereafter analyzed sample consists of 419 children (254 in the intervention group, 165 in the control group) from 53 kindergartens (ranging from 3 to 30 children per kindergarten).

**Table 1** shows the sample's baseline characteristics; the two groups differ significantly in their composition in terms of gender ($\chi^2 = 9.95$; $p = 0.002$). For their motor abilities, at baseline, the children in both groups achieved similar levels of endurance performance (3-min run) as well as flexibility (sit-and-reach) and lower limb strength (long jump). For balance (one-legged stand) however, there was a significant difference at baseline with children in the intervention group performing significantly better than those in the control group [$t_{(417)} = 3.19, p = 0.002$].

## Association of Physical Activity and Organized Sports

At baseline, there was a significant difference for meters run during 3 min between those children who were physically active for a minimum of 60 min per day on at least 4 days per week and those who are not [$t_{(334)} = -2.29, p = 0.02$]. Children who are physically active on most days per week for 1 h achieved 13.5 m more than those who are less physically active (266.7 ($\pm$ 47.7) m vs. 253.3 ($\pm$ 46.3) m, respectively). This effect however, could not be observed for any other motor ability, nor for children's organized sports participation on any of the tested motor variables or at follow-up.

## Intervention Effects

After 1 year, both groups improved their endurance performance significantly as well as their balance and lower limb strength. A decrease in trunk flexibility was evident in both groups, however only significant in the intervention group.

As shown in **Figure 1**, at follow-up, the children in the intervention group ran on average 55.3 m more in 3 min than at baseline; children in the control group improved their endurance performance with 31.6 m more than the previous year significantly less, even if adjusted for gender, age, SES and baseline values ($F\,(1.329) = 20.95,\ p < 0.000,\ \eta^2_P = 0.060$). The overall model explains 37.5% of the variance (*adjusted* $R^2 = 0.375,\ F\,(6.329) = 34.49,\ p < 0.000,\ \eta^2_P = 0.386$).

The intervention effect remains for both genders; boys $\left(F\,(1.172) = 13.66,\ p \leq 0.000,\ \eta^2_P = 0.074\right)$ and girls $\left(F\,(1.152) = 7.48,\ p \leq 0.007, \eta^2_P = 0.047\right)$, adjusted for age, SES and baseline values. The model for the boys explains 36.7% of the variance (*adjusted* $R^2 = 0.367,\ F\,(5.172)\ 21.49,\ p < 0.000, \eta^2_P = 0.384$), the model for the girls explains 36.6% of

**TABLE 1** | Baseline characteristics of the total sample, intervention and control group.

| | Missing values | Intervention group | Control group | Total sample |
|---|---|---|---|---|
| Number (n; %) | | 254 (60.6) | 165 (39.4) | 419 (100) |
| Gender [boys] (n; %)[a] | | 140 (55.1) | 74 (44.8) | 214 (51.1) |
| Age [years] (m; sd) | | 3.7 (0.6) | 3.7 (0.5) | 3.7 (0.6) |
| Body weight [kg] (m; sd) | 7 | 17.4 (2.4) | 17.4 (2.8) | 17.4 (2.6) |
| Height [cm] (m; sd) | 6 | 105.6 (5.8) | 105.8 (5.4) | 105.0 (5.6) |
| BMI percentiles (m; sd) | 7 | 51.1 (25.6) | 47.9 (26.2) | 49.8 (25.9) |
| Overweight/obese (n; %) | 7 | 14 (5.6) | 9 (5.5) | 23 (5.6) |
| Socio-economic status (n; %) | 83 | | | |
| Low | | 19 (9.4) | 13 (9.8) | 32 (9.5) |
| Medium | | 67 (33.0) | 46 (34.6) | 113 (33.6) |
| High | | 117 (57.6) | 74 (55.6) | 191 (56.8) |
| **Physical activity** | | | | |
| Physically active during leisure time (organized and unorganized) (n; %) | 67 | 175 (82.5) | 105 (75.0) | 280 (79.5) |
| Participation in organized sports (n; %) | 19 | 121 (51.1) | 83 (50.9) | 204 (51.0) |
| MVPA for at least 1 h/day [n days] (m; sd) | 83 | 2.7 (2.0) | 2.3 (1.8) | 2.5 (2.0) |
| MVPA for at least 1 h/day on most (i.e., 4 or more) days/week (n; %) | 83 | 57 (27.5) | 27 (20.9) | 84 (25.0) |
| **Motor abilities at baseline (m; sd)** | | | | |
| 3-min run [m] | | 253.8 (48.6) | 257.8 (43.9) | 255,3 (46.8) |
| One-legged stand [n floor contacts][b] | | 18.4 (8.6) | 21.2 (9.0) | 19.5 (8.8) |
| Sit-and-reach [cm] | | 2.7 (4.7) | 2.3 (6.0) | 2.5 (5.2) |
| Standing long jump [cm] | | 67.6 (20.0) | 63.6 (21.2) | 66.0 (20.5) |

*[a]significant difference between both groups ($p = 0.04$); [b]significant difference between both groups ($p = 0.002$).*
*n, number; m, mean; sd, standard deviation; overweight/obese, BMI percentiles ≥ 90; MVPA, moderate to vigorous physical activity.*

the variance (*adjusted* $R^2 = 0.366$, $F(5.152)$ 17.11, $p < 0.000, \eta_P^2 = 0.386$).

For the remaining three motor tests, no intervention effects were found (**Table 2**). Further, no gender differences in motor abilities could be seen within the study year; which applies to intervention and control group.

## Stratified Intervention Effects on Endurance Performance

For the intervention effect on endurance performance, it became apparent that the initial performance level ($F(1.329) = 1661.01$, $p < 0.000$, $\eta_P^2 = 0.329$), children's gender $\left(F(1.329) = 4.89,\ p < 0.028,\ \eta_P^2 = 0.015\right)$, age $\left(F(1.329) = 4.25,\ p < 0.040,\ \eta_P^2 = 0.013\right)$ and SES $\left(F(2.329) = 3.82,\ p < 0.023,\ \eta_P^2 = 0.023\right)$ are significantly associated with endurance performance.

### Initial Performance

Children with low initial performance showed the greatest increase in endurance performance in control and intervention group. Yet, only children with average and high baseline performance in the 3-min run benefited from the intervention, controlled for group factor, age, gender, and SES ($intervention: \bar{x}_{average} = 56.92;\ \bar{x}_{high} = 23.76;\ control: \bar{x}_{average} = 28.91;\ \bar{x}_{high} = -3.4$). In both performance groups (high and average), the development of endurance performance was significantly higher than that of children in the control group with the same initial level ($average: F(1.160) = 15.07,\ p \leq 0.000,\ \eta_P^2 = 0.09;\ high: F(1.78) = 5.54, p = 0.02;\ \eta_P^2 = 0.07$). In children with low motor abilities at baseline, no intervention effect was seen ($low: intervention: \bar{x}_{low} = 87.51; control: \bar{x}_{low.} = 78.10;\ F\ (1, 80) = 0.94,\ p = 0.336,\ \eta_P^2 = 0.01$).

### Socio-Economic Status

Intervention effects are also seen in children with medium ($medium\ SES: \bar{x}_{IG} = 61.46;\ \bar{x}_{CG} = 25.37;\ F = (1.108)\ 11.74,\ p \leq 0.001, \eta_P^2 = 0.10$) and high SES ($high\ SES: \bar{x}_{IG} = 56.44;\ \bar{x}_{CG} = 39.32;\ F = (1.186)\ 8.14,\ p \leq 0.005, \eta_P^2 = 0.04$). Children with low SES in the intervention group did not significantly increase their endurance performance in comparison to those in the control group ($low\ SES: \bar{x}_{IG} = 41.37;\ \bar{x}_{CG} = 17.31;\ F(1.27) = 2.26,\ p = 0.144,\ \eta_P^2 = 0.08$).

### Age

Three- and four-year-old children benefited from the intervention ($3\ years: \bar{x}_{IG} = 63.88;\ \bar{x}_{CG} = 48.98;\ F(1.106) = 5.60,\ p \leq 0.02, \eta_P^2 = 0.05$) ($4\ years: \bar{x}_{IG} = 54.25;\ \bar{x}_{CG} = 24.94;\ F(1.200) = 12.01,\ p \leq 0.001, \eta_P^2 = 0.06$), whereas, 5-year-old children in the intervention group performed no differently than those in the control group ($5\ years: \bar{x}_{IG} = 43.63;\ \bar{x}_{CG} = 0.5;\ F(1.12) = 3.69,\ p \leq 0.08, \eta_P^2 = 0.24$).

## DISCUSSION

This study investigated intervention effects of the health promotion programme "Join the Healthy Boat" on motor abilities through kindergarten-based physical activity promotion.

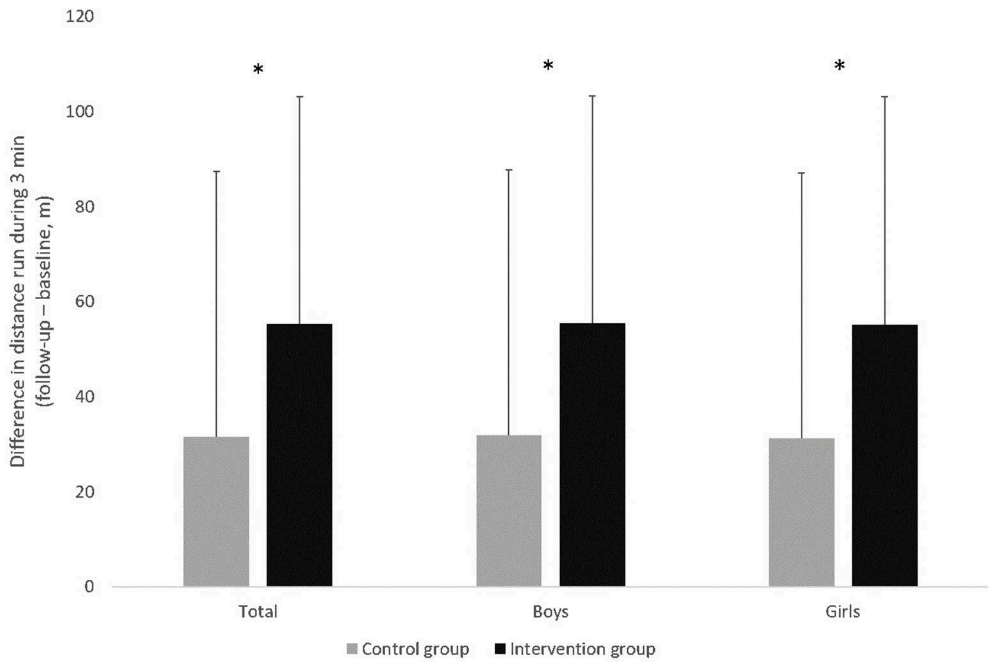


**FIGURE 1 |** Development of endurance performance (3 min run; difference follow-up – baseline) for total sample, boys and girls as well as intervention and control group. Values are displayed as means and standard deviation, *significant difference ($p < 0.05$).

**TABLE 2 |** Intervention effects for motor abilities of intervention and control group, for total sample, boys and girls [difference follow-up – baseline; values are displayed as m (sd)].

| | Intervention group | | | Control group | | |
|---|---|---|---|---|---|---|
| | **Boys ($n = 149$)** | **Girls ($n = 114$)** | **Total ($n = 254$)** | **Boys ($n = 74$)** | **Girls ($n = 91$)** | **Total ($n = 165$)** |
| 3-min run [m][a,b,c] | 55.4 (48.5) | 55.2 (47.2) | 55.3 (47.9) | 32.0 (49.0) | 31.3 (55.8) | 31.6 (52.7) |
| One-legged stand [n floor contacts][b] | −6.4 (8.7) | −5.9 (8.1) | −6.2 (8.4) | −9.7 (8.7) | −8.8 (9.4) | −9.2 (9.1) |
| Sit-and-reach [cm] | −1.6 (5.5) | −0.8 (4.3) | −1.3 (5.0) | −1.1 (4.9) | −0.1 (5.6) | −0.5 (5.3) |
| Standing long jump [cm] | 20.9 (20.0) | 17.0 (20.4) | 19.2 (20.2) | 21.3 (21.2) | 20.4 (19.8) | 20.8 (20.3) |

*[a]significant difference between intervention and control group ($p < 0.001$), adjusted for baseline values, age, gender and SES; [b]significant difference for boys between intervention and control group ($p < 0.001$), adjusted for baseline values, age and SES; [c]significant difference for girls between intervention and control group ($p \leq 0.007$), adjusted for baseline values, age, and SES.*

*n, number; m, mean; sd, standard deviation, SES, socio-economic status.*

Within the 1-year study period, children in both groups (control and intervention) have improved their endurance, strength and balance; and decreased their trunk flexibility. Since early childhood is considered to be a phase of rapid motor development (48, 49), it is not surprising that the entire sample has improved in three out of four motor abilities. Physiological and physical changes support that development process (49), but during those years at kindergarten, motor abilities are practiced and completed mainly through the children's urge to play and move.

This is where the here investigated programme tries to intervene. During the intervention period, the teachers were asked to implement 20 exercise and games lessons as well as 30 ready-to-use action alternatives and ideas in order to get children to be more physically active and gain knowledge about their body and health as well as eat more healthily. In order to incorporate additional physical activity into the daily kindergarten routine, short activity games of 5–7 min each were introduced and performed twice a day. This was as much as the pedagogical advisory board, which was consulted during intervention planning, considered as possibly feasible to incorporate into a normal kindergarten routine if high and lasting implementation of the intervention was sought.

## Bounce, Flexibility, and Balance

Various kindergarten-based health promotion programmes have shown to have significant effects on bounce, balance and motor coordination in early childhood (22, 24, 26, 27). While there is a tendency for an increased development of bounce (standing long jump) in the intervention group, none of the above mentioned results can be confirmed by the here available results of "Join the Healthy Boat."

The result of flexibility and balance (sit-and-reach and one-legged stand) indicate that children in the control group tended to perform slightly better than their counterparts in the intervention group and even showed a decrease in trunk flexibility in both groups after 1 year. The latter maybe age-related but one can only speculate to why this showed statistical significance in the intervention group. Similarly, to why – although no significant differences were found – balance tended to be slightly more pronounced in children in the control group, although they started off with worse values at baseline. Especially the short activity games of the intervention, which were implemented twice a day, have plenty of exercises to use and practice balance, as well as flexibility. According to teachers' information on implementation rates (not shown), those activities were used very regularly and children enjoyed performing those exercises.

## Endurance Performance

Further, this low-threshold intervention, mainly promoting daily physical activity in order to inter alia increase children's motor abilities found significant intervention effects for endurance performance, when controlled for gender, age, SES and baseline values; this applies to boys as well as girls, although there were more boys in the intervention group, compared to the control group. Since aerobic endurance is considered a positive predictor of well-developed health-related fitness (50), which again is positively associated with various health aspects such as cardiovascular health and weight status (51), endurance performance is looked at in most interventions assessing children's motor abilities. Like Latorre-Román et al. (25) who were able to show similar effects using a shorter (10 weeks) but much more intense programme including 3 weekly exercise lessons á 30 min focussing on the promotion of physical fitness through aerobic exercise games. Correspondingly, the health promotion programme "Ballabeina" was able to demonstrate positive intervention effects on endurance performance in kindergartens with a high proportion of children with migration background (26). This has also been confirmed for slightly older children (first and second grade of primary school) where children in the intervention group but especially boys with migration background benefited from a low-threshold school-based health and physical activity promotion and showed significantly improved endurance performance after 1 year (40, 41).

## Age Differences in Endurance Performance

Then again, looking at the significant intervention effects (for endurance performance) in more detail, it becomes apparent that children's initial motor abilities, SES, and age are significantly associated to their development of endurance performance. Three-year-olds in intervention and control group were the most likely to improve their endurance performance. Yet, significant intervention effects were found for children aged three and four, but not five. Reasons for this are unclear, especially since the materials provided for the intervention include actual activity games and exercises but also lessons for children to gain knowledge, which should theoretically address the older children more but maybe there was already a limit reached. It is difficult to valuate these findings, since only one study in kindergarten children known to date has differentiated their results according to age. In contrast to the results reported here, Birnbaum et al. (22) found intervention effects only for 4.3–5 year old children on bounce and coordination during jumping. Yet, their results and these can only be compared with each other to a limited extent, since different motor abilities were assessed.

## Differences in Endurance Performance on the Basis of Initial Performance Level

With regards to different levels of motor abilities, it was repeatedly reported that children who have particularly weak motor abilities benefit most from interventions at an early age (16, 24). Although here, the largest increase in endurance performance in both groups was seen in children with low abilities, intervention effects were only visible in children with moderate and high endurance performance at baseline. This is contraire to another German study examining effects of a physical activity promotion measure in kindergarten children, where children with low and moderate motor abilities were more likely to benefit from the intervention (24). However, the performance groups of that study (24) refer to an entire motor abilities test and have been determined on the basis of the standard values. Endurance performance levels of children in the present study were determined by quartiles of the sample distribution. In order to judge why the here assessed measure has shown effects only in children with moderate and high initial endurance performance, further qualitative details should have been collected. Whether it was that children with little interest in physical activity and possibly thus low motor ability levels were not reached because of reasons on their side, such as lack of motivation; or even on the teacher's side, e.g., excluding those children from some exercises because they know they cannot do them well so they want to spare them the disappointment. Further, maybe some of the children with low motor abilities have a pathological condition, that was not considered here.

## Differences in Endurance Performance on the Basis of Socio-Economic Background

In addition to age and initial endurance performance, children's SES was also associated to their motor abilities during the intervention period. Stratified analyses for SES showed that intervention effects on endurance performance were only significant in children from a middle and high socio-economic background; even though there was a tendency for children with low SES in the intervention group to show better results in the 3-min run. Children with low SES also showed less change in performance levels compared to those with medium and high SES; this applies to children in the intervention as well as the control group. It is already known that children with a lower SES are less physically active (4) and display worse motor abilities than children with a high SES (52, 53). Based on the present findings however, it should be considered to not only work holistically and preventive in the kindergarten setting but to try and reach those children from a socio-economically disadvantaged background as well as their parents especially with an intervention and a more specific and intense health promotion measure. "Join the Healthy Boat" already tries to reach parents with regular information about health promoting content, including letters in different languages, but possibly those letters and information do not reach parents of children from a socio-economically disadvantaged background and more joint activities, including exercises or hands-on information are needed.

While findings show that some motor abilities can be influenced by targeted promotion in early life already, and that for endurance performance "Join the Healthy Boat" can be applied in that area, there are also several limitations to be considered when interpreting the here presented results. In contrast to other physical activity promotion interventions, the duration of the individual exercise sessions (two short exercises per day and on average one game, lesson or activity per week) is below average (24–27), which may have resulted in the low intervention effects. Yet, it should be noted (as mentioned above) that this intervention was designed as a low-threshold measure so it would not interfere with the daily kindergarten routine in order to ensure high implementation rates. This however, is in conflict with a longer duration of individual physical activity sessions, as recommended by Jaščenoka and Petermann (54). On the positive side, because of the little interference of this health-promotion programme in the day-to-day routine, this intervention can be carried out from the first year at nursery, throughout kindergarten to the end of primary school, and thus support a healthy lifestyle including physical activity and well-developed motor abilities over nearly 10 years during a formative phase in children's lives. Nonetheless, this study only lasted 1year and follow-up assessments were carried out straight after a 6-week summer break with no intervention, so it can be surmised that a follow-up before the holidays (55), a shorter more intense or a multi-year low-level implementation would have had stronger effects. Further, the often discussed influence of teachers on children's development but also on the quality of health promotion measures in kindergartens (54) was not taken into consideration. On a further limiting note, only four motor tests were used in this study (speed was ignored). Motor abilities, however, are understood as the sum of all control and function processes that underlie posture and movement (56) and therefore all dimensions (endurance, strength, coordination, speed and flexibility) should be taken into account (57); again, this was owed to feasibility. Additionally, there were significantly more boys in the intervention group, compared to the control group, which might have led to a distortion of the results, at least in some aspects. Also, since "Join the Healthy Boat" encompasses physical activity promotion in order to promote motor abilities as well as nutrition advice and a reduction of screen media use in order to achieve a holistic change in health behavior, the intervention effects can probably not solely be attributed to the physical activity module of the programme, but rather that the intervention in its entirety could have led to the results. Moreover, data on physical activity, leisure time behavior and SES were taken from a parental questionnaire, which leads to the possibility of a systematic bias due to recall and social desirability bias. Finally, although the sample was large, its representativeness and transferability to other regions are limited since only children from kindergartens in south-west Germany were included and participation was voluntary. Yet, the cluster-randomized longitudinal design of the intervention study with an intervention and control group is a strength of this study.

## CONCLUSION

To summarize, the relationship between physical activity and motor abilities and their positive relationship to health and development of children is well-established. For kindergartens, there are only few studies examining the influence of health promotion measures on motor abilities. The present study contributes to new findings in the bespoke research gap. The kindergarten-based health promotion programme "Join the Healthy Boat" has shown positive effects on aerobic endurance, and thus on a health-related measure, in both boys and girls after a 1-year intervention. This could be achieved by a low-threshold intervention with a comparatively short duration of exercise sessions. There was no evidence of intervention effects for children with a low initial endurance performance, for children from a low socio-economical background, and for older children. In order to achieve development in terms of coordination, bounce and flexibility (which were also assessed but showed no increases), it may be necessary to have a longer lasting and/or more specific and intense intervention. This and some qualitative data on why those groups could not be reached should be investigated in future studies. The results of existing intervention studies suggest that measures with the aim to promote physical activity of kindergarten children have positive effects on endurance performance. Structured and evidence-based physical activity promotion measures should be used to support motor abilities from an early age on and across all social groups in different settings. In future interventions, motor-impaired children and children from socially disadvantaged families should be given special attention and materials should also be designed on a target-group-specific basis.

## DATA AVAILABILITY STATEMENT

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

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The Ministry of Education, as well as Ulm University's ethics committee (https://www.uni-ulm.de/einrichtungen/ethikkommission-der-universitaet-ulm/) have approved the study. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kind; participants' verbal assent was also given. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

## AUTHOR CONTRIBUTIONS

SK, OW, CL, and JS designed the study. SK, OW, and CL carried out the study. SK, LH, and BS performed the statistical analyses. SK and LH drafted the manuscript. OW, CL, BS, and JS revised the manuscript. All author contributed to the article and approved the submitted version.

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# Children's Physical Activity, Academic Performance, and Cognitive Functioning: A Systematic Review and Meta-Analysis

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Researching the relationship between physical activity and academic performance is becoming an important research topic due to increasing evidence about the positive effect of physical activity on cognitive functioning. The present systematic review and meta-analysis (PROSPERO registration number: CDR132118) is a unique contribution to the recently published reviews since it only includes interventions longer than 6 weeks and acknowledges the influence of the qualifications of practitioners who deliver interventions. After identifying 14,245 records in five databases and selecting 247 full-text articles assessed for eligibility, 44 interventions passed all eligibility criteria. This meta-analysis uses validity generalization in a random effects model, which shows that academic performance itself is not solely caused by increased physical activity. The weighted mean population effect of all included interventions was $r_W = 0.181$. Most of the studies had serious limitations since they did not report physical activity intensity, which is an essential component to achieving positive exercise effects on cognition. In addition, the qualifications of the staff who administer the interventions were largely ignored in existing literature. It was found that 13 out of 20 physical activity interventions with significant positive effects on academic performance were performed by practitioners who held higher qualifications in the field of physical education and exercise science, who could mediate higher physical activity intensities of the given interventions. The population effect in studies where interventions were administered by practitioners with lower qualifications in the field ($r_W = 0.14$) was lower compared to interventions performed by staff with higher qualifications ($r_W = 0.22$). There was also a significant difference in academic performance with regard to staff qualification level ($\chi = 4.464$; $p = 0.035$). In addition to activity duration, future physical activity intervention studies including those investigating academic performance should focus on the importance of physical activity intensity and include measures of physical fitness as objective indicators to enable more reliable analyses to establish physical activity influence on academic performance.

**Keywords: physical activity, academic performance, teaching qualifications, children, adolescents, intervention**

# INTRODUCTION

Regular physical activity (PA) at an adequate intensity and duration is indispensable for maintaining a healthy lifestyle due to its continued positive impact on skeletal (1), metabolic (2), cardiovascular (3) and psychosocial functioning of the human body (4). Low levels of PA, on the other hand, lead to low cardiorespiratory fitness and are associated with a decline in academic performance (AP) (5), possibly due to the deterioration of brain structure, and thus, cognitive abilities and brain function (6–8). PA increases oxygen saturation (9) and angiogenesis (10) in brain areas responsible for task performance. The positive effects of PA on the prefrontal cortex and the hippocampus have been emphasized in many studies (11–13). Furthermore, the molecular architecture and behavior of the basal ganglia may also be directly influenced by PA (8).

Some studies have found positive results between PA and academic performance (AP) (14–17), whereas other studies have found no difference, or even negative correlations between the two factors (18, 19). Review articles using effect size (ES) suggest that PA itself has positive effects on AP (6). For example, one of the earliest meta-analyses in which 1,260 ES were calculated, reported an overall ES of 0.25 and suggested that PA has a small, yet positive effect on cognition (20). ES has been shown to be the largest in studies investigating cognition as a function of fitness level (ES = 0.53). For example, Sibley and Etnier (6) calculated ES for each study that met their study eligibility criteria. They concluded that there is a statistically-significant positive effect of PA on cognition in children, reporting an overall ES of 0.32.

Contemporary children often experience a lack of physical exercise and an abundance of sedentariness in their school and domestic environments, which inevitably leads to deterioration of PA. School-based PA as a part of the normal physical education classes (PE) and extracurricular activities are often the only stable access to PA for many children, and have shown to provide a significant impact on classroom behavior (21), self-esteem (4), self-image (22), and cognitive function (5–7). This is why the competencies of PE teachers and other specialists who deliver school-based PA programmes are so critical, and can affect student outcomes considerably. Formally gained knowledge and professional experiences that assure the professional competencies of the practitioners are key elements for the safe and effective implementation of any PA-enhancing intervention (23, 24). However, the professional competencies of the practitioners who deliver such interventions (and really, any school-based PA programme), are often ignored or not represented in the literature. This meta-analysis does differentiates professional qualifications of staff who perform interventions and measurements in the physical activity classes.

In this regard, our meta-analysis provides a unique contribution to the recently published reviews (25–29), since it exclusively includes interventions longer than 6 weeks (30) and also considers the influence of the qualifications of the PE teachers and practitioners administering the interventions.

Thus, the main purpose of this review is to examine whether primary and secondary school children who were involved in PA-enhancing school-based interventions demonstrated higher AP than their peers who were not involved in regular PA, and whether the improvements observed in AP were influenced by practitioners with higher professional competencies compared to less qualified practitioners. This review examines only those interventions completed in studies with an experimental design, and which reportclear and reliable measures and indicators of both PA and AP. The studies also had to be implemented in school settings.

# METHODS

The meta-analysis was performed and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (31, 32). The present work was registered at the International Prospective Register for Systematic Reviews, identification code CDR132118.

## Literature Search

Two review authors (VS and GS) independently searched literature from databases PubMed, Scopus and ScienceDirect, which were accessed between January 2017 and July 2017 and searches were re-run from February 2019 and June 2019. Gray literature of published interventions and systematic reviews was searched through Google Scholar and Dart electronic databases from February 2019 to June 2019. Unpublished studies won't be sought. The international prospective register of systematic reviews (PROSPERO database) was also searched to identify any unpublished and/or important ongoing meta-analyses. Titles and abstracts of studies retrieved using search string and those from additional sources were screened independently by two review authors to identify potential studies whereas the third review author (GJ) mediated any disagreement until a consensus was reached. Abstracts were screened using following search string: children AND intervention AND school AND (physical activity OR physical education OR extracurricular activity) AND (cognition OR academic performance OR academic achievement). All articles generated from the initial search were stored on Mendeley reference management software & researcher network (Elsevier, Amsterdam, Netherlands) which removed duplicate references.

## Inclusion Criteria

Since the primary objective of the current study was to determine any impact and/or consequences of increased PA on children's behavior and AP, the reviewed interventions had to be published as articles in peer-reviewed scientific journals, as proceedings, or as doctoral dissertations with a focus on healthy school-aged children between 5 and 16 years of age, without disadvantages regarding socio economic standard and with evenly distributed sample in both genders.

The articles also needed to report an obvious measure of increased PA (expressed in minutes per week), including one or more of extracurricular or morning PA, PE, school sports, excluding professional sport activity, including standardized measures of AP (e.g., grade point average, standardized national tests, cognition and intelligence tests, validated tests from algebra, reading and writing).

**TABLE 1 |** All interventions included in study.

| **Author (year)** | ***N*** | **Age of children (years or school grade)** | **Intervention duration** | **Experimental design** | **Type of activity and *AP assessment*** | **Staff implementing intervention and measurements (HQ or LQ)** | **Intervention min/week** | **Effects on AP (ES)** |
|---|---|---|---|---|---|---|---|---|
| Ahamed et al. (18) | 288 | 9–11 years old** (4th and 5th grade) | 16 months, 5 days/week; 15 min/day | CG and IG | Increased PA time; *Canadian achievement test* | Classroom teachers (LQ) | 47 | No effect (0.00) |
| Alesi et al. (33) | 44 | 8–10 years old | 6 months; 2 days/week; 75 min/day | CG and IG | Increased PA time; *Corsi block test, Forward digit span test, The backward digit span test* | PE teacher (HQ) | 150 | Significantly better executive functions in IG (1.62) |
| Ardoy et al. (34) | 67 | 12–14 years old (II–V Tanner Grade) | 17 weeks, 2 days/week; 55 min/day | CG and 2 IG. (1st IG had only increased PE time, 2nd IG had increased PE time, and intensity of PE lessons) | Enhanced PE and increased PA time*; IGF-M Intelligence Test, and school grades (mathematics, language, natural sciences, English)* | PE teachers (HQ) | 110 | Significantly better results in mathematics (0.47) and in GPA (2.60) |
| Beck et al. (35) | 165 | 7.5 (±0.02) years old | 6 weeks; 3 days/week; 60 min/day | CG and 2 IG (CG: non-motor enriched mathematical teaching; IG1: fine motor math group; IG2: gross motor math group) | Increased PA time (during academic narrated lessons); *standardized mathematical test, modified Eriksen Flanker test, CANTAB* | Classroom teachers (LQ) | 180 | No effect (0) after the last testing. Right after the intervention only normal math subgroup in gross motor math IG benefited compared to CG and fine motor IG |
| Bunketorp Käll et al. (36) | 545 | 12 years old (5th grade) | 3 years; 2 days/week; 30–45 min/day | CG and IG | Increased PA time; *Academic performance grades of mathematics, English, and Swedish language* | Not reported (LQ) | 75*** | No effect (0.00) |
| Chaddock-Heyman et al. (37) | 32 | 8–9 years old | 9 months; 5 days/week; 2 school periods/day | CG and IG | Increased PA time; *fMRI* | At university by research staff (HQ) | 425*** | No effect (0.00) |
| Coe et al. (38) | 214 | 10–11 years old** (6th grade) | 1 semester, 5 days/week, On average 19 min of MVPA/day | CG and IG. 1st group was assigned in PE in 1st semester; 2nd group was assigned to PE during 2nd semester | One semester without PE, other semester increased PE time; *Terra Nova Test and individual grades* | Not reported (LQ) | 95 | No effect (0.00) |
| Costigan et al. (39) | 65 | 15.8 (±0.6) years old | 8 weeks; 1(3)****days/week; 30(120)****min/day | CG and 2 IG (CG had normal PE-2 school hours/week; IG had high-interval PE) | Increased PA and enhanced PE; *The trail making test (TMT)* | PE teachers (HQ) | 30 | No effect (0.00) |
| Davis et al. (40) | 94 | 7–11 ($M = 9.2$) years old | 15 weeks, 5 days/week, 40 min/day | CG (no-exercise) and 2 IG (low-dose exercise group, high-dose exercise group) | Aerobic PA; average heart rate > 150 bpm; *CAS* | PE teachers, researchers (HQ) | 200 | Significantly better AP in high-dose exercise group (2.24) |
| Greeff et al. (41) | 499 | 8.1 years old (2nd and 3rd grade) | 2 years; 22 weeks/year; 3 days/week; 20–30 min/day | CG and IG | Increased PA time (during academic narrated lessons); *Golden stroop test, Digit Span backward, and Visual span backward test, M-WCST* | Primary and classroom teachers (LQ) | 75*** | No effect (0.00) |

*(Continued)*

**TABLE 1** | Continued

| Author (year) | *N* | Age of children (years or school grade) | Intervention duration | Experimental design | Type of activity and *AP assessment* | Staff implementing intervention and measurements (HQ or LQ) | Intervention min/week | Effects on AP (ES) |
|---|---|---|---|---|---|---|---|---|
| Dwyer et al. (14) | ~500 in 1st phase (1978); 216 in 2nd phase (1980) | 10 years old | 14 weeks, 5 days/week, 60 min/day | CG and 2 IG (fitness group and skill programme group) | Enhanced PE time and increased intensity of PA in skill programme group; *arithmetic and reading test* | Researchers (HQ) | 225 | No effect (0.00) |
| Ericsson (42) | 251 | 6–9 years old; (1st, 2nd, and 3rd grades) | 3 years, 3 days/week; 45 min/day | CG and 2 IG | Increased PE time (in CG normal curriculum-–2 h per week, in IG 5 h per week); *LUS, national tests in Swedish and mathematics, word, and reading test* | PE teachers (HQ) | 135 | Significantly better AP in both intervention groups (in national test in mathematics) (0.21) |
| Ericsson and Karlsson (43) | 220 | 6–9 years old; (1st, 2nd, and 3rd grades) at baseline—follow-up till the 16 years of age | 7–9 years, 3 days/week; 45 min/day | CG and IG | Increased PE time (in CG normal curriculum-–2 h per week, in IG 5 h per week); *LUS, national tests in Swedish and mathematics, word, and reading test* | PE teachers (HQ) | 135 | Significantly better AP in boys IG (1.5) and no effect in IG in girls (0.0) |
| Erwin et al. (44) | 29 | 8–9 years old (*M* = 8.87) (3rd grade) | 20 weeks; 5 days/week; 20 min/day | CG and IG | Increased PA time; *reading and mathematics fluency, school grades, standardized test scores* | Classroom teachers (LQ) | 100 | Significantly better AP on CBM scores (1, 24) and no effect on standardized tests (0.00) and teachers' grades (0.00) |
| Fedewa and Davis (45) | 460 | 8–11 years old** (3rd-–5th grade) | 8 months; 5 days/week; 20 min/day | CG and IG | Increased PA time (breaks); *Fluid intelligence (SPM), academic performance grades (mathematics and reading)* | Classroom teachers (LQ) | 100 | No effect (0.00) |
| Fisher et al. (46) | 64 | 5–7 years old | 10 weeks, 120 min/week | CG and IG | Aerobic PA; *CAS, CANTAB, ANT, Conner's Behavior Rating Scale* | Researchers, PE teachers and classroom teachers (HQ) | 90 | Significantly better AP in intervention group (in ANT and CANTAB and Conner's Behavioral Rating Scale) (0.14) |
| Gao et al. (47) | 208 | 10–12 years old (*M* = 10, 3 years) (3rd–6th grade) | 2 years; 3 days/week; 30 min/day | CG and IG | Increased PA time; *reading and math scores for Utah Criterion Referenced Test* | Classroom teachers (LQ) | 90 | No effect (0.00); nevertheless greater improvement on math scores of intervention children in Year 1 and 2, the difference was not statistically significant (0.00) |
| Hedges and Hardin (48) | 152 | 6–7 years old (1st grade) | 5 months, 5 days/week, 20 min/week | CG and IG | Increased PA time; *S.A.A.T* | Classroom teachers (LQ) | 100 | No effect (0.00) |
| Hillman et al. (49) | 221 | 7–9 years old | 9 months; 5 days/week; 2 school periods/day | CG and IG | Increased PA time; *Flanker task, RT, Switch task* | At university by research staff (HQ) | 425*** | Significantly better results in IG in inhibition (0.27), cognitive flexibility (0.35) |

*(Continued)*

**TABLE 1** | Continued

| Author (year) | N | Age of children (years or school grade) | Intervention duration | Experimental design | Type of activity and *AP assessment* | Staff implementing intervention and measurements (HQ or LQ) | Intervention min/week | Effects on AP (ES) |
|---|---|---|---|---|---|---|---|---|
| Hollar et al. (50) | 2,494 | 6–13 years old | 2 years, 5 days/week, 10 min/day | CG and IG | Increased PA and lessons about healthy lifestyle, integrated and replicable nutrition; *FCAT (mathematics and reading)* | Researchers (HQ) | 50 | Significantly better AP in FCAT math scores (0.21) |
| Ismail (51) | 142 | 10–12 years old | Academic year, 5 days/week, 60 min/day | CG and IG | Enhanced PE and increased PA with an emphasis on coordination and balance; *S.A.A.T and Otis test* | PE teachers (HQ) | 225 | Intervention group performed significantly better in AP (0.35) |
| Kamijo et al. (52) | 36 | 7–9 years old | 9 months; 5 days/week; 90 min/day | CG and IG | Increased PA time; *Sternberg cognitive task, EEG activity* | At university by research staff (HQ) | 425*** | Response accuracy was better in IG (0.73), three letter condition was significantly better in IG (0.65) |
| Katz et al. (53) | 352 | 7–9 years old** (2nd−4th grade) | 8 months; 5 days/week; 30 min/day | CG and IG | Increased PA time*; MAP, academic performance grades from communication, mathematics, and arts* | Classroom teachers (LQ) | 150 | No overall significant change was seen in math AP scores (0.00). |
| Koutsandreou et al. (54) | 71 | 9–10 years old (3rd and 4th grade) | 10 weeks; 3 days/week; 45 min/day | CG and 2IG (the motor-demanding exercise program and cardiovascular exercise program) | Increased PA time; *Letter Digit Span test* | Experienced exercise instructor (HQ) | 135 | No effect (0.00) |
| Kvalø et al. (55) | 449 | 10–11 years old (5th grade) | 10 months; 5/2 days/week; 20/45 min/day | CG and IG | Increased PA time (during academic narrated lessons, breaks and active homework); *Stroop test, verbal fluency test, digit span, and Trail Making test* | Classroom teachers (LQ) | 188 | Significantly increased executive function in intervention group (0.21) |
| Ludyga et al. (56) | 36 | 12–15 years old | 8 weeks; 5 days/week; 20 min/day | CG and IG | Increased PA time; *Sternberg cognitive task, EEG activity* | Experienced instructors (HQ) | 100 | No effect (0.00) in accuracy rates and significant impact on reaction time (0.79) |
| Mahar et al. (57) | 342 | 5–11 years old | 15 weeks, 5 days/week, 10 min/day | CG and IG | Increased PA (during academic narrated lessons); *knowledge test* | Classroom teachers (LQ) | 50 | No effect (0.00) |
| Mcclelland et al. (58) | 348 | 7–13 years old | 12 weeks; 5 days/week; 20 min/day | CG and IG | Increased PA time; *National examinations in mathematics, reading, and writing.* | Classroom teachers (LQ) | 100 | IG performed significantly better than CG (0.86) for national exams and (1.24) for progress through National Curriculum levels in reading, maths and writing. |

*(Continued)*

**TABLE 1 |** Continued

| Author (year) | *N* | Age of children (years or school grade) | Intervention duration | Experimental design | Type of activity and *AP assessment* | Staff implementing intervention and measurements (HQ or LQ) | Intervention min/week | Effects on AP (ES) |
|---|---|---|---|---|---|---|---|---|
| Mullender-Wijnsma et al. (59) | 81 | 8.1 years old (2nd and 3rd grade) | 22 weeks; 3 days/week; 20–30 min/day | CG and IG | Increased PA; *Tempo test Rekenen (speed test, arithmetic), Een-Minut Test, Reading* | Classroom teachers (LQ) | 75 | Mathematics (4.97) and reading (3.38) grades of 3nd grade children were significantly higher and mathematics grade of 2nd grade children were significantly lower (−5.17) |
| Mullender-Wijnsma et al. (60) | 499 | 8.1 years old (2nd and 3rd grade) | 44 weeks, 3 days/week, 45 min/day | CG and IG | Increased PA (during academic narrated lessons); *mathematic speed test and general mathematics skills test, reading, and spelling* | Qualified primary teachers at the beginning of the study, later classroom teachers (LQ) | 135 | Intervention group perform significantly better in AP: mathematic speed, general mathematics, and spelling (0.43) |
| Murray et al. (61) | 893 (193) | 8–11 years old | 1.5 years; 5–20 min/day | CG and IG | Increased PA (during academic narrated lessons); *Stanford 10 reading comprehension and math problem-solving achievement tests* | Classroom teachers (LQ) | 50*** | Intervention group perform significantly better in math score and reading (0.31) |
| Peternelj et al. (62) | 134 | 7–15 years old (1st−8th grade) | 8 years; 2 (1st−6th grade) or 1 time/week (7th and 8th grade); 45 min/day | CG and IG | Increased PE time; Academic performance grades (mathematics and language), GPA | PE teachers (HQ) | 78, 75*** | Significant effect only in boys on the language (0.83) and GPA (0.54), whereas no effect in girls (0.00) |
| Reed et al. (63) | 155 | 7–10 years old | 4 months, 3 days/week, 30 min/day | CG and IG | Aerobic PA; *PACT, SPM, Fluid Intelligence Tests* | Researchers and classroom teachers (HQ) | 90 | Intervention group performed better in Fluid intelligence testing and in PACT tests (0.31) |
| Resaland et al. (64) | 1,129 | (*M* = 10.2 years) | 8 months;30 min/day (3 times/week); 15 min/day (every day) | CG and IG | Increased PA time (during academic narrated lessons, homework and breaks); *Standard Norwegian national tests (mathematics, reading, English)* | Classroom teachers (LQ) | 165 | No effect (0.00), some significant effects in subgroups (poorest in the baseline). |
| Riley et al. (65) | 240 | 10–12 years old (*M* = 11.13) (5th and 6th grade) | 6 weeks; 3 days/week; 60 min/day | CG and IG | Increased PA time (during academic narrated lessons); *math performance* | Classroom teachers (LQ) | 180 | No effect (0.00) |
| Sallis et al. (19) | 655 | 10–11 years old** (5th and 6th grades) | 2 years, 27–42 min/day | CG and 2 IG (group taught by professional PE teachers and group taught by untrained classroom teachers) | Enhanced PE; *Metropolitan achievement tests* | PE teachers and classroom teachers (HQ) | 35.5 | No effect (0.00) |

*(Continued)*

**TABLE 1** | Continued

| Author (year) | *N* | Age of children (years or school grade) | Intervention duration | Experimental design | Type of activity and *AP assessment* | Staff implementing intervention and measurements (HQ or LQ) | Intervention min/week | Effects on AP (ES) |
|---|---|---|---|---|---|---|---|---|
| Shephard et al. (17) | 546 | 6–12 years old** (1st grade-–6th grade) | 6 years, 5 days/week, 60 min/day | CG and IG | Increased PA; *Standard provincial tests, teacher grades, WISC test* | PE teachers (HQ) | 225 | No effect (0.00); intervention group showed some insignificant improvements in AP grades and performed significantly better in Math Provincial Test Scores but significantly worse in overall score and English score. |
| Sjöwall et al. (66) | 470 | 6–13 years old (1st–6th grade) | 2 years; 3 days/week; 60 min/day | CG and IG | Increased PA time; *working memory, arithmetic test* | Activity leader (LQ) | 120 | No effect (0.00) |
| Spitzer and Hollmann (67) | 44 | 12–13 years old [*M* = 12,5(IG) and 13 years (CG)] (6th grade) | 4 months; 3 days/week; 45 min/day | CG and IG | Increased PA time; *academic performance grades from mathematics, German, and English language* | Classroom teacher (LQ) | 135 | No effect (0.00) |
| Tarp et al. (68) | 855 | 12–14 years old (6th and 7th grade) | 20 weeks; 5 days/week; 60 min/day | CG and IG | Increased PA time; *Eriksen flanker test for cognitive control, mathematics skills test (algebra, arithmetic, problem-solving, geometry)* | Researchers—external collaborator (also responsible for inviting schools) (HQ) | 300 | No effect (0.00) |
| Tuckman and Hinkle (69) | 154 | 9–12 years old | 12 weeks, 3 days/week, 30 min/day | CG and IG | Aerobic PA (running); *TDT* | Two experimenters and two undergraduate students (LQ) | 90 | No effect (0.00) |
| Niet et al. (70) | 112 | 8–12 years old | 22 weeks; 2 days/week; 30 min/day | CG and IG | Increased PA time (break time); *Stroop test, VMS, TMT, ToL* | PE teachers (HQ) | 60 | No effect (0.00); when taking baseline scores into account, intervention children showed small improvement in Stroop test but no significant differences were found on other executive functioning measures. |

*(Continued)*

**TABLE 1** | Continued

| Author (year) | *N* | Age of children (years or school grade) | Intervention duration | Experimental design | Type of activity and *AP assessment* | Staff implementing intervention and measurements (HQ or LQ) | Intervention min/week | Effects on AP (ES) |
|---|---|---|---|---|---|---|---|---|
| Vazou et al. (71) | 284 | (4th and 5th grade) | 8 weeks; 5 days/week; 25–50 min/day | CG and IG | Increased PA time (during academic narrated lessons); *Academic performance grades (mathematics)* | Classroom teachers (LQ) | 185 | Intervention group performed significantly better in math (0.68) |
| Zervas et al. (72) | 26 | 11–14 years old | 25 weeks, 3 days/week, 75 min/day | CG and IG | Aerobic PA; *Cognitrone test* | PE teachers (HQ) | 225 | Intervention group performed significantly better in Cognitrone test (2.01) |

*Bpa, beats per minute; MVPA, moderate to vigorous PA; CG, control group; IG, intervention group; HQ, staff with higher professional qualifications; LQ, staff with lower professional qualifications; IGF-M, Medium version of the Spanish Overall Factorial Intelligence Test; CAS, Cognitive Assessment Treatment; M-WCST, modified Wisconsin card sorting test; WIAT-II, Wechsler Individual Achievement Test-2nd Edition; LUS, Reading development test; CANTAB, Cambridge Neuropsychological Test Battery; ANT, Attention Network Test; FCAT, Florida Comprehensive Achievement Test; S.A.A.T., Stanford Academic Achievement Test; MAP, Missouri Academic Performance; PACT, Palmetto Achievement Challenge Tests; SPM, Standard Progressive Matrices; WISC, Wechsler Intelligence Scale for Children; TDT, Test of divergent thinking; VMS, Visual Memory Span test; TMT, Trailmakig test; ToT, The tower of London test. **age was calculated using national primary and lower secondary school enrolment information; ***time was calculated using average minutes; ****overall intervention time.*

Only interventions longer than 6 weeks, with control and experimental groups, and with more than 25 participants were included in this review. Results with $p < 0.05$ were considered statistically significant. All AP outcomes have been recalculated according to the same scale—ES, considering one of the two criteria: (1) ES = 0, no effect; or (2) ES > 0.01, intervention group academically performing better than the control group. Interventions meeting all eligibility criteria are presented in **Table 1**.

## Data Extraction and Statistical Analysis

One review author extracted data (VS), while the second (GS) and third (GJ) reviewer checked the entered data. Two review authors (VS and GS) extracted outcome data in duplicate, discussing and resolving discrepancies between them and consulted third (GJ) reviewer if necessary. Data supplied for included meta-analysis were checked for missing data and internal data consistency. Summary tables of entered data were checked with the trial protocol and latest trial report or publication. Any discrepancies or unusual patterns were checked with the study investigator. Hunter-Schmidt estimate was used for reducing the amount of bias and Fisher's z transformation was applied to samples' ES to display publication bias (31, 32). We also assessed publication bias with Egger bias test (73).

Chi-square statistical analysis were performed to establish the difference in the effects of interventions on AP in regards to the staff qualifications in PE teaching and exercise science. In the review, we differentiated between staff groups with higher professional qualifications, including exercise science researchers and PE teachers, and staff groups with lower professional qualifications, such as classroom teachers and students, who performed interventions and measurements.

The review includes only studies with enough data to calculate the standardized mean difference (ES) between the intervention and the control group's AP score. For this calculation, the Cohen's (74) and Rosenthal and Rosnow's (75) formulas were used: $ES = M_1 - M_2/SD_{pooled}$ (where $SD_{pooled} = \sqrt{[(SD_1^2 + SD_2^2)/2]}$) and $ES = 2t/\sqrt{df}$), where $M_1$ represents the intervention group, $M_2$ represents the control group, $SD_{pooled}$ is the pooled standard deviation of both groups, $SD_1$ represents the standard deviation of the intervention group, and $SD_2$ represents standard deviation of the control group.

In studies that enabled the calculation of more ES, the average ES was used for further analysis. The ES of each intervention was converted to correlation ($r_w$) determined by Hunter-Schmidt approach (76), which suggests using pooled within-group SD, because it has less sampling error than the control group. In other words, the aforementioned method corrects ES for measurement error under the condition of equal ES. $R_w$ was multiplied by the sample size of each study ($r_w \times N$), which represents the numerator and sum of sample sizes represents the denominator of the equation to calculate population effect ($r_p$). The generalizability of $r_p$ was corrected using an artifact correction and variance sample ES, where the sampling error variance ($V_{obs}$) was based on the population correlation estimate ($r_i$) and the average sample size N. The variance due to sampling error was conducted using the equation: $V_s = (1\text{-}r_w^2)^2/(N\text{-}1)$,

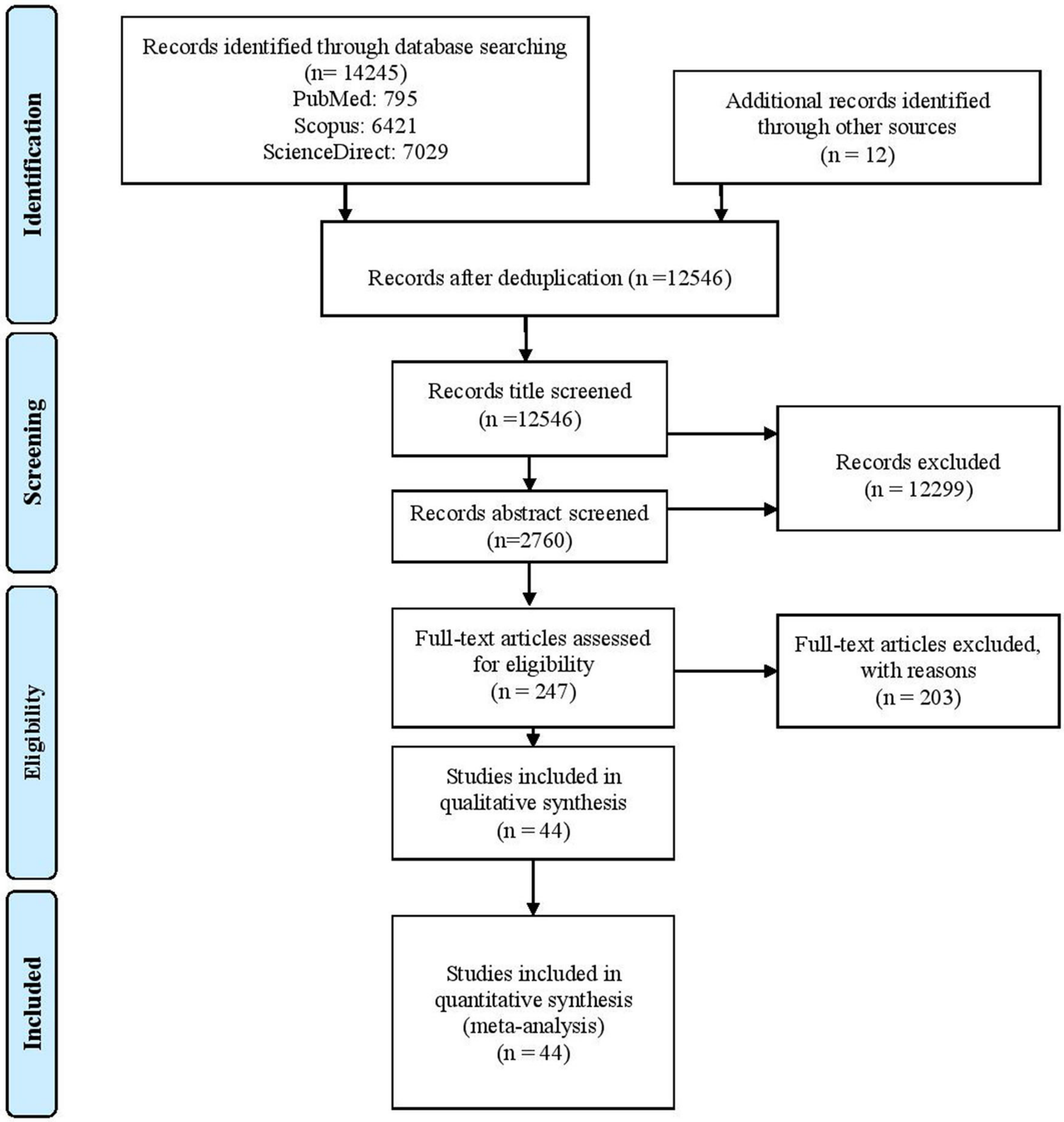


**FIGURE 1 |** The flow of articles through review.

where N is the sample size across studies. Estimates of the variance in ES have been calculated using the equation: $V_p = V_{obs}$-$V_s$. For weighted mean ($r_w$), 95% credibility interval: $CI_w = r_w + 1.96\sqrt{V_p}$ and $I^{2and}$ Q statistics to measure heterogeneity of ES were calculated. Descriptors for the used magnitudes of ES were suggested by Cohen (74) and expanded by Sawilowsky (77).

## Assessment of Bias Risk

The assessment of bias risk in the final sample ($n = 44$ studies) was conducted using the criteria previously used by Sneck et al. (78), including the criterion of power calculations. Each study received "0" (does not meet the criterion) or "1" (meets the criterion) based on an analysis of the reporting described in the original article. The Grades Research, Assessment, Development and Evaluation (GRADE) approach was applied to the meta-analysis to determine the quality of evidence; this involved grading the evidence based on a criteria for risk of bias, imprecision, inconsistency, indirectness and publication bias, in conformation with studies reported elsewhere (79, 80).

# RESULTS

The flow of the review process is shown in **Figure 1**. Altogether 14,245 records were identified. After removing duplicates from

**TABLE 2 |** Descriptive statistics of the main characteristics of interventions included in the review.

| | Number of participants | | | Duration of all interventions (week) | | | Intervention time (min/week) | | |
|---|---|---|---|---|---|---|---|---|---|
| **PA effect on AP** | all | + | − | all | + | − | all | + | − |
| **Min** | 26 | 26 | 29 | 6 | 8 | 6 | 30 | 50 | 30 |
| **Max** | 2,494 | 2,494 | 1,129 | 411 | 411 | 411 | 425 | 425 | 300 |
| **Median** | 211 | 142 | 215 | 25 | 28.5 | 22 | 115 | 135 | 100 |
| **Mean** | 240.5 | 281.8 | 294.2 | 60.6 | 73.2 | 69.8 | 144.5 | 170.9 | 118.3 |

*All, presents all studies included in the meta-analysis; +, studies with positive effect on AP; −, studies with null or negative effect on AP.*

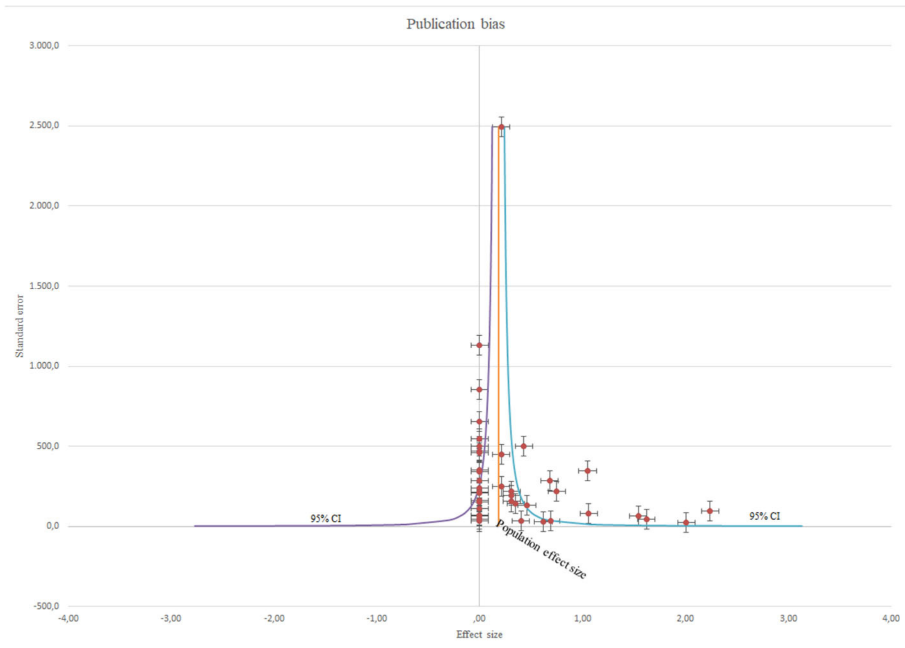


**FIGURE 2 |** Distribution of ES.

three different search engines, 591 abstracts with matching key words were identified, and 247 full-text papers were further reviewed. Among them, 68 were intervention studies with the control group. These were thoroughly reviewed, which left 44 intervention studies that met the final criteria for inclusion in the final review.

Altogether, 13,681 children participated in the interventions ($n = 44$) meeting the eligibility criteria. Present review covers over five decades of research studies, ranging from 1967 (51) to 2018 (56). All interventions, meeting all predefined criteria are presented in **Table 1**.

The mean of intervention time was 60.6 weeks and 144.5 min/week per intervention (**Table 2**). Duration of intervened time/week in studies with positive effect on AP was 170.9 min/week and 118.3 min/week in studies with no significant effect on AP. Duration of the average intervention time/week was 44.6% longer in studies with positive effect, also, the average study duration (weeks) was 4.9% longer in studies reporting a positive effect compared to studies with none or negative effect of increased PA on AP. Positive results of PA were evidenced in 20 interventions; of this, in 13 studies (65%) the interventions were performed by staff with higher professional qualifications. Negative or null effects on AP were reported in 24 interventions; of these in 9 studies (38%) the intervention(s) were performed by staff with higher professional qualifications (**Table 1**).

The Hunter-Schmidt method (76) for isolation and correction of sources of error, such as sampling error and reliability of measurement variables, was used. Unweighted mean effect of population is $r_u = 0.351$, whereas weighted mean effect or population effect size is $r_w = 0.181$. This means that groups with increased PA experienced a positive weak effect on AP compared to control groups. Since the variance across sample ES consists of the variance of ES and the sampling error, sampling error variance ($V_{obs}$) for every intervention and variance due to sampling error, using population effect ($r_p$), were calculated.

Variance due to sampling error ($Vs = 0.003$) and variance of population correlations ($V_p = 0.107$) were estimated. An average sample size of $N = 240$ yields a population effect size of $r_p = 0.181$with 95% confidence interval ranging from 0.083 and 0.279 and 80% credibility interval ranging from −0.237 and 0.600. Such

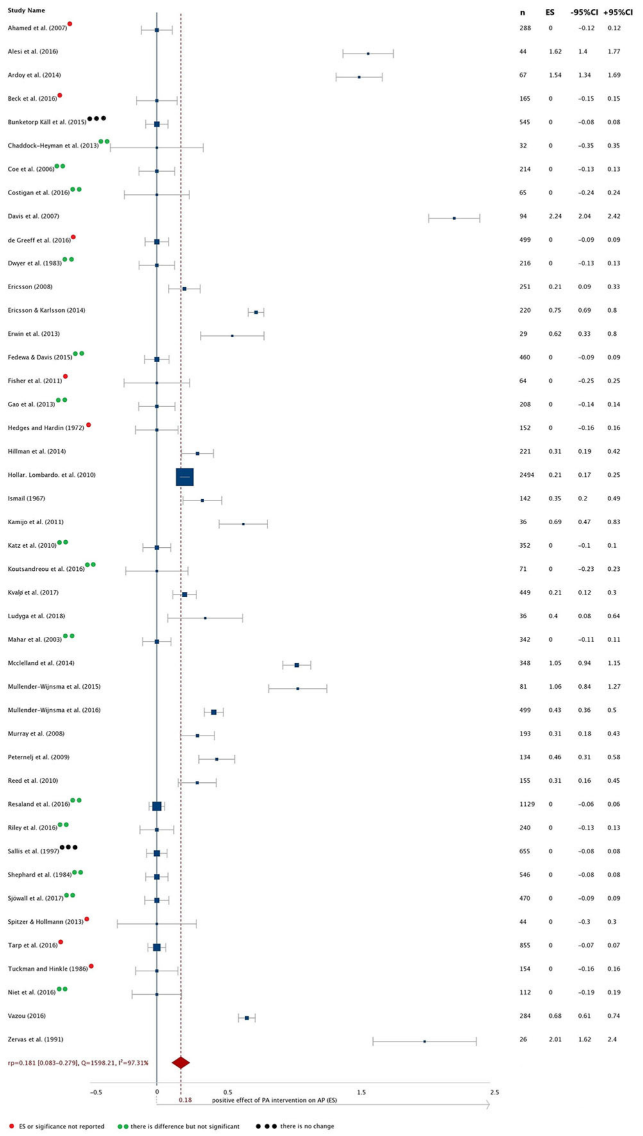


**FIGURE 3 |** Forest plot of all included studies.

reliable differences between studies that give rise to varying effects could be due to publication bias of included studies (31). The Egger bias test (73) provides significant evidence for publication bias (bias = 4.137, 95% CI: 0.805–7.469, $p = 0.019$). There were considerable differences between the ES's from all individual studies ($I^2 = 97\%$; Q = 1598.2; $p = 0.000$), in studies where staff with higher professional qualifications performed intervention ($I^2 = 97\%$; Q = 970.5; $p = 0.000$) and in studies where staff with lower professional qualifications performed intervention ($I^2 = 96\%$; Q = 622.8; $p = 0.000$). Distribution of ES in all eligible interventions and publication bias (**Figure 2**), and a forest plot of all included studies (**Figure 3**) are presented.

The positive effect of a PA intervention on AP was estimated in 13 out of 20 significant interventions in which staff with higher professional qualifications performed the intervention and measurements. The weighted mean effect of the population effect size in interventions, performed by staff with higher professional qualifications, is 0.22 and in interventions performed by staff with lower professional qualifications is 0.14. Chi-square statistics were calculated and showed a significant difference ($\chi^2 = 4.464$; $p = 0.035$) on AP between studies in which the intervention and measurement were performed by practitioners with higher professional qualifications compared to those conducted by staff with lower professional qualifications, or in studies that lacked this information. Cramer's V value (0.319) showed there is a strong association between staff qualification and its effect on AP ($p = 0.035$).

The results of the risk-of bias assessment analysis are shown in **Table 3**. Of the 44 studies, 29 were rated as having a low risk of bias (> 67% of total score) with average of 0.79 of total score and 15 were rated as having moderate risk of bias (between 33 and 67% of the total score) with average of 0.50 of total score. None of the studies was rated as having a high risk of bias. Only 11 studies (25 %) reported power calculations to determine sufficient sample size, of those reporting positive effects of PA on academic performance/cognition, power calculations were provided in five studies (34, 46, 49, 55, 60). The quality of evidence (GRADE) where staff with higher and lower qualifications performed intervention and measurements was moderate (**Table 4**).

## DISCUSSION

This systematic review and meta-analysis investigated the impact of school-based PA interventions on the AP of primary and lower- secondary schoolchildren; it considered the amount of PA in the interventions and the qualifications of staff administering interventions in its analysis. The main findings of the study are that changes in AP itself is not caused solely by an increase in frequency and/or duration of PA, but studies must also take into consideration the intensity of PA administered. Secondly, and of equal import, is the significant positive effect observed when PA interventions are delivered by practitioners with higher professional qualifications, who were able to mediate higher PA intensity and focus of interventions.

Despite some promising results in the reviewed interventions (31, 33, 34, 37, 40, 42, 46, 49, 50, 52–55, 57, 58, 60, 61, 63, 71, 72), it is essential to emphasize that future research on the relationships between AP and PA should consider more qualitative aspects of PA, including intensity and types of activities. Namely, positive effects of AP may only accrue when of moderate-to-vigorous PA is increased (41, 42). Although the effects of PA on AP are seemingly well-documented in the literature most research and review studies have focused on the behavioral aspects of PA, such as frequency and duration, whereas PA intensity was hardly addressed, even though it is essential for properly elucidating the effects of exercise on cognition (43).

To avoid reporting sometimes misleading results of short interventions that are often affected by an initial increase in motivation of study participants (i.e., researchers, teachers, parents and children), only interventions longer than 6 weeks' duration were included for this analysis. The analysis showed that

**TABLE 3** | Results of the risk-of bias assessment.

| Author (year) | 1. Randomization | 2. Baseline comparable | 3. Baseline values accounted for in analyses | 4. Timing | 5. Blinding of measuring | 6. Validated outcome measures | 7. Dropout analysis | 8. Reporting of results | 9. Power calculation | Total score of the risk of bias (decimal format) |
|---|---|---|---|---|---|---|---|---|---|---|
| Ahamed et al. (18) | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 7/9 (0.78) |
| Alesi et al. (33) | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 4/9 (0.44) |
| Ardoy et al. (34) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 9/9 (1.00) |
| Beck et al. (35) | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 6/9 (0.67) |
| Bunketorp Käll et al. (36) | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 3/9 (0.33) |
| Chaddock-Heyman et al. (37) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 8/9 (0.89) |
| Coe et al. (38) | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 5/9 (0.56) |
| Costigan et al. (39) | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 8/9 (0.89) |
| Davis et al. (40) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 7/9 (0.78) |
| Greeff et al. (41) | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 8/9 (0.89) |
| Dwyer et al. (14) | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 7/9 (0.78) |
| Ericsson (42) | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 5/9 (0.56) |
| Ericsson and Karlsson (43) | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 6/9 (0.67) |
| Erwin et al. (44) | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 5/9 (0.56) |
| Fedewa and Davis (45) | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 5/9 (0.56) |
| Fisher et al. (46) | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 8/9 (0.89) |
| Gao et al. (47) | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 5/9 (0.56) |
| Hedges and Hardin (48) | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 4/9 (0.44) |
| Hillman et al. (49) | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 8/9 (0.89) |
| Hollar et al. (50) | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 6/9 (0.67) |
| Ismail (51) | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 4/9 (0.44) |
| Kamijo et al. (52) | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 6/9 (0.67) |
| Katz et al. (53) | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 7/9 (0.78) |
| Koutsandreou et al. (54) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 8/9 (0.89) |
| Kvalø et al. (55) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 9/9 (1.00) |
| Ludyga et al. (56) | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 7/9 (0.78) |
| Mahar et al. (57) | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 7/9 (0.78) |
| Mcclelland et al. (58) | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 4/9 (0.44) |
| Mullender-Wijnsma et al. (59) | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 6/9 (0.67) |
| Mullender-Wijnsma et al. (60) | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 7/9 (0.78) |
| Murray et al. (61) | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 6/9 (0.67) |
| Peternelj et al. (62) | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 6/9 (0.67) |
| Reed et al. (63) | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 7/9 (0.78) |
| Resaland et al. (64) | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 8/9 (0.89) |
| Riley et al. (65) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 9/9 (1.00) |

*(Continued)*

**TABLE 3 |** Continued

| Author (year) | 1. Randomization | 2. Baseline comparable | 3. Baseline values accounted for in analyses | 4. Timing | 5. Blinding of measuring | 6. Validated outcome measures | 7. Dropout analysis | 8. Reporting of results | 9. Power calculation | Total score of the risk of bias (decimal format) |
|---|---|---|---|---|---|---|---|---|---|---|
| Sallis et al. (19) | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 5/9 (0.56) |
| Shephard et al. (17) | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 4/9 (0.44) |
| Sjöwall et al. (66) | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 5/9 (0.56) |
| Spitzer and Hollmann (67) | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 4/9 (0.44) |
| Tarp et al. (68) | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 7/9 (0.78) |
| Tuckman and Hinkle (69) | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 6/9 (0.67) |
| Niet et al. (70) | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 5/9 (0.56) |
| Vazou et al. (71) | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 7/9 (0.78) |
| Zervas et al. (72) | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 6/9 (0.67) |
| Average of all studies | 0.68 | 0.84 | 0.93 | 0.98 | 0.34 | 0.82 | 0.45 | 0.95 | 0.25 | 0.69 |

**TABLE 4 |** Summary of quality of evidence using the GRADE approach.

| Quality assessment | | | | | | | | Effect | Quality of evidence—GRADE |
|---|---|---|---|---|---|---|---|---|---|
| **Outcome** | **Study design** | **No. of studies (no. of participants)** | **Risk of bias** | **Inconsistency** | **Indirectness** | **Imprecision** | **Other considerations** | **Rw (95 % CI)** | |
| Positive effect on AP where staff with higher professional qualifications performed intervention | 15 randomized, 7 non-randomized | 22 (6,536) | No serious risk of bias (15 low risk of bias, 4 moderate risk of bias). | *No serious inconsistency* $I^2 =$ 97.8% | No serious indirectness. | No serious limitations. | None | 0.22 (0.07–0.37) | ⊕⊕⊕□ **MODERATE** (6 high, 13 moderate, 3 low) |
| Positive effect on AP where staff with lower professional qualifications performed intervention | 15 randomized, 7 non-randomized | 22 (7,145) | No serious risk of bias (2 moderate risk of bias, 5 high risk of bias). | *No serious inconsistency* $I^2 =$ 96.6% | No serious indirectness. | No serious limitations. | None | 0.14 (0.02–0.27) | ⊕⊕⊕□ **MODERATE** (4 high, 14 moderate, 4 low) |

*GRADE, Grades of Research, Assessment, Development and Evaluation (GRADE Working Group).*
⊕⊕⊕⊕ *(high): We have a lot of confidence that the true effect is similar to the estimated effect.*
⊕⊕⊕□ *(moderate): We believe that the true effect is probably close to the estimated effect.*
⊕⊕□□ *(low): We believe that the true effect might be markedly different from the estimated effect*
⊕□□□ *(very low): We believe that the true effect is probably markedly different from the estimated effect.*

in the longer-lasting interventions there was a greater decline in moderate-to vigorous PA across the intervention time.

Samples in interventions which reported positive PA impacts were larger than the ones in the interventions with negative or no impact; this should be taken into consideration when interpreting the results. The population effect ($r_p$) was shown to be small, which means that increased PA in experimental groups had only a small effect on AP compared to control groups. Since the connection between both variables was small, PA alone may not be the best predictor of children's AP. When researching the relationships between cognition and activity, researchers should start thinking about utilizing and reporting more stable measures, like the level of physical fitness, which is a marker outcome of habitual physical activity. For example, it has been shown that after-school PA improves cardiovascular endurance in children, which then mediates improvements in AP (81). A meta-analysis of published evidence on the relationship between physical fitness and AP between 2005 and 2015 asserts that cardiorespiratory fitness, speed-agility, motor coordination, and perceptual-motor skills are highly associated with AP (45), but the findings on the relationship between AP to strength and flexibility remain unclear in this regard. Indeed, it can be argued that physical fitness may be a better predictor of AP than PA. Several studies have identified a positive relationship between cardiorespiratory fitness, weight and AP (46–49) or with overall physical fitness (82). For example, researchers from Portugal have shown that cardiorespiratory fitness is independently related to AP; moreover, students with normal weight tended to have the best academic performance (52). The influence of moderators and mediators to PA, such as socioeconomic status, parental education (83), concentration (84) gender (85), personality (86), motivation, body-image, self-esteem (87), have also been shown to have an impact on AP.

In almost all analyzed interventions, the higher qualifications of the involved staff were shown to positively influence changes observed in AP. We know that PE lessons led by trained PE teachers provides more activity to students than ones led by generalized classroom teachers (25, 88–90). In general, the pedagogical qualifications of classroom teachers for delivering PE classes are far lower than those for of specialist PE teachers. The classroom teachers are of course qualified teachers, but with a rather limited training in PE teaching and exercise science, which requires specialist training to perform well. They often experience insufficient expertise and ability to organize PE with its distinctive content in an effective way (91). Breslin et al. (92) showed that the PE specialists show higher levels of self-determination toward exercise, are more autonomous in their decisions to be active, are more physically active and have a higher level of perceived qualification in delivering a PE lesson than the generalist teachers do. In addition, McKenzie et al. (89) reported that children taught by PE specialists spend 57% more time in moderate-to vigorous PA, with a concurrently increased emphasis on the promotion of physical fitness. This also has the important advantage of maintaining positive health-related behaviors that may last beyond childhood (93, 94).

### Study Strengths and Limitations

The present review covers more than five decades worth of research studies, but analyses only PA interventions that have met the predefined criteria. Therefore, only interventions published in peer-reviewed scientific journals with a focus on primary and lower secondary school-children, evenly represented genders, exceeding 6 weeks and with reported ES or with data that enables the calculation of ES were included in the meta-analysis. The analysis did not: (i) distinguish between the published results that used moderate-to vigorous PA as a significant predictor that might affect AP and the ones that used low or vigorous physical activity; (ii) it did not take into consideration the differences between the results deriving from subjective or objective measures of PA; (iii) it did not take into consideration different instruments for assessing AP that were used in various studies, thus results cannot be generalized to different measures of AP; (iv) it did not take into consideration the differences between studies with large sample size that were able to detect even small differences and the ones with smaller sample sizes that could not, which can lead to potential bias; and it should always be noted that (v) statistically non-significant results are less-likely to be published, resulting in upwardly biased meta-analytically derived effect sizes for any analysis of this kind.

## CONCLUSION

Parents are often concerned that time allocated to PA and sport may negatively affect children's AP. The present analysis shows that PA itself does not negatively affect AP; moreover, there are positive, (although relatively small) relationships between the two, and that changes in AP itself is not caused solely by an increase in frequency and/or duration of PA, but studies must also take into consideration the intensity of PA administered. Secondly, the significant positive effect of PA interventions are most observed when delivered by practitioners with higher professional qualifications who are able to mediate higher PA intensity in the interventions. Finally, in interventions with long durations, there are greater declines in moderate-to vigorous PA, suggesting a challenge to maintaining interventions across the intervention time-span. Finally, when reporting the monitoring, surveillance and evaluation of PA interventions, using physical fitness as criteria measure of PA is much more effective in terms of both the economic and organizational sense.

## DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/supplementary material.

## AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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# Effects of Installing Height-Adjustable Standing Desks on Daily and Domain-Specific Duration of Standing, Sitting, and Stepping in 3rd Grade Primary School Children

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**Background:** Aim of this intervention study was to evaluate whether availability of standing desks in classrooms may reduce sitting time and enhance standing and stepping time during lessons and breaks. Further, we evaluated if differences in standing desk use differed by physical fitness (PF) levels of children.

**Methods:** To assess sitting, standing and stepping during a typical school week in 3rd grade primary school children ($N = 52$), activPAL monitors were used at baseline: T0, 1st follow-up: T1 and 2nd follow-up: T2. At baseline, PF was measured using the standing long jump and the 6-min jog-walk to assign children as having low PF (LPF) or high PF (HPF). Standing desks were assigned randomly to intervention and control groups at T1 (group 1) and T2 (group 2) with a cross-over design. Changes of sitting, standing and stepping were analyzed to investigate intervention effects at follow-up, using linear mixed models.

**Results:** At baseline, children spent about 60 and 30% of time sitting during lessons and breaks, respectively. After installing standing desks (T1), significantly lower proportions of sitting were observed in the intervention group 1 [−13.1%, 95%-CI: (−20.5; −5.72)] and the control group 2 [−9.78%, 95%-CI: (−17.3; −2.28)]. Compared to the baseline measurement (T0), lower proportions of sitting were particularly expressed during school breaks in group 1 and 2 after intervention in T1 [group 1: −10.3%, 95%-CI: (−16.4; −4.25)] or in T2 [group 2: −8.59%, 95%-CI: (−15.2; −1.94)]. In general, children with higher physical fitness were less sedentary and more active, but intervention effects did not differ by fitness levels.

**Conclusion:** Standing desks provide an opportunity to reduce sedentary time during lessons and breaks at school in primary school children, but do not directly increase PA of high intensity such as stepping. Future studies should consider potential bandwagon effects caused by structural interventions.

**Keywords: objective measurement, lessons, breaks, leisure time activity, physical fitness**

## BACKGROUND

The World Health Organization (WHO) recommends that children and adolescents between 5 and 17 years should engage in moderate-to-vigorous physical activity (MVPA) for at least 60 min every day (1), but only one fifth of German school children (2) meet this recommendation. Regarding sedentary behavior, the WHO recommends that children and adolescents should limit the amount of time spent being sedentary, in particular the amount of recreational screen time. However, associations between sedentary behavior and child health are still discussed controversially (3–5), but there is evidence that sedentary behavior tracks from childhood to adulthood underpinning importance of health promotion activities targeting the reduction of sitting time already early in life (6). Possible health benefits resulting from the reduction of sedentary time in childhood may relate to a healthier weight status, blood pressure, metabolism, fitness, self-esteem and social behavior and may even improve academic performance (7). A large number of studies observed a gradient between time spent sedentary and worsening of health, but evidence is inconclusive with regard to a clear dose-response relationship. For screen time, adverse health effects are observed from up to 2 h. (8) This is alarming insofar as primary school children are sitting ∼6.5 h at school (9–12), particularly German children and adolescents spent up to 9 h sedentary during a typical school day (13) and sitting duration increases as children get older (9–12, 14).

In recent years, multiple strategies aiming to decrease daily sedentary time and motivate children to move more during the day have been discussed (15). One strategy to reduce sitting time during school hours was addressed but still requires deeper investigation: the installation of height-adjustable standing desks (in the following named simply "standing desks"). Although some reviews have been published in this field (16, 17), research findings are contradicting and do not yet allow to draw final conclusions. Recent studies showed that implementing standing desks in schools could significantly decrease durations of sitting per day, without any disadvantages such as reduced concentration during lessons at school (16–19). On the contrary, positive effects of standing desks were observed in primary children rather than in secondary school children (20).

Only few high-quality studies have been conducted in this fieldwhere only about half of them included control groups as highlighted by Minges et al. (16). Additionally, short follow-up duration and unreliable sensors to distinguish between sitting and standing time (e.g., Actigraph accelerometers) were also highlighted as limitations by Sherry et al. (17). In general, three main obstacles are known in research to investigate sitting and standing in children with standing desks provided at school. First, recent studies can afford only a low number of standing desks due to the high costs of this structural intervention strategy. Second, mostly the duration of sitting/standing during the total day or during total school hours is analyzed rather than assessing how sitting/standing changes during lessons and breaks, respectively, if standing desks are (un-) available. Third, researchers focused on durations of sitting and standing until now, but did not investigate potential factors associated with the acceptability or use of standing desks.

Hence, the aim of this study was to investigate whether the availability of standing desks in primary school children leads to less sitting and more standing and stepping time during school hours—particularly during lessons and breaks—and whether shorter vs. longer standing time during school hours affected leisure time activities of children after school. Further, we explored possible differences in the effects of standing desk use with regard to the physical fitness (PF) levels of children prior to the intervention.

## METHODS

### Study Sample

The study was conducted in one primary school in Ludwigsburg, Germany. All 59 children of the entire third grade, distributed into three classes, were invited to participate in the study (**Figure 1**). Parents were informed during a parent evening and by provision of study information. Parents were asked for written informed consent; additionally, all children were asked for oral consent prior to the assessment. In total, written informed consent was provided by parents of 54 children. The study was carried out in accordance with the Declaration of Helsinki, and the study protocol was approved by the institutional review board of the University of Bremen (19.09.2017).

### Study Design

This case-crossover study was carried out between January and March 2018. Since the case-crossover design is useful to evaluate brief and changing exposures, it was chosen to ensure an identical environment and reduce confounding (e.g., by schedule, or weather) for intervention and control group (21). At baseline (T0, January 2018), all measurements were applied in all children (**Figure 1**). Baseline measurements for all children included: objective measurement of sitting, standing and physical activity (PA), anthropometry and PF as well as a parental questionnaire assessing socioeconomic status. After completion of the baseline survey (T0), a total of 32 standing desks were equally distributed among the three classes. The standing desks were assigned randomly to half of all children in each class (intervention group at T1, referred to as group 1), whilst the other half of the children worked at their traditional working desks (control group at T1, referred as group 2). In the third week after installing the standing desks, the first follow-up examinations (T1, February 2018) included the identical measurements conducted at T0 (except anthropometry and PF) in all participating children. After the T1 measurements were completed, standing desks were assigned to those children, who belonged to the control group previously (group 2, now intervention group at T2). The remaining children (group 1: intervention group at T1, now control group at T2) were assigned to the traditional working desk at this time. Again, after a washout period of 2 weeks, the second follow-up was conducted (T2, March 2018), including the identical measurements from T1 and T0. In summary, to address the crossover design in the analyses, groups were distinguished as having the intervention, i.e., having

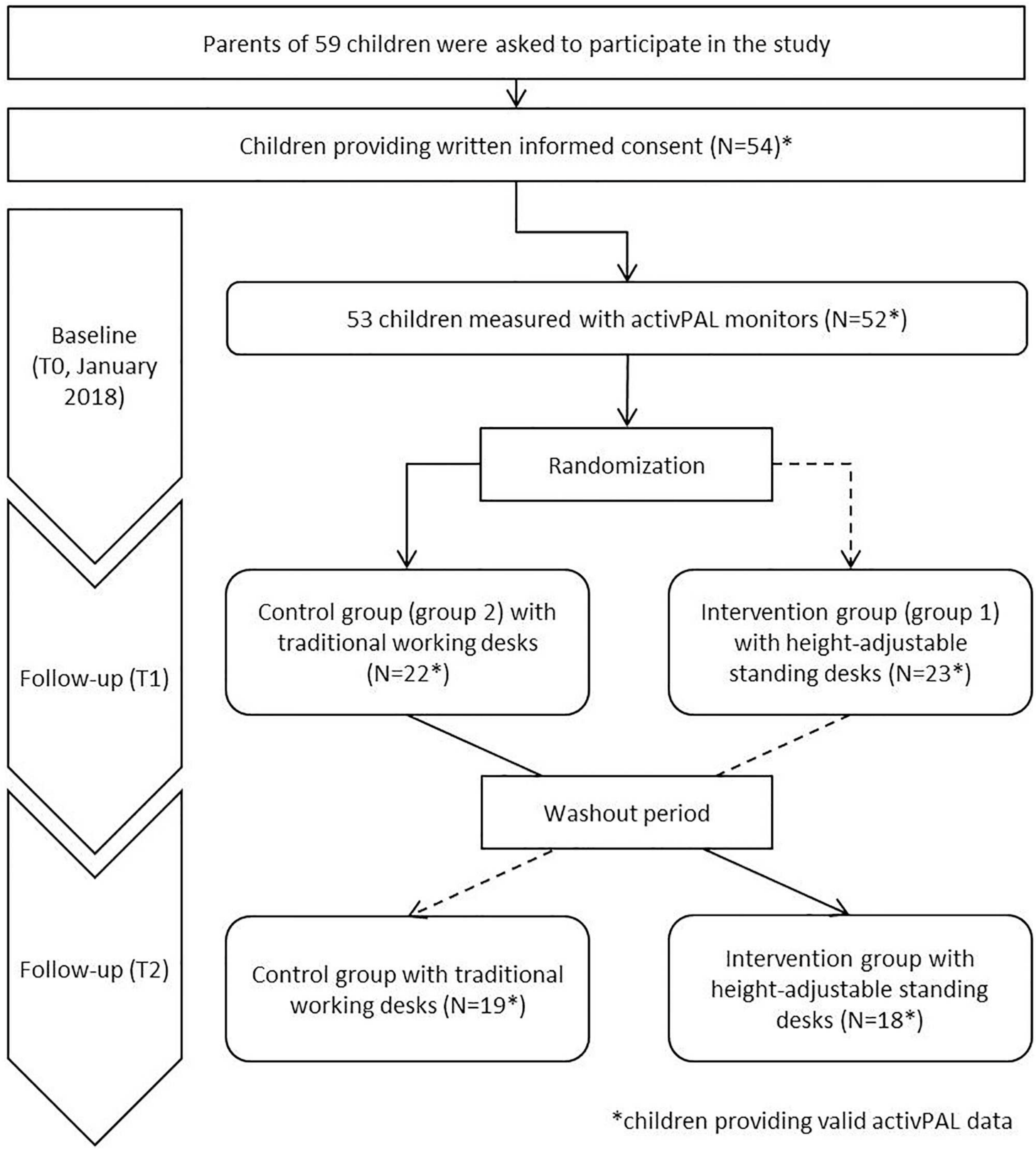


**FIGURE 1 |** Study design and number of participants.

standing desks designated to half of the children within each classroom, between baseline and first follow-up (group 1) and between first and second follow-up, for the other half of the classroom (group 2).

## Height-Adjustable Standing Desks

The city of Ludwigsburg provided 32 standing desks (Rondo-Lift-KF ($N = 21$) and SitAndStand ($N = 11$) by VS Middle East, height-adjustable between 69–113 cm and 70–115 cm, respectively). Children were able to sit at the desks with their usual chairs at minimum height. Desk bases had lockable castors and were freely movable. Spatial arrangement was carried out by the teachers so that children who choose to stand did not bother the view of sitting children. In general, children with standing desk were allowed to lift and lower their standing desks at its own discretion; they were not reminded or encouraged to stand during lessons. The height of the standing position was not assessed.

## Activity Behavior

*Sitting, standing and PA* were assessed by activPAL inclinometer (PAL Technologies Ltd., Glasgow, UK). At each survey period, the devices were distributed during physical education classes. Study personnel instructed verbally how to use the devices and directly helped attaching the devices at the mid-point on the front of the right thigh. Additionally, all children received an information sheet explaining the handling of the device, in order to inform their parents. All participating children were asked to wear the devices for 24 h on 10 consecutive days (except during swimming and bathing). To assess standing, sitting and stepping in primary children, activPAL monitors have been proven to be valid and reliable (22–25). We derived PA intensities from counts in 15 s epochs within the daily time frame of 6:30 am to 8:30 pm in order to reduce bias through inaccurate estimates of get up or sleep times. We restricted the analysis to children with PA data of at least 2 days with at least 10 h of measured time. The measured duration of PA was considered per domain i.e., lessons, school breaks and leisure time and generated using exact time stamps of the respective weekly schedule of each class for each child. Further, daily information on PA intensities was cleaned with regard to extreme values in steps and sedentary time, i.e., days with <1,000 steps and/or a sedentary time of more than 90% of the measured time were excluded. Eventually, we averaged habitual PA, i.e., stepping, standing, and sitting, over weekdays (not weekend days) for children providing at least 3 days of valid measurements at each survey. Time spent sitting, standing and stepping was measured by the devices and later processed in minutes per day. In order to describe the distribution of activity intensities per day and domain, i.e., lessons, school breaks or leisure time, minutes per day spent sitting, standing or stepping were summed up based on all weekdays and for any specific domain. This duration was then divided by the total measured minutes per weekday and domain, respectively. Accelerometry data derived from the activPAL3-software (activPAL Professional v7.2.29, PAL Technologies Ltd., Glasgow UK) was processed using R Version 3.5.1 and particularly R-packages dplyr, ggplot2, and scales.

## Parental Questionnaire and School Information

Sex and age of all participating children were obtained by the written informed consent. The parent completing the questionnaire answered questions about the highest level of education and highest professional qualification of both parents. Both were classified according to the international standard classification of education (ISCED) (26), which were categorized as low (ISCED level 1 or 2), medium (ISCED levels 3 or 4), and high (ISCED level 5 or higher) and using the maximum of both parents (if data available) as an indicator of the family educational status. Parents were also asked if their child participated in organized youth sports. Teachers provided the class-specific schedules to facilitate the assignment of objectively measured activity and sedentary behaviors to the timing of school breaks and lessons throughout the school day.

## Anthropometry

Anthropometric measurements were carried out by trained study personnel using standardized instruments. Height was measured using a telescopic stadiometer (Seca 225, seca, Birmingham, UK) to the nearest 0.1 cm (27). Body mass was measured using the TANITA BC 420 SMA, a digital weighing scale (TANITA, Tokyo, Japan) that was previously used in young children (28). We calculated BMI as weight in kilograms divided by squared height in meters and categorized weight status of children as overweight or obese according to the German reference system by Kromeyer-Hausschild using the 90th percentile for the age 8, 9 and 10 (29).

## Physical Fitness

In order to briefly classify the participants into children with less or more ability to stand longer as a potential confounder, two motor tests (standing long jump and 6-min jog-walk) were conducted to assess components of physical fitness (explosive strength and endurance capacity).

Both PF tests were conducted after a typical warm-up at the beginning of physical education lessons. The standing long jump test was used to assess the lower-limb explosive strength. Children had to jump off a marked line with both feet and to land on both feet at the same time, if possible. The recorded value was the difference (in cm) between the marked line and the last heel mark (30). To assess endurance capacity, we applied the 6-min jog-walk, a quick and convertible test during physical education lessons to assess the maximal oxygen uptake. Children had to run a 54 m round as often as possible within 6 min. They were allowed to walk if they could not run anymore. The test has proven to moderately correlate with a spiroergometry in children aged 8–10 years (31). The PF at baseline was categorized into high PF (HPF) for children who at least performed more than of 17 rounds in the 6-min jog-walk or jumped more than 128 cm in the standing long jump test and low PF (LPF), if none of the above applied. Since only two motor tests were conducted and in order to enable a specific classification within our sample, the median values of our results was chosen as cutoffs (17 rounds, 128 cm) for low and high PF.

## Statistical Analysis

We calculated descriptive statistics, such as mean and standard deviation (SD) as well as range for continuous variables in this study and proportions for categorical variables with regard to the overall study sample and stratified by PF levels.

We used linear mixed models to investigate the effect of the implementation of standing desks in classrooms on PA, i.e., sitting, standing, and stepping in children. Linear mixed models provide the flexibility to model the time and intervention effect, i.e., the interaction, while accounting for repeated measurements by means of a random residual effect and particularly based on unbalanced data, i.e., incorporating the complete sample despite loss to follow up.

Outcome variables, sitting, standing, and stepping were considered as continuous dependent variables in the linear mixed models. For each PA outcome we modeled the exposition to the intervention a) for each group over time using two main effects for the survey wave and group assignment and b) the interaction of survey wave with group assignment (group 1 at T1 and group 2 at T2) which are presented as the actual intervention effect. Outcome variables were modeled using total school time data as well as considering the domain-specific data during lessons, school breaks, and leisure time. Further, all models were adjusted for sex, age, weight status, PF, parental education and class. Mixed models were also conducted stratified by PF to assess whether effects of the intervention differed by children's PF levels at T0. From each of these linear mixed models, least-square means (LSM) and 95% confidence limits (95% CI) of dependent PA variables were estimated for each group ($k = 2$) per survey ($t = 3$) as well as all possible fifteen ($(k^*t-1)!$) LSM-differences of mean PA variables and the 95% CI for each combination of survey wave and group assignment. This way, both direct intervention effects (group 1: T1 – T0, group 2: T2 – T0) and potential indirect effects, either between group assignment or over survey waves could be identified. Normality of outcome variables was assessed using residual and Q-Q plots. Confidence intervals were estimated considering the sidak adjustment for multiple testing within each regression model. Significance level was set to $\alpha = 0.05$, however we did not adjust for multiple testing with regard to number of regression models.

## RESULTS

Among the total of 53 participating children at baseline, 52 participants provided valid activPAL data of at least 2 days with at least 10 h per day (**Figure 1**). Of those, 61.5% were girls ($N = 17$) (**Table 1**). The average age of all participating children was 8.4 years (SD: 0.7) and the proportion participating in organized youth sports was 76.9%. About one fourth of the study sample was categorized as having overweight or obesity (23%). About twice as many children were categorized as having low fitness levels than having high fitness levels. Further, children with higher fitness levels ran about four rounds more during the 6 min run and achieved ∼30 cm more distance at the standing long jump than the less fit children. In general, children spent about 7 h per day and about half of their leisure time sitting. Almost two thirds of the time in school lessons were spent sedentary, whereas in school breaks only one third was spent sitting. In contrast, at least 70% of school breaks was spent active in children either with low and high fitness levels (**Table 1**). Total daily sitting time revealed only small differences between fitness level, whereas children with higher fitness level had 30 min longer stepping duration per day (168.4 min/day), compared to children with lower fitness level.

**Table 2** presents results of linear mixed models showing estimated means (Est) with 95% confidence intervals (95% CI) of PA variables during lessons for group assignment and survey wave as well as differences of survey waves per group to identify intervention effects. Estimated proportions of sitting, standing and stepping during lessons varied substantially per survey wave and intervention group (**Table 2**).

Across survey waves, group 1 almost persistently showed less sedentary and more active pattern during lessons, compared to group 2. Between T0 and T1, sitting time significantly decreased between T0 and T1 in the intervention group [group 1: −13.1, 95%CI (−20.5; −5.72)], but also in the control group [group 2: −9.78, 95%CI (−17.3; −2.28)]. In addition, standing time significantly increased after the first intervention in T1 [group 1: 11.6, 95%CI (4.85, 18.3) as well as in the control group (group 2: 8.63, 95%CI (1.78; 15.5)].

**Table 3** presents PA patterns during school breaks. At both follow-ups (T1 and T2), about ten percentage points less sitting during breaks were found in all children in both groups. Compared to T0, in group 1 significantly lower proportions of sitting [−10.3%, 95%-CI: (−16.4; −4.25)] and higher proportions of standing: [6.20%, 95%-CI: (1.37; 11.0)] were measured during school breaks at T1. Similarly, group 2 showed lower proportions of sitting [−8.59%, 95%-CI: (−15.2; −1.94)] and higher proportions of standing [8.08%, 95%-CI: (2.78; 13.4)] after the intervention in T2.

**Table 4** summarizes PA patterns during leisure time. In group 1, slightly higher values (1–4 percentage points) have been observed regarding the time standing and stepping across all survey periods, compared to group 2. No intervention effect was observed regarding sitting, standing or stepping during leisure time.

Regarding overall PA per day, group 1 accumulated less sitting time and more standing and stepping time per day, across all survey periods, compared to group 2 (**Table 5**). Regarding the total time per day spent sitting, standing and stepping, no intervention effects were observed across survey periods and groups.

Results of linear mixed models stratified by fitness levels are presented in **Supplemental Tables 1–4**. Basically, children with higher fitness levels spent between 44 and 47% of their leisure time per day with sitting, whereas children with low fitness levels spent more than half of their leisure time sedentary (53–54%). At T0, children with high fitness levels spent four to seven percentage points less sitting during breaks [group 1: 26.1%, 95%-CI: (19.7; 32.6), group 2: 24.3%, 95%-CI: (12.0; 36.6)], compared to children showing low fitness levels [group 1: 30.3% 95%-CI: (25.0; 35.7), group 2: 31.4%, 95%-CI: (26.7; 36.0)]. Children with higher fitness levels of the intervention group at T1 (group 1) increased their standing time about twice as much [15.7%, 95%-CI: (4.04; 27.3)], compared to children of group 1 with low fitness levels [7.79%, 95%-CI: (−1.20; 16.8)].

**TABLE 1 |** Study characteristics and total as well as domain-specific time during spent sitting, standing and stepping on weekdays in school children at baseline ($N = 52$).

| | All (*N* = 52) | | Fitness level | | | |
|---|---|---|---|---|---|---|
| | | | Low (*n* = 32) | | High (*n* = 16) | |
| | *N* | % | *N* | % | *N* | % |
| **Sex** | | | | | | |
| Male | 20 | 38.5 | 12 | 33.3 | 8 | 50 |
| Female | 32 | 61.5 | 24 | 66.6 | 8 | 50 |
| Sports Club member | 40 | 76.9 | 26 | 72.2 | 14 | 87.5 |
| **Weight status** | | | | | | |
| Normal weight | 41 | 78.9 | 25 | 69.4 | 16 | 100 |
| Overweight/obese | 11 | 21.1 | 11 | 30.6 | | |
| **ISCED categories** | | | | | | |
| Low (0–2) | 8 | 15.4 | 6 | 16.7 | 2 | 12.5 |
| Medium (3,4) | 16 | 30.8 | 13 | 36.1 | 3 | 18.8 |
| High (5+) | 28 | 53.9 | 17 | 47.2 | 11 | 68.8 |
| | **Mean (SD)** | **Range** | **Mean (SD)** | **Range** | **Mean (SD)** | **Range** |
| Age (years) | 8.4 (0.7) | (8–10) | 8.4 (0.7) | (8–10) | 8.2 (0.4) | (8,9) |
| Body Mass Index | 17.7 (3.4) | (12.3–27.5) | 18.5 (3.8) | (12.3–27.5) | 16.1 (1.5) | (14.1–19.2) |
| Fat Free Mass (kg) | 24.7 (4.0) | (18.5–36) | 25 (4.3) | (18.5–36) | 24.0 (3.3) | (19.2–32.8) |
| Six min run (rounds) | 16.0 (2.6) | (10–21) | 14.7 (1.8) | (10–17) | 18.6 (1.7) | (16–21) |
| Standing long jump (cm) | 115.4 (21.1) | (62–153) | 104 (14.8) | (62–127) | 137.4 (12.1) | (119–153) |
| **Overall** | | | | | | |
| Sitting time (min/day) | 419.9 (62.1) | (294–556) | 423.2 (62.2) | (301–556) | 412.5 (63.4) | (294–531) |
| Standing time (min/day) | 232.7 (49.9) | (114–354) | 234.1 (54.2) | (114–354) | 229.5 (40.40) | (154–299) |
| Stepping time (min/day) | 147.6 (33.8) | (58–220) | 138.4 (27.6) | (58–220) | 168.4 (38.1) | (93–216) |
| **Domain lessons** | | | | | | |
| Sitting (%) | 58.2 (14.0) | (30.8–83.3) | 58.2 (13.1) | (30.8–81.9) | 58.3 (16.2) | (33.1–83.3) |
| Standing (%) | 30.8 (12.4) | (11.7–57.6) | 30.8 (12.0) | (11.8–57.6) | 30.5 (13.6) | (11.7–54.0) |
| Stepping (%) | 11.3 (3.2) | (4.0–20.0) | 10.9 (3.1) | (4.0–20 0) | 11.1 (3.4) | (5.0–16.2) |
| **Domain school breaks** | | | | | | |
| Sitting (%) | 28.0 (8.3) | (9.5–53.3) | 29.2 (8.5) | (9.5–53.3) | 25.4 (7.2) | (11.5–44.0) |
| Standing (%) | 34.1 (5.8) | (23.3–46.1) | 34.2 (5.6) | (24.4–46.1) | 34.0 (6.3) | (23.5–43.3) |
| Stepping (%) | 37.8 (9.1) | (13.9–56.4) | 36.6 (9.1) | (13.9–54.0) | 40.6 (8.7) | (26.6–56.4) |
| **Domain leisure time** | | | | | | |
| Sitting (%) | 50.4 (11.4) | (23.3–85.4) | 51.7 (11.5) | (25.8–85.4) | 47.3 (10.8) | (23.3–66.0) |
| Standing (%) | 30.5 (8.2) | (8.1–50.2) | 30.9 (9.1) | (8.1–50.2) | 29.5 (5.8) | (22.2–40.8) |
| Stepping (%) | 19.2 (6.8) | (3.9–36.3) | 17.4 (5.8) | (3.9–32.2) | 23.2 (7.5) | (11.4–36.3) |

## DISCUSSION

The present study aimed to investigate whether installing height-adjustable standing desks affects proportions of sitting, standing and stepping on typical school days and in particular domains (lessons, breaks and leisure time). By measuring PF levels at baseline, we were able to investigate whether potential intervention effects in primary school children differed by PF levels, since the latter indicates increased motivation and capability for PA. We observed significant shorter durations of sitting and longer durations of standing during lessons at T1 in both, the control group (group 2) and the intervention group (group 1). This observation that not only children with but also children without standing desks increased standing during lessons, might be explained by a bandwagon effect, which is a common phenomenon in intervention studies (32). In particular during breaks, positive intervention effects, i.e., significant lower sitting and higher standing durations were observed in both groups after each intervention at T1 and T2, respectively, compared to the baseline measurement (T0).

In general, children with higher fitness levels were found to accumulate more standing time during the day. Further, children having higher fitness levels were more active (up to 7 percentage points more stepping/day) and less likely to have an

**TABLE 2 |** Results of linear mixed models in terms of estimated means of sitting, standing, and stepping time in percentage (%) of total time during lessons per intervention group and survey as well as differences of least-square means (LSM) for direct intervention effects (group 1: T1 – T0, group 2: T2 – T0) and differences across all surveys for $N = 134$ observations of $n = 48$ children.

| | | Sitting time in % during lessons | | Standing time in % during lessons | | Stepping time in % during lessons | |
|---|---|---|---|---|---|---|---|
| **Group** | **Survey** | **Estimate** | **95% CI** | **Estimate** | **95% CI** | **Estimate** | **95% CI** |
| Group 1 | | | | | | | |
| | T0 | 58.4 | (51.7; 65.0) | 30.5 | (25.6; 36.3) | 11.2 | (9.67; 12.7) |
| | T1 | 45.3 | (38.3; 52.3) | 42.0 | (35.8; 48.2) | 12.8 | (11.2; 14.3) |
| | T2 | 56.0 | (48.8; 63.1) | 31.5 | (25.1; 37.8) | 12.6 | (11.0; 14.2) |
| | Mean differences | | | | | | |
| | T1 - T0 | **−13.1** | **(−20.5; −5.72)** | **11.6** | **(4.85; 18.3)** | **1.57** | **(0.10; 3.05)** |
| | T2 - T0 | −2.40 | (−10.2; 5.44) | 0.99 | (−6.16; 8.15) | 1.45 | (−0.12; 3.02) |
| | T2 - T1 | **10.7** | **(2.47; 18.9)** | **−10.6** | **(−18.1; −3.09)** | −0.12 | (−1.77; 1.53) |
| Group 2 | | | | | | | |
| | T0 | 60.8 | (53.4; 68.1) | 28.7 | (22.3; 35.2) | 10.5 | (8.85; 12.2) |
| | T1 | 51.0 | (43.4; 58.6) | 37.4 | (30.7; 44.1) | 11.7 | (9.96; 13.4) |
| | T2 | 57.1 | (49.2; 65.0) | 31.8 | (24.8; 38.8) | 11.2 | (9.44; 13.0) |
| | Mean differences | | | | | | |
| | T1 - T0 | **−9.78** | **(−17.3; −2.28)** | **8.63** | **(1.78; 15.5)** | 1.16 | (−0.34; 2.66) |
| | T2 - T0 | −3.69 | (−11.8; 4.40) | 3.02 | (−4.36; 10.4) | 0.69 | (−0.93; 2.31) |
| | T2 - T1 | 6.09 | (−2.06; 14.3) | −5.61 | (−13.1; 1.83) | −0.47 | (−2.09; 1.16) |

**TABLE 3 |** Results of linear mixed models in terms of Estimated means of sitting, standing, and stepping time in percentage (%) of total time during school breaks per intervention group and survey as well as differences of least-square means (LSM) for direct intervention effects (group 1: T1 – T0, group 2: T2 – T0) and differences across all surveys for $N = 134$ observations of $n = 48$ children.

| | | Sitting time in % during breaks | | Standing time in % during breaks | | Stepping time in % during breaks | |
|---|---|---|---|---|---|---|---|
| **Group** | **Survey** | **Estimate** | **95% CI** | **Estimate** | **95% CI** | **Estimate** | **95% CI** |
| Group 1 | | | | | | | |
| | T0 | 28.7 | (24.7; 32.8) | 34.7 | (37.1; 44.6) | 36.7 | (32.6; 40.8) |
| | T1 | 18.4 | (14.0; 22.8) | 40.9 | (37.1; 44.6) | 40.8 | (36.4; 45.2) |
| | T2 | 17.0 | (12.4; 21.6) | 39.8 | (35.9; 43.6) | 43.2 | (38.7; 47.7) |
| | Mean differences | | | | | | |
| | T1 - T0 | **−10.3** | **(−16.4; −4.25)** | **6.20** | **(1.37; 11.0)** | 4.12 | (−1.14; 9.37) |
| | T2 - T0 | **−11.8** | **(−18.2; −5.31)** | 5.11 | (−0.03; 10.3) | **6.52** | **(0.92; 12.1)** |
| | T2 - T1 | **−1.45** | **(−8.19; 5.29)** | −1.09 | (−6.47; 4.29) | 2.40 | (−3.46; 8.26) |
| Group 2 | | | | | | | |
| | T0 | 29.5 | (25.1; 34.0) | 30.9 | (27.1; 34.6) | 39.8 | (35.3; 44.2) |
| | T1 | 17.7 | (13.0; 22.4) | 38.7 | (34.7; 42.6) | 43.8 | (39.1; 48.4) |
| | T2 | 20.9 | (15.9; 25.9) | 38.9 | (34.7; 43.2) | 40.2 | (35.3; 45.1) |
| | Mean differences | | | | | | |
| | T1 - T0 | **−11.8** | **(−18.0; −5.63)** | **7.82** | **(2.90; 12.7)** | 4.01 | (−1.34; 9.37) |
| | T2 - T0 | **−8.59** | **(−15.2; −1.94)** | **8.08** | **(2.78; 13.4)** | 0.44 | (−5.33; 6.21) |
| | T2 - T1 | 3.23 | (−3.52; 9.97) | 0.26 | (−5.11; 5.63) | −3.57 | (−9.40; 2.26) |

overall sedentary lifestyle (<50% sitting on average school days), compared to children with low fitness levels. To summarize, standing desks were able to reduce sitting, but did not enhance PA in terms of stepping. After installing standing desks, overall PA was not affected across survey periods and intervention effects did not differ by fitness levels. We also might preclude potential selection bias in terms of PA levels and body composition since basic characteristics of our study sample were comparable to other study populations (20). In particular, the proportion of overweight children was around 20% which is similar to other studies (33, 34) and most primary school children spent up to 10 h sedentary per day (17).

**TABLE 4 |** Results of linear mixed models in terms of Estimated means of sitting, standing, and stepping time in percentage (%) of total time during leisure time on weekdays per intervention group and survey as well as differences of least-square means (LSM) for direct intervention effects (group 1: T1 – T0, group 2: T2 – T0) and differences across all surveys for $N = 134$ observations of $n = 48$ children.

| | | Sitting time in % during leisure time | | Standing time in % during leisure time | | Stepping time in % during leisure time | |
|---|---|---|---|---|---|---|---|
| **Group** | **Survey** | **Estimate** | **95% CI** | **Estimate** | **95% CI** | **Estimate** | **95% CI** |
| Group 1 | | | | | | | |
| | T0 | 51.4 | (46.3; 56.6) | 31.3 | (27.7; 34.8) | 17.3 | (14.4; 20.2) |
| | T1 | 52.1 | (46.6; 57.6) | 30.2 | (26.4; 34.0) | 17.7 | (14.6; 20.8) |
| | T2 | 50.9 | (45.2; 56.6) | 29.9 | (26.0; 33.9) | 19.2 | (15.9; 22.4) |
| | Mean differences | | | | | | |
| | T1 - T0 | 0.69 | (−6.25; 7.62) | −1.04 | (−5.71; 3.64) | 0.36 | (−3.73; 4.46) |
| | T2 - T0 | −0.54 | (−7.91; 6.84) | −1.33 | (−6.31; 3.64) | 1.83 | (−2.53; 6.19) |
| | T2 - T1 | −1.22 | (−8.94; 6.50) | −0.30 | (−5.51; 4.91) | 1.47 | (−3.09; 6.03) |
| Group 2 | | | | | | | |
| | T0 | 55.2 | (49.6; 60.9) | 28.9 | (24.9; 32.8) | 15.9 | (12.8; 19.1) |
| | T1 | 55.9 | (50.1; 61.8) | 28.5 | (24.4; 32.6) | 15.5 | (12.2; 18.8) |
| | T2 | 58.7 | (52.4; 64.9) | 26.1 | (21.8; 30.4) | 15.2 | (11.7; 18.7) |
| | Mean differences | | | | | | |
| | T1 - T0 | 0.71 | (−6.36; 7.77) | −0.32 | (−5.09; 4.44) | −0.39 | (−4.57; 3.78) |
| | T2 - T0 | 3.45 | (−4.16; 11.1) | −2.75 | (−7.88; 2.39) | −0.71 | (−5.20; 3.79) |
| | T2 - T1 | 2.74 | (−4.96; 10.4) | −2.42 | (−7.61; 2.77) | −0.32 | (−4.24; 4.87) |

**TABLE 5 |** Results of linear mixed models in terms of Estimated means of sitting, standing, and stepping time in min./day of weekdays per intervention group and survey as well as differences of least-square means (LSM) for direct intervention effects (group 1: T1 – T0, group 2: T2 – T0) and differences across all surveys for $N = 134$ observations of $n = 48$ children.

| | | Average sitting time min./day | | Average standing time min./day | | Average stepping time min./day | |
|---|---|---|---|---|---|---|---|
| **Group** | **Survey** | **Estimate** | **95% CI** | **Estimate** | **95% CI** | **Estimate** | **95% CI** |
| Group 1 | | | | | | | |
| | T0 | 422.9 | (392.3; 453.5) | 235.3 | (212.1; 258.5) | 140.3 | (126.2; 154.4) |
| | T1 | 391.1 | (358.7; 423.6) | 260.4 | (235.9; 285.0) | 144.9 | (129.9; 156.0) |
| | T2 | 416.7 | (383.5; 450.0) | 231.9 | (206.7; 257.0) | 149.9 | (134.4; 165.3) |
| | Mean differences | | | | | | |
| | T1 - T0 | −31.7 | (−67.7; 4.24) | 25.1 | (−1.60; 51.9) | 4.62 | (−12.9; 22.1) |
| | T2 - T0 | −8.90 | (−44.4; 32.1) | −9.76 | (−55.1; 35.6) | 9.56 | (−9.07; 28.2) |
| | T2 - T1 | 25.5 | (−14.5; 65.7) | −28.5 | (−58.4; 1.30) | 4.94 | (−14.6; 24.5) |
| Group 2 | | | | | | | |
| | T0 | 445.0 | (411.2; 478.8) | 217.7 | (192.1; 243.3) | 128.3 | (112.7; 143.9) |
| | T1 | 425.6 | (390.6; 460.6) | 241.6 | (215.1; 268.2) | 131.1 | (114.9; 147.3) |
| | T2 | 457.6 | (421.0; 494.1) | 212.9 | (185.2; 240.6) | 123.6 | (106.6; 140.6) |
| | Mean differences | | | | | | |
| | T1 - T0 | −19.4 | (−56.0; 17.3) | 23.9 | (−3.29; 51.2) | 2.85 | (−15.0; 20.7) |
| | T2 - T0 | 12.6 | (−26.9; 52.0) | −4.80 | (−34.2; 24.5) | −4.65 | (−23.9; 14.6) |
| | T2 - T1 | 31.9 | (−7.91; 71.7) | −28.7 | (−58.3; 0.86) | −7.50 | (−26.9; 11.9) |

Similar to our findings, Verloigne et al. recently found a short-term intervention effect leading to decreased sitting time by installing standing desks in primary school children, but also highlighted that alternative study designs need to be explored and encouraging the continuous use of standing desks is necessary (20). In general, the observed high proportions spent sitting during lessons are typical for school children since they were obviously forced to sit about two thirds during lessons. However, children were likely to compensate their sedentary lesson time with activities such as standing and stepping during breaks (<30% sedentary). However, no compensatory effects such as lower or higher activity during leisure time was observed after installing standing desks, which is in line with the reviews of Kidokoro et al. (35) as well as Silva et al. (36). In contrast to our results, Kidokoro et al. found children to accumulate about 20 min more high-intensity PA per day, when having standing desks (35).

Since most standing desk interventions do not integrate strategies to increase high-intensity PA such as MVPA, such strong increases of MVPA are uncommon if the intervention was not focused on enhancing PA. Furthermore, the applied devices to assess PA (Actigraph accelerometers) are not the most robust monitor to reliably distinguish between sitting and standing (37).

Recent studies questioned the long-term effects of cost-effective structural interventions, that aim to change behavior without study personnel that regularly motivates to be physically active (38). Such an intervention was conducted by Silva et al. (36) who combined standings desks with teacher training and motivation sessions (36). By incorporating students and parents, they achieved significant decreases of sitting (−7%) and increase of standing (+30%) during school hours. This indicates beneficial effects for complementary behavioral strategies to maintain the use of standing desks as a change of daily lifestyle.

### Strengths and Limitations

Main strength of this study was the objective PA measurement using activPAL monitors and the standardized study protocol. These devices have recently been shown to reliably quantify sitting and standing time in children (37). Since we wanted to particularly investigate within-day differences in specific domains rather than describing the "habitual" PA of a typical week by using accelerometry, we decided to use an uncommon inclusion criteria of 2 valid days of 10 h in order not to loose more participants. Further, we explored an alternative study design using the cross-over design that has rarely been evaluated (39). We may however not preclude that other intervention effects might be observed only by the cross-over design, since another study ($N = 27$) with a traditional control group (another classroom) showed significant decreases (∼10%) of sitting time (18). Due to the cross-over study design, whose advantages have recently been highlighted by Ee et al. (39), we were able to preclude effects by season and different teachers confounding the intervention effects. Until now, PF levels have not been highlighted as a potential confounder in recent reviews on this topic (16, 17). However, we need to acknowledge that PF was derived by assessing important, but only two components (explosive strength and endurance capacity) of PF. An important limitation is the follow-up duration of 3 months that only enables to summarize the observed effects that all children reduced sitting and increased standing time from baseline to T1 as a case of short-term reactivity. Finally, the small sample size was due to the limited number of standing desks affordable, which indeed is typical for most studies evaluating standing desks interventions (17, 35). Since our study was only conducted in the 3rd grade of one primary school, caution should be taken when generalizing our findings and more confounders appear to be relevant.

## CONCLUSION

Providing height-adjustable standing desks in primary schools offers the opportunity to replace sedentary time during school hours by more active behavior such as standing during lessons and particularly during school breaks. When evaluating the compliance and effects of standing desk interventions, psychological (e.g., bandwagon effect) physiological (e.g., PF) should be taken into account in future studies. To increase and maintain the use of standing desks in primary children and working in a standing position during lessons needs to accompanied by motivational strategies.

## DATA AVAILABILITY STATEMENT

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

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional review board of the University of Bremen (19.09.2017). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

## AUTHOR CONTRIBUTIONS

OS, AH, HG, and JB designed the study. OS and AH trained the study personnel. HG and JB conducted the field experiments. OS and CB drafted the manuscript and analyzed the data. All authors revised the paper and approved the final version.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2020.00396/full#supplementary-material

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# Can School-Based Physical Activity Projects Such as Skipping Hearts Have a Long-Term Impact on Health and Health Behavior?

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Low physical activity, limited motor skills, and an increased number of overweight or obese children are major public health problems. Numerous school-based programs try to improve physical activity and health behavior in children but investigations on sustainable effects of these programs are rare. Therefore, we examined the long-term effects of the *Skipping Hearts* health promotion project. 486 children (57.7% female, 9.0 ± 0.6 years at baseline) participated in this non-randomized controlled longitudinal trial within a follow-up period of 3.5 years. Of these, 286 subjects received a one-time 90-min workshop in rope skipping (Basic-Workshop) and 140 additionally received 10 lessons in rope skipping (Champion-Program), 78 students served as controls. Anthropometrics, blood pressure, motor skills, screen-based media use, self-assessment of physical fitness, and physical activity were collected at both measurement points; endurance capacity and health-related quality of life only at follow-up. Standard deviation scores of body-mass-index ($\eta^2 = 0.005$) and systolic blood pressure ($\eta^2 = 0.006$) decreased, while diastolic blood pressure ($\eta^2 = 0.004$), motor performance ($\eta^2 < 0.001$), physical fitness, subjective physical activity ($\eta^2 = 0.008$), and screen-based media use ($\eta^2 = 0.001$) increased without significant difference in development between groups (all $p > 0.05$). At follow-up, groups did not differ in endurance capacity ($\eta^2 = 0.010$) and health-related quality of life ($\eta^2 < 0.001$). *Skipping Hearts* does not affect the long-term improvement of health status, motor performance, or health behavior. To improve the effects, the project should be implemented as a daily routine in schools to force the transfer of health behavior-related knowledge. Nevertheless, the project offers a physical activity that can be performed in children's everyday life without high costs.

**Keywords: physical activity, health behavior, accelerometry, body composition, long-term evaluation, children, adolescents**

## INTRODUCTION

Poor physical activity in childhood and adolescence is associated with a higher risk for cardiovascular and chronic diseases and is, therefore, a major public health problem (1, 2). Several studies have found an adverse correlation between regular physical activity in childhood and adolescence and body mass index (BMI), waist circumference, and blood pressure (3–6). Having these risk factors at an early age leads to higher mortality and morbidity in adulthood (7). Ward et al. (8) report a 1 in 10 probability that 5-year-old obese children will not be obese by the age of 35 years.

Although countless projects promoting physical activity in this span of life exist, only 26% of German children and adolescents meet the recommendation of at least 60 min of moderate-to-vigorous physical activity (MVPA) per day (9, 10). It is of great significance that the physical activity level declines with increasing age during childhood and adolescence. Jekauc et al. (11) found an age-related continuous decrease in physical activity, especially in girls. The probability of meeting the World Health Organization's physical activity recommendations decreases every year by 17% in childhood and by 19% in adolescence (11).

The maturation of distinct motor skills is of crucial importance for early childhood development. Several studies have shown a positive correlation between motor skills and total, light-to-moderate, and MVPA in childhood and adolescence (12–14). Regular physical activity is not only important for physical health, but it is also associated with psychical well-being at an early age (15). Finne et al. (16) have shown a positive relationship between physical activity and health-related quality of life (HRQoL) and a negative association between HRQoL and screen-based media use (SBM), respectively. Therefore, the need for programs promoting health behavior, health status, and physical performance in childhood is particularly high.

Numerous projects and intervention studies, both national and international, promote physical activity in this age group with the main goal of changing their behavior towards a healthier lifestyle. The conceptions of these projects range from one-time offers to regular interventions lasting several hours and weeks, from projects limited to physical activity promotion to multimodal projects including nutrition or stress management, and from the integration only of children to the additional inclusion of parents (17). School seems to be particularly suitable as a setting for such projects since nowhere else can so many different children and adolescents be reached at the same time (18). Furthermore, Pate et al. (19) point out that it is an important task for schools to promote health behavior because of the increasing number of overweight children and adolescents.

Previous school-based programs in primary schools in Germany showed only a limited impact on children's health and health behavior. The URMEL-ICE study found no short-term effect on BMI but on waist circumference and subscapular skinfold thickness (20). The program "Join the Healthy Boat" resulted in a short-term reduction in cardiovascular disease risk and SBM, improvements in motor skills and a tendency of higher physical activity pattern (21–23). Graf et al. (24) conducted the CHILT Project which aimed to promote a healthy lifestyle in primary schools and consisted of health education lessons, physical activity breaks, and games for leisure. After 4 years, they observed higher improvements in lateral jumping and balancing backwards in the intervention group (25). Concerning the measured endpoints, Dobbins et al. (17) conclude in their systematic review that school-based interventions to promote physical activity and fitness have little or no effect on television viewing behavior, physical activity, blood pressure, and BMI. In addition, the authors suggest that significant changes in physical activity were observed in programs with longer duration and that interventions with significant effects included changes in school curricula and printed teaching materials. The recent review by Love et al. (26) also concludes that school-based intervention programs do not lead to a change in physical activity and that there are no differences between girls and boys and between children from different socioeconomic backgrounds. Changing health and health behavior through school-based programs is a necessary task from the point of view of public health, but also a challenging one in order to achieve the required effects in the short and long-term.

Of particular note is the fact that a long-term evaluation of such projects and interventions over the years is rather rare: only 2 out of 23 school-based intervention studies that measured the impact on physical activity duration had a follow-up of 12 months or more (17).

In 2006, the German Heart Foundation initiated the *Skipping Hearts* project, which aims to promoting physical activity and an active lifestyle through rope skipping during childhood. Skipping rope is the modern form of jumping rope and strengthens physical fitness, complex movement patterns, and social skills in girls and boys (27). The project is free of charge for schools and contains a two-staged concept: a one-time 90-min Basic-Workshop (supervision of a trainer of the German Heart Foundation) and the subsequent Champion-Program with 10 45-min rope skipping lessons (standardized curricula, implementation by the teacher). All participating schools and classes receive a package of materials, including a teacher's handbook. Up until August 2017, 12,487 school classes had completed the Basic-Workshop and 2,924 school classes had received the Champion-Program. In total, more than 500,000 children participated in *Skipping Hearts*. Therefore, *Skipping Hearts* is one of the largest projects promoting physical activity in Germany. It is well-described in a short-term evaluation with a 5-month follow-up, where the positive effects of both project parts on physical activity, body composition, and motor skills were determined (28).

This study aimed to investigate the long-term effect of the established *Skipping Hearts* project on anthropometric and cardiovascular parameters, motor performance, self-assessed physical fitness level, physical activity, SBM, and HRQoL in

**Abbreviations:** BMI, body mass index; DBP, diastolic blood pressure; HRQoL, health-related quality of life; MVPA, moderate-to-vigorous physical activity; SBM, screen-based media use; SBP, systolic blood pressure; SDS, standard deviation score; SH-B, skipping hearts basic group; SH-CH, skipping hearts champion group.

children. Therefore, an additional follow-up examination 3 years later was conducted. The effect sizes of the short-term evaluation were small and it was therefore of interest whether the Basic-Workshop and Champion-Program led to the effects being maintained or strengthened in the long term or whether the effects disappeared. We hypothesized that only the Champion-Program leads to long-term improvements in the mentioned parameters and that the Basic Workshop shows no long-term effects.

# MATERIALS AND METHODS

## Study Design

*Skipping Hearts* was evaluated in a non-randomized controlled longitudinal design between 2011 and 2016. The study included a fitness test (anthropometrics, health parameters, and motor skills), a health behavior questionnaire, and an accelerometer-based assessment of children (baseline: 10/2011-03/2012, follow-up: 03/2015-07/2015). Moreover, children's exercise capacity and HRQoL were evaluated in cross-section with a self-assessment and external assessment (parents). Informed consent was obtained from all children and parents.

## Sampling Procedures

The sample consisted of the same subjects as the short-term evaluation study—pupils in the 3rd and 4th grade of primary school in Upper Bavaria (28). Children who only received the 90-min Basic-Workshop comprised group SH-B. Group SH-CH consisted of pupils who received the Champion-Program in addition to the Basic-Workshop. The schools registered with the German Heart Foundation for the *Skipping Hearts* project. It was up to the schools to decide whether a class would be involved in the Basic-Workshop only (42 classes) or also in the Champion-Program (26 classes). The control group (18 classes) consisted of children from schools that had neither the Basic-Workshop nor the Champion-Program. Between baseline and follow-up, the former primary school children moved to secondary school and were invited individually to join in the follow-up examination at a sports hall near their former primary school. Of 1,662 children with baseline data (838 SH-B, 480 SH-CH, 344 control group), 1,124 children (67.62%) were invited during the recruiting process and 538 (32.37%) were lost to follow-up. The main reason for loss to follow-up was inaccessibility at their secondary schools due to missing contact data.

An a priori power analysis with a small effect size ($f = 0.1$) and a power of 80% revealed a required total sample of $n = 246$ and thus $n = 82$ per group. A total of 486 students out of 1,124 (43.2%) joined in the follow-up examination. Of these, 286 only participated in the Skipping Hearts Basic-Workshop (SH-B), 140 additionally received the Skipping Hearts Champion-Program (SH-CH), and 78 served as controls. The required sample size from the power analysis was achieved in SH-B and SH-CH, in the control group it was only slightly below. A total of 307 parents of the 486 children with longitudinal data answered a questionnaire at follow-up.

Of 105 children with baseline data for short-term accelerometer-based assessment, 43 (41.0%) again took part in the accelerometer-based measurement at follow-up, 27 (25.7%) could not be contacted and 35 (33.3%) refused to participate in the long-term assessment. Seven of 43 subjects did not provide any data and 16 did not meet the inclusion criteria. Due to the small sample size of 20 subjects with baseline and follow-up data, the accelerometer-based assessment was supplemented by a cross-sectional survey at follow-up: 6 children with non-usable baseline data and 102 children without prior activity measurement, who volunteered for accelerometer measurement, were included. In total, of 151 subjects with follow-up examination, 90 completed the activity measurement, 41 did not provide any data, and 20 did not meet the inclusion criteria.

Follow-up examination was voluntary, and the fitness test took place in the afternoon during the children's leisure time. For renewed participation in the study, all children got a gym bag and took part in a lottery game with 1 × 2 concert tickets or 1 × 2 tickets for a German professional soccer league match as the main prize.

## Materials

Blood pressure was measured using Mobil-O-Graph ambulatory blood pressure monitoring system (IEM Healthcare, Stolberg, Germany). After a rest period of at least 5 minutes, the measurement was taken on the left upper arm in a sitting position with the blood pressure cuff at heart level. Individual cuff size was determined by upper arm circumference (29). Based on German reference data, BMI was transformed into standard deviation scores (SDS), according to Kromeyer-Hauschild et al. (30) and systolic (SBP) and diastolic blood pressure (DBP) according to Neuhauser et al. (31).

Body fat was measured using the near-infrared technique (Futrex Advanced Body Fat Analyzer 6100 A/ZL, Futrex, Inc, Maryland, USA) on the right and left upper arm in the middle of the biceps brachii muscle (32). This method has high reliability and can be used in pediatric longitudinal studies to monitor changes in body fat over time (33). The mean of both measurements was used for further analyses.

Standing long jump, jumping sideways, 20-m sprint, and 6-min run were performed to conduct motor performance (34). The 6-min run was only performed in the follow-up examination. The measurement procedure is described in Postler et al. (28) and Graf et al. (24). SDS of these motor tests were calculated according to Bös et al. (34). To make a statement about general motor performance, a motor score was calculated from the three tests that were performed at all times (standing long jump, jumping sideways and 20-m sprint). This was composed of the mean value of the SDS values of the measured parameters and thus forms a single, meaningful parameter for motor performance. The test-retest reliability of the individual tests used ranges from $\alpha = 0.89$ to $\alpha = 0.92$ and the tests show a good overall validity (34). In our study, the reliability of the motor score was $\alpha = 0.71$ for the baseline and $\alpha = 0.77$ for the follow-up measurement.

Activity levels were recorded using the MoMo activity questionnaire (35). The physical activity score was calculated according to Prochaska et al. (36) as the mean value of the questions "How many of the last 7 days have you been physically active for at least 60 min a day?" and "How many days in a normal week are you physically active for at least 60 min a day?" The physical activity score has acceptable reliability and validity in comparison to accelerometer measurements (36). The Cronbach's alpha of the physical activity score was $\alpha = 0.76$ for the baseline and $\alpha = 0.84$ for the follow-up measurement. To assess SBM, children were asked about their daily consumption of TV/video, computer/Internet, gaming consoles, and mobile phone according to Lampert et al. (37) and estimation of their fitness level (How well do you think your physical performance is [=fitness]?) was collected in five categories from "very well" to "not at all well." An SBM index (h/day) was built according to Finne et al. (16). Although the SBM index was used in the reported study, it has not yet been checked for reliability and validity. The reliability of SBM in our study was $\alpha = 0.49$ for the baseline and $\alpha = 0.51$ for the follow-up measurement.

A subsample performed an accelerometer-based measurement using Actigraph GT3X+ to assess objective physical activity, particularly the time spent in MVPA. Study participants should wear the accelerometer for 1 week all day on the right hip. Inclusion criteria were wearing the accelerometer at least 7 h daily on at least 3 workdays and 1 weekend day (38, 39). The cut-points of Freedson et al. (40) were used to determine activity intensity levels. An activity of fewer than 100 counts/min was generally defined as sedentary activity (41). Epoch length was 60 s. Data were classified as wear time and non-wear time according to the algorithm of Choi et al. (42). Besides, children recorded their daily physical activity and wear time in an activity protocol.

The KINDL-R questionnaire was used to assess the HRQoL of children through self-report and parent-report (43). The questionnaire was only used in the follow-up examination. It contains 24 items in 6 subscales (physical well-being, emotional well-being, self-esteem, family, friends, and school), whereby four items make up one subscale. Subscale scores and the total score are transformed from 0 to 100 with a higher score expressing a better HRQoL. In addition to HRQoL, parents were asked about their child's physical activity according to Prochaska et al. (36) (no personal data available). The psychometric characteristics of the KINDL-R revealed a reliability of $\alpha = 0.54$ to $\alpha = 0.73$ for the subscales and $\alpha = 0.82$ for the total score (44). Satisfactory convergent validity is generally attributed to the subscales and the total score (45). The reliability of the scores in our study ranged from $\alpha = 0.43$ (friends) to $\alpha = 0.74$ (family) in the self-report and from $\alpha = 0.66$ (friends) to $\alpha = 0.83$ (physical well-being) in the parent-report. The overall HRQoL score reliability was $\alpha = 0.83$ and $\alpha = 0.87$ in the self-report and the parent-report, respectively.

Standard operation procedure for follow-up was identical to the standard operation procedure for baseline examination. All measurements were performed by previously trained staff.

## Statistical Analysis

Mean and standard deviations are reported for continuous data, median for non-normally distributed continuous data. Absolute and relative frequencies are shown for categorical data.

A comparison of baseline data of originally included participants who were willing to take part in the long-term assessments and those who refused to perform (children who could not be contacted were not considered). Welch two-sample *t*-tests were used to examine differences between children with follow-up and children without follow-up in anthropometrics, cardiovascular parameters, motor performance, physical activity, and SBM at baseline. Fisher's exact test was used for the categorical variable physical fitness in this analysis.

One-way analysis of variance for metric variables and Kruskal–Wallis tests for categorical variables were used for group comparisons at baseline.

Analysis of variance for repeated measures considering time as within-subjects variable and group as between-subjects variable for anthropometrics, cardiovascular parameters, motor performance, physical activity score, and SBM were used to examine changes between baseline and follow-up in total and between SH-B, SH-CH, and the control group over time for all 486 participants with baseline and follow-up data. For the categorical variable physical fitness, we used Wilcoxon signed rank test and Pearson's Chi-squared test in this analysis.

Due to the small sample size in the accelerometer-based assessment, Wilcoxon signed rank test was used to analyze the change between follow-up and baseline data in accelerometer data in total. We further calculated the differences between follow-up and baseline data and used Kruskal Wallis test to analyze the changes between groups, respectively.

Changes over time within groups were examined using paired *t*-tests for anthropometrics, cardiovascular parameters, motor performance, physical activity score, and SBM, and Wilcoxon signed rank tests for accelerometer data and assessment of physical fitness (Bonferroni correction $p < 0.0167$).

One-way analysis of variance was used to analyze only cross-sectional data of follow-up measurement: accelerometer ($n = 90$), 6-min run ($n = 477$), physical activity score (parental report), and HRQoL for both parental report ($n = 307$) and self-report ($n = 455$).

Statistical data analysis was performed using SPSS Statistics 23.0 (IBM Corp., Armonk, NY, USA) and R 3.3.3 (R Foundation for Statistical Computing, Vienna, Austria). The level of significance was set at $p < 0.05$ and $p < 0.1$ was set as the tendency of significance. Effect size is reported for all analyses of variance.

# RESULTS

## Dropout-Analysis: Differences in Subjects With or Without Participation in Long-Term Assessment at Baseline

Children who participated in follow-up had better baseline values in BMI (16.7 ± 2.36 vs. 17.5 ± 2.99, $p < 0.001$), BMI-SDS (0.07 ± 0.96 vs. 0.20 ± 1.07, $p < 0.001$), body fat (15.3 ± 3.14 vs. 15.7 ± 3.63, $p = 0.040$), SBP (113.5 ± 10.9 vs. 115.1 ± 12.0, $p = 0.022$), SBP-SDS (1.34 ± 1.28 vs. 1.52 ± 1.37, $p = 0.027$) and motor performance (0.34 ± 0.73 vs. 0.08 ± 0.72, $p < 0.001$) than children who didn't participate in the follow-up (**Table 1**). No significant differences were found in

**TABLE 1 |** Dropout-analysis: differences in subjects with or without participation in long-term assessment at baseline.

| | Participation in long-term assessment | | | No participation in long-term assessment | | | *p*-value |
|---|---|---|---|---|---|---|---|
| **Welch two-sample *t*-tests** | ***n*** | **Mean (SD)** | **95% CI** | ***n*** | **Mean (SD)** | **95% CI** | |
| Age (years) | 486 | 8.98 (0.60) | [8.93, 9.04] | 638 | 9.09 (0.65) | [9.04, 9.14] | **0.005** |
| Height (cm) | 478 | 135.1 (6.71) | [134.5, 135.7] | 631 | 135.6 (6.87) | [135.0, 136.1] | 0.260 |
| Weight (kg) | 478 | 30.7 (6.32) | [30.1, 31.3] | 631 | 32.5 (7.78) | [31.8, 33.1] | **<0.001** |
| BMI ($kg/m^2$) | 478 | 16.7 (2.36) | [16.5, 16.9] | 631 | 17.5 (2.99) | [17.3, 17.7] | **<0.001** |
| BMI-SDS | 478 | 0.07 (0.96) | [−0.15, 0.02] | 631 | 0.20 (1.07) | [0.11, 0.28] | **<0.001** |
| Body fat (%) | 476 | 15.3 (3.14) | [15.0, 15.6] | 626 | 15.7 (3.63) | [15.4, 16.0] | **0.040** |
| SBP (mmHg) | 460 | 113.5 (10.9) | [112.5, 114.4] | 618 | 115.1 (12.0) | [114.1, 116.0] | **0.022** |
| SBP-SDS | 460 | 1.34 (1.28) | [1.22, 1.46] | 618 | 1.52 (1.37) | [1.42, 1.63] | **0.027** |
| DBP (mmHg) | 460 | 70.3 (9.08) | [69.4, 71.1] | 618 | 71.0 (9.61) | [70.3, 71.8] | 0.191 |
| DBP-SDS | 460 | 1.18 (1.39) | [1.06, 1.31] | 614 | 1.28 (1.46) | [1.17, 1.40] | 0.268 |
| Motor performance | 464 | 0.34 (0.73) | [0.28, 0.41] | 608 | 0.08 (0.72) | [0.03, 0.14] | **<0.001** |
| Physical activity score (days/week) | 405 | 4.06 (1.82) | [3.88, 4.24] | 567 | 3.87 (1.82) | [3.72, 4.02] | 0.108 |
| MVPA relative (% of wear time) | 20 | 22.5 (3.73) | [20.7, 24.23] | 59 | 22.8 (6.61) | [21.1, 24.5] | 0.837 |
| MVPA absolute (minutes/day) | 20 | 170.3 (30.3) | [156.1, 184.4] | 59 | 168.2 (51.0) | [154.9, 181.5] | 0.866 |
| SBM (h/day) | 365 | 1.79 (1.99) | [1.58, 1.99] | 496 | 2.09 (2.74) | [1.85, 2.33] | 0.075 |

| **Fisher's exact test** | ***n* (%)** | ***n* (%)** | ***p*-value** |
|---|---|---|---|
| Physical fitness | 454 (100) | 614 (100) | 0.169 |
| Very well | 197 (43.4) | 230 (37.5) | |
| Well | 191 (42.1) | 271 (44.1) | |
| Medium | 61 (13.4) | 105 (17.1) | |
| Not as well | 3 (0.7) | 7 (1.1) | |
| Not at all well | 2 (0.4) | 1 (0.2) | |

*Significant results marked in bold types. BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; SDS, standard deviation score; MVPA, moderate-to-vigorous physical activity; SBM, screen-based media use.*

the number of days/week with daily at least 60 min of physical activity (4.06 ± 1.82 vs. 3.87 ± 1.82, $p = 0.108$) and relative (22.5 ± 3.73 vs. 22.8 ± 6.61, $p = 0.837$), absolute minutes in MVPA per day (170.3 ± 30.3 vs. 168.2 ± 51.0, $p = 0.866$) and self-assessment of own physical fitness at baseline. Children with participation in long-term assessment showed a tendency of lower SBM (1.79 ± 1.99 vs. 2.09 ± 2.74, $p = 0.075$) at baseline.

## Baseline Characteristics

Four hundred and eighty six children (256 female) had baseline and follow-up data with a mean age at baseline of 8.98 ± 0.60 years (**Table 2**). 10.0% were classified as underweight, 9.6% as overweight, and 2.5% as obese. Mean age in SH-B (9.06 ± 0.64) was ∼2 months higher than in SH-CH (8.89 ± 0.59, $p = 0.019$) and in the control group (8.87 ± 0.46, $p = 0.038$). SH-B (4.13 ± 1.77, $p = 0.033$) and SH-CH (4.20 ± 1.87, $p = 0.038$) reported higher physical activity compared to controls (3.53 ± 1.82). Groups did not significantly differ in BMI, body fat, blood pressure, motor performance, objectively measured physical activity, and SBM (*p*-values not shown). At baseline, 85.4% of the participating children (SH-B: 87.9%, SH-CH: 83.6%, control group: 80.6%, $p = 0.582$) reported a good or very good own physical fitness.

## Changes Between Baseline and Follow-Up in Total

Height (Δ 21.2 ± 3.53, $p < 0.001$), weight (Δ 15.0 ± 5.08 $p < 0.001$), BMI (Δ 1.86 ± 1.47, $p < 0.001$), body fat (Δ 6.41 ± 3.39, $p < 0.001$), SBP (Δ 5.74 ± 13.1, $p < 0.001$), DBP (Δ 4.27 ± 10.3, $p < 0.001$), DBP-SDS (Δ0.14 ± 1.57, $p = 0.027$) and motor performance (Δ0.16 ± 0.57, $p < 0.001$) increased from baseline to follow-up (**Table 2**). Age- and sex-independent BMI-SDS (Δ −0.06 ± 0.52, $p = 0.025$) and SBP-SDS (Δ −0.24 ± 1.48, $p = 0.014$) decreased over time and prevalence of overweight and obesity remained constant ($\chi^2 = 3.98, p = 0.409$). Subjective physical activity score (Δ0.58± 2.22, $p < 0.001$) and daily SBM (Δ 1.61 ± 2.56, $p < 0.001$) increased between baseline and follow-up. A decline of MVPA-minutes ($z = -3.92$, $p < 0.001$) and percentage of MVPA-minutes of daily wear time ($z = -3.92$, $p < 0.001$) was observed. The assessment of own physical fitness declined between baseline and follow-up ($z = -10.0, p < 0.001$).

## Changes Between Baseline and Follow-Up Within Groups

Height, weight, BMI, SBP, DBP, and SBM increased between baseline and follow-up in all groups (**Table 3**). BMI-SDS only decreased in SH-CH (Δ −0.11 ± 0.49, $p = 0.006$). SH-B (Δ −0.34 ± 1.52, $p < 0.001$) and not SH-CH decreased in SBP-SDS. DBP-SDS did not change over time within all groups. Motor

**TABLE 2 |** Descriptive statistics of baseline and follow-up data.

| | Baseline | | Follow-Up | | *p*-value | $\eta^2$ |
|---|---|---|---|---|---|---|
| **Paired *t*-tests from ANOVA for repeated measures** | **Mean (SD)** | **95% CI** | **Mean (SD)** | **95% CI** | | |
| Age (years) | 8.98 (.60) | [8.93, 9.04] | 12.4 (0.60) | [12.3, 12.4] | **<0.001** | 1.00 |
| Height (cm) | 135.1 (6.71) | [134.5, 135.7] | 156.3 (8.22) | [155.6, 157.0] | **<0.001** | 0.996 |
| Weight (kg) | 30.7 (6.32) | [30.7, 31.3] | 45.6 (9.91) | [44.8, 46.5] | **<0.001** | 0.873 |
| BMI (kg/m$^2$) | 16.7 (2.36) | [16.5, 16.9] | 18.5 (2.95) | [18.3, 18.8] | **<0.001** | 0.557 |
| BMI-SDS | −0.07 (0.96) | [−0.15, 0.02] | −0.13 (1.07) | [−0.22, −0.03] | **0.025** | 0.010 |
| Body fat (%) | 15.3 (3.14) | [15.0, 15.6] | 21.70 (5.34) | [21.2, 22.2] | **<0.001** | 0.739 |
| SBP (mmHg) | 113.4 (10.8) | [112.2, 114.4] | 119.2 (12.0) | [118.0, 120.3] | **<0.001** | 0.153 |
| SBP-SDS | 1.34 (1.27) | [1.22, 1.46] | 1.10 (1.26) | [0.98, 1.22] | **0.014** | 0.013 |
| DBP (mmHg) | 70.2 (9.04) | [69.4, 71.1] | 74.5 (8.19) | [73.8, 75.3] | **<0.001** | 0.136 |
| DBP-SDS | 1.18 (1.38) | [1.06, 1.31] | 1.33 (1.21) | [1.21, 1.44] | **0.027** | 0.011 |
| Motor performance | 0.35 (0.73) | [0.28, 0.42] | 0.51 (0.74) | [0.45, 0.58] | **<0.001** | 0.057 |
| Physical activity score (days/week) | 4.06 (1.82) | [3.88, 4.24] | 4.64 (1.69) | [4.47, 4.81] | **<0.001** | 0.064 |
| SBM (h/day) | 1.77 (1.92) | [1.56, 1.97] | 3.38 (2.38) | [3.12, 3.63] | **<0.001** | 0.242 |
| **Wilcoxon signed rank tests** | **Median** | | **Median** | | | |
| MVPA relative (% of wear time) | 22.6 | | 8.7 | | **<0.001** | |
| MVPA absolute (minutes/day) | 170.8 | | 74.6 | | **<0.001** | |
| **Wilcoxon signed rank tests** | ***n* (%)** | | ***n* (%)** | | | |
| Physical fitness | 439 (100) | | 439 (100) | | **<0.001** | |
| Very well | 190 (43.3) | | 75 (17.1) | | | |
| Well | 185 (42.1) | | 227 (51.7) | | | |
| Medium | 59 (13.4) | | 123 (28.0) | | | |
| Not as well | 3 (0.07) | | 14 (3.2) | | | |
| Not at all well | 2 (0.05) | | 0 (0.0) | | | |

*Significant results marked in bold types. BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; SDS, standard deviation score; MVPA, moderate-to-vigorous physical activity; SBM, screen-based media use.*

performance significantly increased over time in both project groups (SH-B: Δ0.17± 0.57, SH-CH: Δ0.16 ± 0.54, $p < 0.001$ for both). Between baseline and follow-up, self-reported physical activity score increased in SH-B (Δ0.53 ± 2.20, $p = 0.001$) and the control group (Δ 1.02 ± 2.04, $p < 0.001$), but not in SH-CH. Absolute and relative MVPA ($z = -2.52$, $p = 0.012$) significantly decreased over time in SH-CH. Between baseline and follow-up, all groups significantly decreased in their assessment of own physical fitness (SH-B: $z = -7.48$, SH-CH: $z = -5.26$, control group: $z = -4.09$, $p < 0.001$ for all).

## Changes Between Baseline and Follow-Up Between Groups: Long-Term Effect of *Skipping Hearts*

Mean changes in all anthropometric and cardiovascular parameters over time did not differ between groups (**Table 4**). In subjective physical activity, no change over time was observed in SH-B and SH-CH compared to controls ($p = 0.243$). A tendency of lower decline of MVPA-minutes in SH-B and SH-CH compared to controls ($\chi^2 = 5.09$, $p = 0.078$) but not in percentage of MVPA-minutes of daily wear time ($\chi^2 = 2.92$, $p = 0.232$) was found. Mean changes in SBM over time did not differ between groups. Self-reported physical fitness showed no interaction between group and time ($\chi^2 = 0.30$, $p = 0.990$).

## Additional Analyzes at Follow-Up

Due to the little number of subjects with accelerometer data at both times of measurement, additionally data derived at the long-term assessment were analyzed without consideration of baseline data to estimate possible outlasting effects of SH. Groups did not differ in the daily MVPA-minutes ($p = 0.568$), percentage of MVPA-minutes of daily wear time ($p = 0.488$) and endurance capacity ($p = 0.098$, **Table 5**). In parental report, no significant group differences were determined in the physical activity score of the children (SH-B: 4.07 ± 1.73, SH-CH: 4.23 ± 1.74, control group: 3.91 ± 1.61, $p = 0.605$, $\eta^2 = 0.003$). In self-assessment of children and parent-report, no significant group differences in total score and all subscales of KINDL-R were observed.

# DISCUSSION

This study aimed to evaluate the long-term effects of the *Skipping Hearts* health promotion project, a donation-funded project of the German Heart Foundation. A positive effect

**TABLE 3 |** Descriptive statistics of baseline and follow-up data (SH-B, SH-CH, control group) and intra-group development over time.

| | SH-B | | | | | | SH-CH | | | | | | Control group | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Baseline | | Follow-Up | | *p*-value* | | Baseline | | Follow-Up | | *p*-value* | | Baseline | | Follow-Up | | *p*-value* |
| **Paired *t*-tests** | ***n*** | **Mean (SD)** | **95% CI** | **Mean (SD)** | **95% CI** | | ***n*** | **Mean (SD)** | **95% CI** | **Mean (SD)** | **95% CI** | | ***n*** | **Mean (SD)** | **95% CI** | **Mean (SD)** | **95% CI** | |
| Age (years) | 268 | 9.06 (0.64) | [8.99, 9.14] | 12.4 (0.64) | [12.4, 12.5] | **<0.001** | 140 | 8.89 (0.59) | [8.79, 8.99] | 12.3 (0.58) | [12.2, 12.4] | **<0.001** | 78 | 8.87 (0.46) | [8.77, 8.97] | 12.2 (0.47) | [12.1, 12.3] | **<0.001** |
| Height (cm) | 260 | 135.3 (6.56) | [134.5, 136.0] | 156.5 (7.71) | [155.6, 157.4] | **<0.001** | 140 | 135.3 (7.07) | [134.1, 136.4] | 156.5 (8.98) | [155.0, 158.0] | **<0.001** | 78 | 134.2 (6.55) | [132.7, 135.7] | 155.1 (8.46) | [153.2, 157.0] | **<0.001** |
| Weight (kg) | 260 | 30.5 (6.19) | [29.8, 31.3] | 45.5 (9.16) | [44.4, 46.6] | **<0.001** | 140 | 30.9 (6.04) | [29.9, 32.0] | 45.9 (10.24) | [44.2, 47.7] | **<0.001** | 78 | 30.7 (7.27) | [29.1, 32.3] | 45.6 (11.7) | [43.0, 48.3] | **<0.001** |
| BMI (kg/m$^2$) | 260 | 16.6 (2.26) | [16.3, 16.8] | 18.5 (2.75) | [18.1, 18.8] | **<0.001** | 140 | 16.8 (2.23) | [16.4, 17.2] | 18.6 (3.03) | [18.1, 19.1] | **<0.001** | 78 | 16.9 (2.88) | [16.2, 17.5] | 18.8 (3.46) | [18.0, 19.5] | **<0.001** |
| BMI-SDS | 260 | −0.13 (0.92) | [−0.24, −0.01] | −0.17 (1.04) | [−0.30, −0.04] | 0.209 | 140 | 0.03 (0.92) | [−0.13, 0.18] | −0.09 (1.06) | [−0.26, 0.09] | **0.006** | 78 | −0.03 (1.14) | [−0.29, 0.22] | −0.06 (1.20) | [−0.33, 0.21] | 0.687 |
| Body fat (%) | 258 | 15.4 (3.18) | [15.0, 15.8] | 21.9 (5.13) | [21.2, 22.5] | **<0.001** | 139 | 15.3 (3.16) | [14.8, 15.8] | 21.7 (5.42) | [20.7, 22.6] | **<0.001** | 78 | 14.8 (2.97) | [14.2, 15.5] | 21.3 (5.88) | [19.9, 22.6] | **<0.001** |
| SBP (mmHg) | 246 | 113.7 (10.7) | [112.3, 115.0] | 118.6 (12.4) | [117.0, 120.1] | **<0.001** | 134 | 112.7 (10.7) | [110.9, 114.5] | 119.1 (11.2) | [117.2, 121.0] | **<0.001** | 77 | 113.8 (11.4) | [111.2, 116.4] | 121.1 (12.2) | [118.3, 123.9] | **<0.001** |
| SBP-SDS | 246 | 1.35 (1.27) | [1.19, 1.51] | 1.01 (1.30) | [0.85, 1.18] | **0.001** | 134 | 1.26 (1.29) | [1.04, 1.48] | 1.11 (1.17) | [0.91, 1.31] | 0.196 | 77 | 1.44 (1.25) | [1.15, 1.72] | 1.36 (1.24) | [1.08, 1.64] | 0.662 |
| DBP (mmHg) | 246 | 70.5 (9.00) | [69.3, 71.6] | 74.1 (7.99) | [73.1, 75.1] | **<0.001** | 134 | 69.6 (9.06) | [68.1, 71.2] | 74.6 (7.55) | [73.3, 75.8] | **<0.001** | 77 | 70.6 (9.21) | [68.5, 72.7] | 75.6 (9.76) | [73.4, 77.8] | **<0.001** |
| DBP-SDS | 246 | 1.21 (1.38) | [1.03, 1.38] | 1.26 (1.19) | [1.11, 1.41] | 0.571 | 134 | 1.09 (1.38) | [0.86, 1.33] | 1.34 (1.10) | [1.15, 1.52] | 0.075 | 77 | 1.26 (1.39) | [0.94, 1.57] | 1.51 (1.44) | [1.18, 1.83] | 0.202 |
| Motor performance | 260 | 0.37 (0.74) | [0.28, 0.46] | 0.53 (0.71) | [0.45, 0.62] | **<0.001** | 136 | 0.30 (0.69) | [0.18, 0.42] | 0.46 (0.79) | [0.32, 0.59] | **0.001** | 60 | 0.39 (0.81) | [0.19, 0.60] | 0.57 (0.74) | [0.38, 0.76] | 0.040 |
| Physical activity score (days/week) | 207 | 4.13 (1.77) | [3.89, 4.37] | 4.66 (1.64) | [4.44, 4.89] | **0.001** | 113 | 4.20 (1.87) | [3.85, 4.55] | 4.63 (1.78) | [4.30, 4.96] | 0.050 | 58 | 3.53 (1.82) | [3.06, 4.01] | 4.55 (1.57) | [4.14, 4.97] | **<0.001** |
| SBM (h/day) | 182 | 1.77 (2.00) | [1.48, 2.06] | 3.32 (2.14) | [3.01, 3.64] | **<0.001** | 97 | 1.78 (2.07) | [1.37, 2.20] | 3.54 (2.99) | [2.94, 4.14] | **<0.001** | 56 | 1.73 (1.31) | [1.38, 2.08] | 3.26 (1.88) | [2.75, 3.76] | **<0.001** |
| **Wilcoxon tests** | | **Median** | | **Median** | | | | **Median** | | **Median** | | | | **Median** | | **Median** | | |
| MVPA relative (% of wear time) | 5 | 22.9 | | 7.80 | | 0.043 | 8 | 21.9 | | 8.90 | | **0.012** | 7 | 22.6 | | 7.90 | | 0.018 |
| MVPA absolute (minutes/day) | 5 | 171.0 | | 67.0 | | 0.043 | 8 | 164.5 | | 76.6 | | **0.012** | 7 | 188.6 | | 67.9 | | 0.018 |
| **Wilcoxon tests** | | ***n* (%)** | | ***n* (%)** | | | | ***n* (%)** | | ***n* (%)** | | | | ***n* (%)** | | ***n* (%)** | | |
| Physical fitness | 289 | | | | | **<0.001** | 128 | | | | | **<0.001** | 72 | | | | | **<0.001** |
| Very well | | 103 (43.1) | | 37 (15.5) | | | | 57 (44.5) | | 25 (19.5) | | | | 30 (41.7) | | 13 (18.1) | | |
| Well | | 107 (44.8) | | 130 (54.4) | | | | 50 (39.1) | | 62 (48.4) | | | | 28 (38.9) | | 35 (48.6) | | |
| Medium | | 25 (10.5) | | 66 (27.6) | | | | 20 (15.6) | | 37 (28.9) | | | | 14 (19.4) | | 20 (27.8) | | |
| Not as well | | 2 (0.8) | | 6 (2.5) | | | | 1 (0.8) | | 4 (3.1) | | | | 0 (0.0) | | 4 (5.6) | | |
| Not at all well | | 2 (0.8) | | 0 (0.0) | | | | 0 (0.0) | | 0 (0.0) | | | | 0 (0.0) | | 0 (0.0) | | |
| Not at all well | | | | | | | | | | | | | | | | | | |

*Corrected according to Bonferroni (significant when $p < 0.0167$). Significant results marked in bold types. SH-B, skipping hearts basic; SH-CH, skipping hearts champion; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; SDS, standard deviation score; MVPA, moderate-to-vigorous physical activity; SBM, screen-based media use.*

**TABLE 4 |** Δ (follow-up—baseline) and group/time-interaction effect in anthropometric and cardiovascular parameters, motor performance, physical activity score and screen-based media use.

| ANOVA for repeated measures | SH-B Δ (follow-up—baseline) n | Mean (SD) | 95% CI | SH-CH Δ (follow-up—baseline) n | Mean (SD) | 95% CI | Control group Δ (follow-up—baseline) n | Mean (SD) | 95% CI | p-value time*goup | $\eta^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Age (years) | 268 | 3.37 (0.04) | [3.37, 3.38] | 140 | 3.37 (0.04) | [3.36, 3.37] | 78 | 3.36 (0.07) | [3.35, 3.38] | 0.100 | 0.009 |
| Height (cm) | 260 | 21.2 (3.39) | [20.8, 21.6] | 140 | 21.3 (3.76) | [20.7, 21.9] | 78 | 20.9 (3.60) | [20.1, 21.8] | 0.791 | 0.001 |
| Weight (kg) | 260 | 14.9 (4.71) | [14.4, 15.5] | 140 | 15.0 (5.44) | [14.1, 15.9] | 78 | 15.0 (5.63) | [13.7, 16.2] | 0.990 | <0.001 |
| BMI (kg/m$^2$) | 260 | 1.88 (1.40) | [1.71, 2.05] | 140 | 1.80 (1.59) | [1.54, 2.07] | 78 | 1.88 (1.49) | [1.54, 2.21] | 0.873 | 0.001 |
| BMI-SDS | 260 | −0.04 (0.53) | [−0.11, 0.02] | 140 | −0.11 (0.49) | [−0.20, −0.03] | 78 | −0.03 (0.55) | [−0.15, 0.10] | 0.338 | 0.005 |
| Body fat (%) | 258 | 6.43 (3.24) | [6.03, 6.83] | 139 | 6.37 (3.33) | [5.81, 6.93] | 78 | 6.43 (3.99) | [5.53, 7.33] | 0.986 | <0.001 |
| SBP (mmHg) | 246 | 4.89 (13.5) | [3.20, 6.59] | 134 | 6.41 (12.0) | [4.36, 8.46] | 77 | 7.26 (13.5) | [4.19, 10.3] | 0.299 | 0.005 |
| SBP-SDS | 246 | −0.34 (1.52) | [−0.53, −0.15] | 134 | −0.15 (1.37) | [−0.39, 0.08] | 77 | −0.08 (1.52) | [−0.42, 0.27] | 0.281 | 0.006 |
| DBP (mmHg) | 246 | 3.66 (10.0) | [2.40, 4.92] | 134 | 4.92 (10.3) | [3.15, 6.68] | 77 | 5.05 (11.1) | [2.54, 7.57] | 0.399 | 0.004 |
| DBP-SDS | 246 | 0.06 (1.53) | [−0.14, 0.25] | 134 | 0.24 (1.57) | [−0.02, 0.51] | 77 | 0.25 (1.69) | [−0.14, 0.63] | 0.438 | 0.004 |
| Motor performance | 260 | 0.17 (0.57) | [0.10, 0.24] | 136 | 0.16 (0.54) | [0.07, 0.25] | 60 | 0.17 (0.64) | [0.01, 0.34] | 0.976 | <0.001 |
| Physical activity score (days/week) | 207 | 0.53 (2.20) | [0.23, 0.83] | 113 | 0.43 (2.33) | [0.00, 0.87] | 58 | 1.02 (2.04) | [0.48, 1.55] | 0.243 | 0.008 |
| SBM (h/day) | 182 | 1.55 (2.36) | [1.21, 1.90] | 97 | 1.78 (3.10) | [1.21, 1.90] | 56 | 1.53 (2.12) | [0.96, 2.09] | 0.789 | 0.001 |

*SH-B, skipping hearts basic; SH-CH, skipping hearts champion; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; SDS, standard deviation score; SBM, screen-based media use.*

**TABLE 5 |** Group comparison in 6-min run, MVPA, and HRQoL at long-term assessment.

| One-way ANOVA | SH-B n | Mean (SD) | 95% CI | SH-CH n | Mean (SD) | 95% CI | Control group n | Mean (SD) | 95% CI | p-value | $\eta^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6-min run (meter) | 262 | 1,076.6 (120.1) | [1,062.0, 1,091.2] | 137 | 1,075.7 (122.5) | [1,055.0, 1,096.4] | 78 | 1,043.8 (124.8) | [1,015.7, 1,072.0] | 0.098 | 0.010 |
| MVPA relative (% of wear time) | 35 | 9.07 (3.70) | [7.80, 10.34] | 27 | 9.99 (3.92) | [8.44, 11.5] | 28 | 10.2 (4.03) | [8.58, 11.7] | 0.488 | 0.016 |
| MVPA absolute (minutes/day) | 35 | 74.1 (29.9) | [63.8, 84.3] | 27 | 80.8 (29.4) | [69.1, 92.4] | 28 | 81.3 (31.6) | [69.0, 93.6] | 0.568 | 0.013 |
| KINDL-R self-report | | | | | | | | | | | |
| Total | 261 | 74.0 (11.1) | [72.6, 75.3] | 131 | 74.4 (12.2) | [72.3, 76.5] | 63 | 73.7 (12.1) | [70.6, 76.7] | 0.911 | <0.001 |
| Physical well-being | 261 | 75.7 (16.9) | [73.6, 77.2] | 130 | 75.4 (18.8) | [72.1, 78.6] | 63 | 77.4 (17.1) | [73.1, 81.7] | 0.739 | 0.001 |
| Emotional well-being | 259 | 82.0 (14.6) | [80.1, 83.7] | 129 | 83.1 (14.9) | [80.6, 85.7] | 62 | 82.3 (12.8) | [79.0, 85.5] | 0.725 | 0.001 |
| Self-esteem | 259 | 55.7 (20.5) | [53.2, 58.2] | 128 | 56.2 (22.8) | [52.2, 60.2] | 61 | 56.0 (20.4) | [50.8, 61.2] | 0.971 | <0.001 |
| Family | 261 | 85.7 (16.3) | [83.7, 87.7] | 131 | 84.8 (16.1) | [82.0, 87.6] | 63 | 83.1 (17.3) | [78.8, 87.5] | 0.534 | 0.003 |
| Friends | 258 | 78.0 (14.7) | [76.2, 79.8] | 131 | 78.6 (15.9) | [75.8, 81.3] | 63 | 76.1 (16.8) | [71.8, 80.3] | 0.555 | 0.003 |
| School | 261 | 66.7 (17.9) | [64.5, 68.9] | 131 | 68.0 (19.3) | [64.7, 71.4] | 63 | 67.0 (20.2) | [62.0, 72.1] | 0.807 | 0.001 |
| KINDL-R parent-report | | | | | | | | | | | |
| Total | 177 | 78.6 (8.7) | [77.3, 79.9] | 88 | 76.7 (10.2) | [74.5, 78.8] | 40 | 75.4 (11.2) | [71.8, 79.0] | 0.082 | 0.016 |
| Physical well-being | 177 | 81.3 (14.9) | [79.1, 83.6] | 88 | 77.3 (17.9) | [73.5, 81.1] | 40 | 75.9 (16.2) | [73.5, 81.1] | 0.050 | 0.020 |
| Emotional well-being | 177 | 84.0 (11.1) | [82.3, 85.6] | 87 | 82.1 (12.7) | [79.4, 84.8] | 40 | 81.4 (14.1) | [76.9, 85.9] | 0.303 | 0.008 |
| Self-esteem | 177 | 70.9 (13.8) | [68.9, 73.0] | 88 | 69.5 (13.5) | [66.7, 72.4] | 40 | 67.2 (14.8) | [62.5, 71.9] | 0.288 | 0.008 |
| Family | 177 | 79.5 (15.0) | [77.3, 81.7] | 89 | 79.4 (14.2) | [76.4, 82.4] | 40 | 79.2 (12.0) | [75.4, 83.1] | 0.991 | <0.001 |
| Friends | 177 | 77.6 (12.7) | [75.7, 79.5] | 88 | 76.5 (13.9) | [73.5, 79.4] | 40 | 73.4 (15.3) | [68.6, 78.3] | 0.210 | 0.010 |
| School | 175 | 78.3 (14.3) | [76.2, 80.5] | 87 | 75.3 (17.2) | [71.6, 78.9] | 40 | 75.2 (14.1) | [70.7, 79.7] | 0.219 | 0.010 |

*SH-B, skipping hearts basic; SH-CH, skipping hearts champion; MVPA, moderate-to-vigorous physical activity.*

of the *Skipping Hearts* Basic-Workshop and Champion-Program regarding the long-term improvement of health and health behavior could not be determined, but a tendency towards a less pronounced decrease of physical activity was observed.

While Postler et al. (28) found significant short-term improvements in motor performance and body fat (SH-B and SH-CH compared to controls) as well as activity level (SH-CH compared to controls), the long-term evaluation could not confirm the positive short-term results. SH-B and SH-CH did not show diverging development in anthropometrics, cardiovascular parameters, motor performance, SBM, and HRQoL compared to the control group between baseline and follow-up. Despite the tendency for *Skipping Hearts* to prevent an age-related decrease of physical activity, this result might be influenced by the high dropout rate of 44.9% in accelerometer measurement.

A decline in BMI-SDS and SBP-SDS was found in all groups. This indicates an age- and sex-independent improvement in these parameters. Furthermore, children in all groups improved their motor performance and physical activity score but the results of objective accelerometer data do not confirm this improvement. The decline within the 3.5 years from baseline to follow-up is in line with the literature: Physical activity decreases between childhood and adolescence (46–49). Even though a direct effect of *Skipping Hearts* was not found, participation in a study-related fitness test can be a motivational factor for children to increase their health status and fitness level. However, comparison of baseline data between children willing to participate in the long-term assessment and those who refused revealed that the healthier children participated again at follow-up. This indicates that the follow-up examination was not attended by those children who were the main target group of the project. Therefore, the current study population was more likely to stay in their initial healthy state.

A review of the relevant literature reveals that there are no consistent findings regarding the long-term effectiveness of prevention and health promotion projects at school. After a 1-year school-based physical activity intervention and a follow-up of 3 years, Meyer et al. (50) found a long-term increase in aerobic fitness compared to controls, but no sustainable effects on physical activity, cardiovascular parameter, and quality of life. Kobel et al. (22) also reported no significant increase in physical activity but a significant decrease in SBM in girls in a 1-year follow-up of the cluster-randomized longitudinal study "Join the Healthy Boat." Anderson et al. (51) conducted a school-based cluster-randomized controlled trial including lessons-plans, teaching materials, parental-child homework activities, training for teachers, and health promotion strategies for parents; but they observed no effect on MVPA and sedentary behavior. In contrast, Lahti et al. (52) reported higher levels of physical activity compared to controls 4 years after ending a 7-year intervention at school. Furthermore, Vander Ploeg et al. (53) observed a greater increase in activity on school days and on weekends in the intervention group 2 years after the implementation of a comprehensive school health program.

In a Cochrane Review of 2013, Dobbins et al. (17) suggest that school-based interventions only have limited effects regarding BMI, blood pressure, pulse rate, and physical activity level. This is interesting insofar as only one out of 44 had a follow-up measurement at 4 years after intervention and the majority of studies had the point of measurement directly post-intervention. Because the findings of every new intervention study are consistent with those from other studies, the probability of improving the tested parameters in a short-term intervention study is high. However, statements regarding the effectiveness of an intervention should be treated with caution because they do not reveal anything about a long-term effect. A long-lasting increase in activity levels and motor performance should be the main goal of every project related to prevention and health promotion research. Therefore, it is not surprising that *Skipping Hearts* is not able to sustainably enable children to do more physical activity. Indeed, the short-term effectiveness of *Skipping Hearts*—both the Basic-Workshop and the Champion-Program—has to be viewed as an unexpected success.

*Skipping Hearts* is not a controlled and scientifically supported intervention, but a donation-funded project of a foundation. The Champion-Program of *Skipping Hearts* is planned as a continuous implementation of 10 45-min prepared lessons. The responsibility of implementation lies within the school administration because there is no supervisor. To a certain extent, the implementation of the Champion-Program is therefore entirely up to the teachers themselves. It may well be that this individual responsibility for the implementation process is the most crucial point for its effectiveness. It can be assumed that teachers implemented the lessons during and not in addition to sports education. On measurement days at school, teachers gave this verbal feedback and mentioned that they did not meet the given guidelines—the large majority did not conduct all 10 lessons and reduced the physical activity duration. To get a detailed insight into the assessment of the project and its conception and implementation into the daily routine of schools, qualitative interviews were conducted with the teachers and headmasters of 64 participating schools. Furthermore, a nationwide survey of all teachers and headmasters ($n = 1474$) who participated in *Skipping Hearts* since its beginning in 2006 was performed. These data are currently being analyzed and will be published elsewhere.

To achieve a long-term effect of the Champion-Program, it may be therefore necessary to instruct trained supervisors at school who serve as contact persons for all teachers. The fact that this concept can be successful is shown by Vander Ploeg et al. (53) in the evaluation of a comprehensive school health approach. A key component of the intervention was the placement of a full-time school health facilitator at each school, who was dedicated to promoting healthy living. Furthermore, Lahti et al. (52) postulate that education for a sustainable active way of living is possible when interventions are implemented in the daily routine of schools. It therefore may be necessary to strive for sustainable implementation of rope skipping in the daily routine of schools. Offering lessons in shorter bouts must not necessarily harm the effectiveness of the Champion-Program. In their systematic review, Barr-Anderson et al. (54) highlight that short, 10–15-min, bouts daily can increase physical activity—if these bouts are implemented in the daily routine of schools.

Taken these findings together, several points impair the proposed project goal, specifically the sustainable motivation of children to be physically active all their lives. Therefore, we recommend considering the following suggestions in the future program planning of *Skipping Hearts*: The Champion-Program should be conducted according to the guidelines of the German Heart Foundation and should be implemented in the daily routine of schools after the end of the project to obtain sustained rope skipping. The project should also force the transfer of knowledge about health behavior, and all involved teachers should undergo specific training. Furthermore, a supervisor should be provided for all schools, who serves as a contact person if problems occur while implementing the project. Teachers should directly motivate pupils to practice rope skipping as part of their school routine (e.g., during their school break) and should integrate parents further into the project (e.g., practicing together at home). Nevertheless, the easy and uncomplicated character of the *Skipping Hearts* project should remain unchanged. With rope skipping, the project offers a physical activity that can be performed in children's everyday life without high costs.

The results are limited due to the non-randomized design of the study, specified by Postler et al. (28). *Skipping Hearts* is not a scientifically supported and controlled intervention but a school project that was carried out under everyday conditions. In addition, the long-term evaluation of *Skipping Hearts* was added subsequently to the short-term evaluation. Therefore, the recruitment of the "original" sample turned out to be very time-consuming and difficult. Since the previous evaluation was not designed for the long-term, there were no contact details for the participants. Children could no longer be reached via the former elementary schools, as they had meanwhile moved on to a secondary school. Therefore, intensive research was carried out in all secondary schools in the catchment area of the former primary schools, and a variety of measures were undertaken to provide information about the continuation of this short-term evaluation. Nevertheless, the missing data could have biased the results. Given that the follow-up examination was voluntary and took place in the afternoon, compounded with the problem that many children could not even be invited due to missing personal data, the participation rate of 43.3% is quite successful. Furthermore, baseline differences between children with and without follow-up of the anthropometric parameter and motor skills could have led to biased results. It should be noted that children answered the questionnaire on their own without the control of teachers or parents. Restrictions regarding the project itself are described in Postler et al. (28). Although good reliability is reported for near-infrared technology in children and adolescents, body fat measured with near-infrared technology is overestimated compared to densitometry by hydrostatic weighing (33). However, the same measurement methodology was applied at all measurement points, as the NIR is suitable for longitudinal studies. The socio-economic status of the parents, the migration background, and the nutritional behavior of the children were not sufficiently investigated in this study. These confounding factors could influence both the collected parameters and the effectiveness of *Skipping Hearts*, which we did not record within this study.

In summary, the observed short-term effects of *Skipping Hearts* could not be confirmed after 3 years. We did not observe long-term effects on children's cardiovascular health, motor skills, physical activity, or quality of life. Nevertheless, *Skipping Hearts* can certainly be used as an initial impulse, but for a long-term effect, the project needs to be revised and schools should be more proactive regarding the promotion of students' health. In addition, every program promoting physical activity and motor skills in youth should strive for the long-term, and intervention studies should test a sustainable effect.

## DATA AVAILABILITY STATEMENT

The datasets analyzed within the study are available from the corresponding author on reasonable request.

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by German Sport University Cologne (project number 113/2014). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

## AUTHOR CONTRIBUTIONS

TP, CG, NF, RO-F, and TS designed the study. LB, TP, and TS performed the data collection. BH performed the data analysis. LB and TP assisted in data analysis and drafted the manuscript. All authors reviewed, edited, and approved the manuscript.

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# Association Between Physical Fitness and Anxiety in Children: A Moderated Mediation Model of Agility and Resilience

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**Background:** Anxiety is one of the most prevalent mental health problems in children. Although physical fitness as a predictor of mental health, the mechanisms underlying any association between physical fitness and anxiety in children have been understudied. Thus, the aim of the present study was to determine whether an association exists between physical fitness and anxiety and to explore the roles of agility and resilience in such an association.

**Methods:** This cross-sectional study investigated 269 children aged 7 to 12 years from three public primary schools in Shanghai (China). Physical fitness and agility were objectively measured, and resilience and anxiety were assessed using self-reported questionnaires. The moderated mediation model was examined using the SPSS PROCESS macro, in which the moderator variable was agility, and the mediator variable was resilience.

**Results:** Physical fitness was inversely associated with anxiety. Resilience partially and indirectly mediated this association, and agility moderated the association between physical fitness and resilience. Physical fitness had a greater impact on resilience in children with higher agility levels.

**Conclusions:** Agility moderated the mediation of resilience on the indirect, inverse association between physical fitness and anxiety; thus, incorporating methods to develop agility and resilience may lead to better outcomes for physical fitness programs designed to prevent or alleviate anxiety in children.

**Keywords: children, physical fitness, agility, resilience, anxiety, moderated mediation**

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## INTRODUCTION

Anxiety is one of the most prevalent mental health problems among children (1, 2), with an estimated prevalence up to 20% (3, 4). Anxiety in children has a negative impact on their school performance (5), social functioning (6), and quality of life (7). In addition, anxiety symptoms during childhood tend to be chronic and may lead to anxiety disorders and other serious psychopathological consequences that persist into later childhood and adulthood (1, 8, 9). Indeed, approximately half the anxiety disorders diagnosed in adults have an onset before 11 years of age (10). In addition to the potential long-term effects on individuals' growth and development, children's anxiety disorders place a burden on society via direct and indirect costs (11); public expenses are more than 20 times as high for a child with vs. without clinically relevant anxiety (12). Hence, to mitigate these negative consequences of childhood anxiety, identifying the factors that affect anxiety and their underpinning mechanisms may contribute to the development of effective prevention and treatment interventions to benefit individuals as well as society.

Previous research has shown various protective factors for anxiety, such as self-efficacy (13), coping style (14), and social support (15). A positive role for physical activity in the prevention of anxiety has also been shown in several types of recent studies (16–18). Physical fitness can be defined as the capacity to perform physical activity (19), and physical fitness is more predictive of health outcomes than is physical activity in children (20). Thus, given the established health benefits of physical activity broadly, increasing evidence indicates a need to explore physical fitness. Physical fitness is considered one of the most important health markers and predictors of future risk of mental health issues (21, 22). In addition, physical fitness also serves as a buffer against stress and stress-related disorders (23). Anxiety is a stress-related mental health problem, but the association between physical fitness and anxiety is still unclear (24, 25). Therefore, investigating the mechanisms underlying the role physical fitness plays in childhood anxiety is critically needed.

To date, it is not well-understood which factors are crucial for the maintenance of physical and mental health. Resilience is a relatively new construct that may be an important factor (26). Resilience is the ability to successfully adapt to stress, trauma, or adversity, enabling individuals to avoid stress-induced mental disorders, such as depression, posttraumatic stress disorder, and anxiety (27, 28). In this regard, exploring how to build resilience may be useful in assisting children affected by anxiety. On the other hand, physical fitness may confer resilience owing to its stress-buffering effects (23). Thus, from a stress perspective, physical fitness, and anxiety may be linked through resilience.

In addition, agility, as the main component of physical fitness, is a combination of physical qualities and cognitive components (22, 29). However, unlike studies examining other main components (e.g., cardiorespiratory fitness, muscular fitness), few studies have focused on the contribution of agility to mental health (19). Within the limited literature, agility was summarized as a major input that enables resilience (30). Research has also reported that regular exposure to diverse agility-type movement challenges may facilitate the movement efficiency of athletes and their resilience to numerous dimensions of movement stress (31). Thus, whether the benefits of physical fitness on childhood anxiety may be enhanced by resilience and the role that agility plays in these relationships warrant further attention.

Therefore, the present study examined the associations among physical fitness, agility, resilience, and anxiety in children. On the basis of previous research results, we proposed the following three hypotheses: (1) physical fitness is inversely associated with anxiety in children; (2) resilience mediates the association between physical fitness and anxiety; and (3) agility moderates the indirect effect of physical fitness on anxiety through resilience, with the association becoming stronger when agility is high and weaker when agility is low. Based on these hypotheses, we proposed a theoretical model to be tested (**Figure 1**). In the proposed model, physical fitness plays a role in enhancing resilience and ameliorating anxiety, and the influence of physical fitness on anxiety is mediated by resilience, with the strength of this mediation conditional depending on the level of agility.

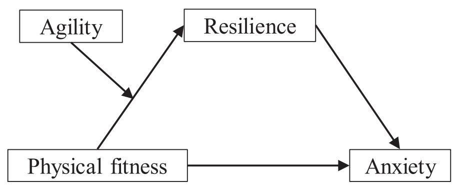


**FIGURE 1 |** The proposed moderated mediation model to be tested.

## MATERIALS AND METHODS

### Participants

The participants were selected from three primary schools in Shanghai (China). A sampling of schools was stratified according to physical fitness with three levels, with the first quartile being the lowest, followed by second and third quartiles, and the highest being the fourth quartile, as described and used in previous studies (32, 33). The current three schools were chosen for their representativeness of each level, considering the accessibility to our research team and the availability of the teachers to assist with logistics. Potential participants who had not received a diagnosis of any disease that made it impossible to complete the test and who understood each item in the questionnaires were included. Participants whose physical fitness test results exceeded the logical limits or whose questionnaires were considered invalid were excluded. After the aim of the study was explained, participants completed the objective measurements and self-reported questionnaires under the supervision of trained volunteers. Participants' names were substituted with codes in the data collection to protect privacy, and they were given an inexpensive gift as a token of appreciation. The results obtained from the tests were offered to the school administrators to provide suggestions for participants' physical activity and mental health.

Valid variables were obtained from 269 participants. The participants were in school grades 2 through 5 and comprised 126 boys and 143 girls, with ages ranging from 7–12 years (mean age = 9.75 years; SD = 1.17 years). The number (percentage) of participants by school grade was 72 (26.8%) in second grade, 67 (24.9%) in third grade, 66 (24.5%) in fourth grade, and 64 (23.8%) in fifth grade.

The study was conducted in accordance with the recommendations of the World Medical Association's

**TABLE 1** | Fitness components and weights of CNSPFS scores in school-age children.

| Second grade | | Third and fourth grades | | Fifth grade | |
|---|---|---|---|---|---|
| **Fitness component** | **Weight (%)** | **Fitness component** | **Weight (%)** | **Fitness component** | **Weight (%)** |
| BMI | 15 | BMI | 15 | BMI | 15 |
| Vital capacity of lung | 15 | Vital capacity of lung | 15 | Vital capacity of lung | 15 |
| 50 m sprint | 20 | 50 m sprint | 20 | 50 m sprint | 20 |
| Sit and reach | 30 | Sit and reach | 20 | Sit and reach | 10 |
| Timed rope-skipping | 20 | Timed rope-skipping | 20 | Timed rope-skipping | 10 |
| | | Timed sit-ups | 10 | Timed sit-ups | 20 |
| | | | | 50 m × 8 shuttle run | 10 |

*BMI, Body Mass Index; CNSPFS, Chinese National Student Physical Fitness Standard.*

Declaration of Helsinki as revised in 1989 and was approved by the Shanghai University of Sport Ethics Committee (Shanghai, China). Written informed consent was obtained from the guardians of all participants.

## Measures

### Physical Fitness

To minimize variability, all physical fitness tests were conducted by trained volunteers from the Shanghai Research Center for Physical Fitness and Health of Children and Adolescents. The volunteers all majored in kinesiology and were already familiar with the testing methods.

Physical fitness was measured using the Chinese National Student Physical Fitness Standard (CNSPFS), a standardized test commonly used in Chinese schools (34). As indicated in the CNSPFS guidelines, the results of different fitness components were scored according to sex and school grade level. The total physical fitness score was composed of the product sum of the scores and weights of each component. The weights of the CNSPFS scores for each fitness component stratified by school grade are given in **Table 1**.

### Agility

Agility was assessed using the side-step test, which is an effective and commonly used measure (35). For this test, the participant stood over a central line. At the start of the test, the participant moved laterally, side-stepping toward a far-right line (1 m from the central line) until the right foot crossed the far-right line. Once the right foot crossed that line, the participant changed directions and moved laterally, side-stepping to the left until the left foot crossed the far-left line (1 m from the central line). After reaching the far-left line, the participant moved laterally to return to the central line. This motion was repeated for 20 s, and one point was given for each line passed. The test was conducted twice, and the highest side-step score was recorded.

### Resilience

Resilience was obtained using the Resilience Scale for Chinese Adolescents (RSCA), which has shown excellent psychometric properties and has been widely used in evaluating the resilience of Chinese children (36). It includes 27 items that have been classified into five factors: target concentration, emotional control, positive thinking, family support, and interpersonal assistance. Participants were asked to rate themselves on questions using a 5-point Likert scale ranging from a score of 1, indicating "not true at all," to 5, indicating "true nearly all the time." The total score for the RSCA ranged from 27 to 135, with a higher score indicating a higher level of resilience. Cronbach's alpha for this test in the present study was 0.74.

### Anxiety

Anxiety was defined using the Chinese version of the Multidimensional Anxiety Scale for Children (MASC), a 39-item self-report scale for assessing children's anxiety (37). The items clustered into the following four scales: physical symptoms, harm avoidance, social anxiety, and separation anxiety. Response options ranged from 0, indicating "never true," to 3, indicating "often true." The total score (range, 0–117) was generated by adding the scores of all items; thus, a higher score reflected a greater degree of anxiety. Cronbach's alpha for this scale in this study was 0.89.

### Statistical Analysis

The data were analyzed using SPSS, version 22.0, and the PROCESS macro program for SPSS (38). Both graphical (normal probability plots) and statistical (Kolmogorov–Smirnov test) methods were used to examine the nature of the variables, and all were found to fit a normal distribution. Thus, parametric statistics were used. Harman's single–factor test was conducted, and the results indicated that no serious method bias existed in the present study.

We conducted descriptive statistics for the main study variables (reported as means ± standard deviations) and Pearson correlation for bivariate associations (reported as values of $r$). We then used the PROCESS macro to perform a regression-based path analysis, which is similar to structural equation modeling but takes into consideration irregular sampling distributions (39). As noted by Edwards and Lambert (40), the distribution of the indirect effect can be non-normal even if the constituent variables are normal. Given this possibility, all regression coefficients were tested using the bias-corrected percentile Bootstrap method (41, 42). We tested the theoretical hypothesis model, controlled for age and sex, by estimating the 95% confidence intervals (CIs) for the mediation and

**TABLE 2 |** Descriptive statistics and correlations between variables.

| Variable | Mean ± SD | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| (1). Physical fitness | 81.50 ± 9.80 | – | | | |
| (2). Agility | 37.18 ± 9.03 | 0.408*** | – | | |
| (3). Resilience | 93.10 ± 13.77 | 0.248*** | 0.267*** | – | |
| (4). Anxiety | 43.33 ± 19.18 | −0.244*** | −0.154* | −0.247*** | – |

*SD, standard deviation; *p < 0.05, ***p < 0.001.*

**TABLE 3 |** Mediation modeling results assessing the effect of physical fitness on anxiety.

| Effect | Path | β | SE | *t* | LLCI | ULCI |
|---|---|---|---|---|---|---|
| Total effect | Physical fitness–anxiety | −0.256 | 0.060 | −4.261*** | −0.374 | −0.137 |
| Direct effect | Physical fitness–resilience | 0.249 | 0.060 | 4.139*** | 0.131 | 0.367 |
| | Resilience–anxiety | −0.190 | 0.060 | −3.145** | −0.308 | −0.071 |
| | Physical fitness–anxiety | −0.208 | 0.061 | −3.423** | −0.328 | −0.089 |
| Indirect effect | Physical fitness–resilience–anxiety | −0.047 | 0.019 | - | −0.088 | −0.013 |

*β, standardized coefficients; SE, standard error; LLCI and ULCI, lower level and upper level of the bias-corrected 95% bootstrap confidence interval; **p < 0.01, ***p < 0.001.*

moderation effects, with 5,000 resampled samples. When a 95% CI did not include 0, the result was considered statistically significant. We selected the Model 4 in PROCESS to examine the simple mediation effect of resilience on the association between physical fitness and anxiety. We then incorporated the proposed moderator variable (agility) into the model by conducting moderated mediation (also known as a conditional indirect effect) analysis using the Model 7 in PROCESS to determine whether the indirect path was conditionally moderated by the "strength" or value of agility. This model uses ordinary least squares regression to assess the conditional indirect effect and tests the effect with bootstrap CIs for different values of the moderating variable (agility) to determine whether the indirect effect varies. Before formal data analysis, all variables were standardized. Values of $p < 0.05$ were considered statistically significant.

## RESULTS

Descriptive statistics and correlations of the study variables are shown in **Table 2**. We found that physical fitness, agility, and resilience were inversely correlated with anxiety; physical fitness was directly correlated with agility and resilience; and agility was directly correlated with resilience.

As shown in **Table 3**, the results of simple mediation model testing using Model 4 indicated that physical fitness was directly associated with resilience ($\beta = 0.249$, $t = 4.139$, $p < 0.001$). Resilience was inversely associated with anxiety ($\beta = -0.190$, $t = -3.145$, $p < 0.01$). The association between physical fitness and anxiety was also significant ($\beta = -0.208$, $t = -3.423$, $p < 0.01$). We also found a significant indirect effect of physical fitness on anxiety via resilience: the bootstrapping results indicated an indirect effect [$\beta = -0.047$; 95% CI: (−0.088, −0.013)]. The indirect effect accounted for 18.4% of the total effect, suggesting that resilience played a partial mediating role in the association between physical fitness and anxiety. These findings supported our first and second study hypotheses.

Moderated mediation analysis using Model 7 was conducted to assess whether anxiety was indirectly affected by physical fitness via mediation through resilience and whether this effect was conditionally moderated by agility. We hypothesized that children with higher agility scores would show a stronger association between physical fitness and resilience compared with those with lower agility scores. **Table 4** shows the results of the moderated mediation model test. The effect of the interaction between physical fitness and agility on resilience was statistically significant ($\beta = 0.167$, $t = 2.597$, $p < 0.05$). **Figure 2** illustrates the interaction at high (plus 1 SD) and low (minus 1 SD) levels of physical fitness and agility. The plots indicate the interaction between physical fitness and agility on resilience and suggested that for children with higher agility levels, there was a stronger positive association between physical fitness and resilience compared with children having lower agility levels.

The conditional indirect effect of physical fitness on anxiety through resilience at various values of agility was analyzed when the agility score was the sample mean and also at plus or minus 1 SD. The results revealed that the conditional indirect effect was significant at the mean and at a high level (plus 1 SD) of the moderator (agility), but not at a low level (minus 1 SD), and the bootstrap 95% CIs supported these results (see **Table 5**). In addition, the moderated mediation index was also statistically significant. These results supported our third study hypothesis because the association between physical fitness and the outcome variables became more evident as the moderator value increased.

## DISCUSSION

In the present study, we used a moderated mediation model analysis to assist in understanding the mechanisms underlying any association between physical fitness and anxiety in children. Our results supported our three study hypotheses, namely, that

**TABLE 4 |** Moderated mediation modeling results assessing the effect of physical fitness on anxiety.

| Outcome variable | Factor | β | SE | *t* | LLCI | ULCI | $R^2$ | *F* |
|---|---|---|---|---|---|---|---|---|
| Resilience | Physical fitness | 0.222 | 0.067 | 3.312** | 0.090 | 0.353 | 0.119 | 7.129*** |
| | Agility | 0.144 | 0.068 | 2.119* | 0.010 | 0.278 | | |
| | Physical fitness × agility | 0.167 | 0.064 | 2.597* | 0.040 | 0.293 | | |
| | Age | 0.045 | 0.052 | 0.859 | −0.058 | 0.147 | | |
| | Sex | −0.052 | 0.118 | −0.444 | −0.283 | 0.179 | | |
| Anxiety | Physical fitness | −0.208 | 0.061 | −3.423** | −0.328 | −0.089 | 0.109 | 8.061*** |
| | Resilience | −0.190 | 0.060 | −3.145** | −0.308 | −0.071 | | |
| | Age | −0.052 | 0.050 | −1.031 | −0.150 | 0.047 | | |
| | Sex | 0.187 | 0.118 | 1.586 | −0.045 | 0.419 | | |

*β, standardized coefficients; SE, standard error; LLCI and ULCI, lower level and upper level of the bias-corrected 95% bootstrap confidence interval; *p < 0.05, **p < 0.01, ***p < 0.001.*

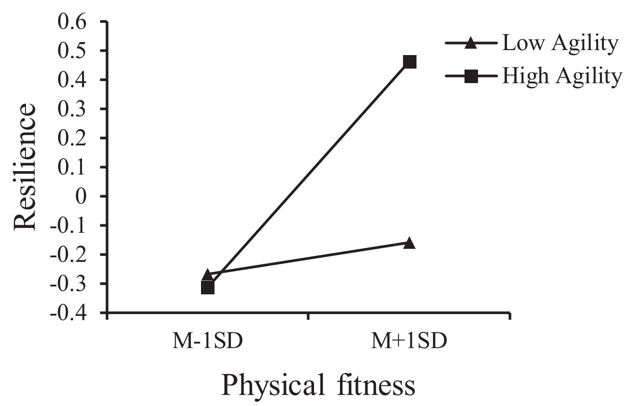


**FIGURE 2 |** Agility moderated the effect of physical fitness on resilience.

**TABLE 5 |** Moderated mediation effect of physical fitness on anxiety at specific conditional values of agility.

| | Specific conditional values of agility | | | |
|---|---|---|---|---|
| | β | SE | LLCI | ULCI |
| −1 SD | −0.010 | 0.015 | −0.046 | 0.017 |
| Mean | −0.042 | 0.017 | −0.077 | −0.010 |
| +1 SD | −0.074 | 0.030 | −0.134 | −0.017 |
| | **Index of moderated mediation** | | | |
| | **Index** | **SE** | **LLCI** | **ULCI** |
| Agility | −0.032 | 0.016 | −0.066 | −0.003 |

*β, standardized coefficients; SD, standard deviation; SE, standard error; LLCI and ULCI, lower level and upper level of the bias-corrected 95% bootstrap confidence interval.*

(1) higher physical fitness levels were associated with lower anxiety levels in children, (2) resilience mediated physical fitness and anxiety, and (3) agility moderated the mediation of resilience on the association, which was stronger in children with higher levels of agility.

Our results suggested that higher levels of physical fitness were associated with lower anxiety levels in children. A plausible explanation for this finding is that individuals who display higher levels of physical fitness tend to have more positive perceptions of anxiety symptoms and thus feel less anxious (25). This supposition is supported by several studies that have shown that improvements in physical fitness are associated with reductions in levels of anxiety (43–45). However, Rodriguez-Ayllon et al. (19) found no relationship between physical fitness components and anxiety indicators. In addition to the demographic characteristics of the participants, these discrepant results may be because those previous studies focused on specific components of physical fitness (46), but physical fitness components relate in different ways to the various aspects of mental health (19). Our study results were based on the total physical fitness scores of children obtained by CNSPFS. This comprehensive outcome reflects the basic physical fitness of children and is an important basis for judging the overall level of physical fitness in children. Further analysis of physical fitness as a protective factor may provide a new approach for the prevention or intervention of childhood anxiety. Moreover, the fitness components, standards for evaluation, and score weights vary in the CNSPFS to adjust for the growth and development of children. Thus, incorporating interventions to reduce the level of anxiety through physical fitness programs that are appropriate at each age in children may lead to better outcomes.

Our mediation model revealed that resilience mediated the association between physical fitness and anxiety, indicating that establishing good physical fitness was conducive to resilience in children, which in turn ameliorates their anxiety. Physical fitness appears to confer resilience by blunting or optimizing neuroendocrine and physiological responses (e.g., the hypothalamic-pituitary-adrenal axis, the sympathetic nervous system) to physical and psychosocial stressors (23). In line with previous studies (47–49), our result is meaningful in that it supports physical fitness being an effective manner of building resilience in children. On the other hand, resilience can also indirectly reduce the negative effects of stress on anxiety through its mediation effect (50, 51). As a dynamic process, resilience is construed as an active adaptation mechanism that may help alleviate anxiety (27), which was observed in our study. In other words, resilience accounting for an important part of the variations in anxiety symptoms suggests that interventions should target ways to enhance resilience (50).

We speculate that a biological mechanism that might provide an explanation for our findings is that physical fitness may promote resilience by minimizing inflammation. The benefits of physical fitness may, in part, be attributed to anti-inflammatory effects via changes in body composition and skeletal muscle (23). On the other hand, Interleukin-8 as an inflammatory marker, has been suggested to be involved in the biological mechanisms mediating resilience to anxiety (52). Overall, resilience may serve as a "bridge" linking physical fitness and anxiety; thus, it would be insufficient to attempt to reduce anxiety in children by promoting physical fitness alone because resilience also plays an important role.

Our moderated mediation model offered a more detailed picture of the mechanisms that associated physical fitness with anxiety, providing a basis for improving anxiety in children using physical fitness via full consideration of the characteristics of agility. However, in research investigating the relationship between physical fitness and mental health, to the best of our knowledge, there is no in-depth analysis examining the importance of agility. Therefore, in our study, we used agility as an independent moderator to assess its influence. Interestingly, we found that physical fitness did not have a significant effect on resilience when the level of agility was low, but the positive effect of physical fitness occurred with the improvement of agility. More importantly, these results were confirmed in our physical fitness–anxiety model. These findings support our hypothesis that in relation to mental health, agility plays a critical role in the effects of physical fitness.

The self-efficacy based model of resilience suggests that executive function provides much of the capacity for resilience in individuals, with executive function enhancing self-efficacy to enable successful adjustment (53, 54). Additionally, executive function yields a greater propensity for resilience in children (55, 56). On the other hand, recent evidence suggests that agility is a key component for executive function, and children with higher levels of agility have shown better performance in executive function (46, 57). Taken together, these findings indicate that executive function combines agility with resilience—which to some extent reflects the adaptation and coping ability of children (56)—to help explain the pathway between agility and resilience and provide a new perspective for further understanding how physical fitness affects resilience. More interestingly, the side-step test used in the present study is also considered useful for improving cardiorespiratory and muscular fitness (35). These main fitness components may all contribute to the promotion of resilience (19, 23). Therefore, the potential connections appear to demonstrate the value of agility, which should be taken into account for physical fitness to benefit resilience. To gain greater insight into the moderation effect of agility on the association between physical fitness and anxiety, both theoretical and empirical research studies are needed in the future.

Our study has some limitations that should be considered when interpreting our results. First, this study used a cross-sectional design, which prevented us from making any cause-and-effect conclusions. Therefore, longitudinal studies should be designed to validate the findings. Second, our study relied in part on self-reported data, which may affect the outcomes. Future studies should measure mental health objectively, such as through neuropsychological tests. Third, our findings were obtained from children in public primary schools, and whether the results are applicable to other populations will require further testing.

## CONCLUSIONS

The current study offers some insight into the mechanisms underlying the association between physical fitness and anxiety. Physical fitness is a valuable factor, providing some protection against anxiety for children. This protective effect is partially mediated through the resilience, which is moderated by agility. The moderation effect may enable children with higher agility levels to show better outcomes in the association between physical fitness and anxiety. The analysis conducted in the present study using a moderated mediation model analysis expands on the current knowledge by providing evidence to support potential mechanisms. The results of this analysis suggest that incorporating methods to develop agility and to improve resilience may lead to better outcomes when designing physical fitness programs to prevent or alleviate anxiety in children.

## DATA AVAILABILITY STATEMENT

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

## ETHICS STATEMENT

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

## AUTHOR CONTRIBUTIONS

YL, FM, and CZ contributed to the conception and design of the study. XX and FM organized the database. YL and XX performed the statistical analysis and wrote the first draft of the manuscript. CZ revised the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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# Physical Activity and Sedentary Behavior of Children in Afterschool Programs: An Accelerometer-Based Analysis in Full-Day and Half-Day Elementary Schools in Germany

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**Background:** Regular physical activity (PA) and reduced sedentary behavior (SB) are positively related to children's health and considered as pillars of a healthy lifestyle. Full-day schools with their afterschool programs (ASPs) have an impact on children's daily PA and SB. Studies investigating PA and SB in ASPs, which compare PA and SB between the organizational forms full-day and half-day schools, are rare. The aim of this study is to describe elementary school children's PA and SB during ASPs and to compare the results to other time periods of the day, e.g., teaching hours and leisure time. Additionally, PA and SB of children in full-day and half-day schools are compared. Further, relevant factors influencing the achievement of the World Health Organization's (WHO's) PA guidelines for children, e.g., time spent in ASPs, are investigated.

**Methods:** PA and SB of 332 German students ($n = 198$ full-day school children; $n = 134$ half-day school children) from 11 different elementary schools were measured via accelerometry for 5 consecutive days within one school week in 2017. PA and SB during ASPs and other times of the day were analyzed via one-way and factorial ANOVA, correlation, and logistic regression.

**Results:** Children attending full-day schools show the highest percentage of moderate-to-vigorous PA (MVPA) (13.7%) and the lowest percentage of SB (49.5%) during ASPs, in comparison with teaching hours and leisure time. In the afternoon hours, full-day school children show 20 min less SB than half-day school children. Children spending more time in ASPs obtain significantly more SB ($r = 0.23$) and less MVPA ($r = -0.15$). Further, they less likely reach WHO's PA guidelines odds ratio (OR = 0.98).

**Conclusion:** Peers and the choice as well as offer of extracurricular activities promote PA in ASPs. Media availability leads to higher SB in leisure time. ASPs help to be more active and less sedentary. Time spent in ASPs should be limited, so that full-day school children still have the possibility to join other PA offers in leisure time. ASP time should contain a certain minimum amount of MVPA in line with ASP guidelines.

**Keywords: physical activity, sedentary behavior, full-day school, after-school program, children, accelerometry**

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# INTRODUCTION

Physical inactivity and sedentary behavior (SB) are determinants of poor health (1). On the contrary, a basic level of physical activity (PA) is one pillar of a healthy lifestyle. There is manifold evidence for health benefits resulting from regular PA (2, 3) and reduced SB (1). Especially for children, regular PA and reduced SB are important health factors. Based on Dahlgren and Whitehead's (4, 5) model of *Social Determinants of Health*, behavior patterns such as PA and SB are significantly influenced by the social network and living as well as working conditions. For children, these living and working conditions are primarily the family, the commune they grow up in, and the school they attend. Considering the amount of time children spend at school on weekdays, the factor *school* contributes substantially to children's daily PA as well as SB and therefore their health.

In industrialized countries, almost every child is enrolled in school, and school has the most intensive and continuous impact on children aged 6–15 (6). Overall, in Germany, two organizational forms of school exist: full-day schools and half-day schools. The main difference is the amount of time spent at school. Children at half-day schools on average stay 5 h in school. Children at full-day schools on average spend 7–8 h in school. Time beyond teaching hours is usually spent in extracurricular activities of afterschool programs (ASPs). This extra time in full-day schools also provides a large amount of free time for PA, and this can reduce SB. In Europe, most countries offer full-day school programs (7). In the USA, extracurricular activities are usually part of the school system. The organizational form of Germany's school system, especially considering elementary schools, currently changes from half-day to full-day schools. Full-day schools feature diverse characteristics: mandatory vs. voluntary attendance, partly rhythmization of lessons and ASPs as well as a varying overall duration. Parents can typically choose if their children attend a full-day or half-day class within one school. All full-day schools offer a variety of ASPs. Sports activities are the most frequent offers in German full-day school ASPs (8, 9). Federal regulations ensure that either teachers or trained staff organize and guide ASPs or observe free play. Children typically have to sign up for an activity for one term. Age groups are usually mixed. A standard school day in German full-day schools starts with teaching in the morning until lunch break, followed by rarely more teaching or time for homework and extracurricular activities in the afternoon. Prolonged attendance at full-day schools compared with half-day schools impacts children's lifestyle and leisure behavior as well as health behavior depending on the organizational form or ASPs' duration. Full-day schools providing PA offers within ASPs in a low-threshold way can help to reach guidelines for PA and SB, independent of social network (4, 5) or participation in organized sports (10). Full-day schools can therefore influence health-related behavior patterns.

The World Health Organization (WHO) recommends at least 60 min of moderate-to-vigorous PA (MVPA) daily for children aged 5–17 (11). These *Global Recommendations on Physical Activity for Health* (WHO PA GL) are a marker for a healthy lifestyle in the meaning of daily PA. Besides the WHO PA GL, there are several recommendations, policies, or guidelines regarding the amount of PA in ASPs (12). These requirements postulate that up to 60 min of MVPA should take place in ASPs (13–15). It is also recommended that 20–50% of PA in ASPs should be MVPA (14). Most organizations, e.g., the United States National Afterschool Association, call for 30 min MVPA in ASPs (14). This means that ASPs should provide half of the recommended MVPA (12). The WHO PA GL states physical inactivity or SB as evidence of poor health. Specific recommendations regarding SB for children aged 5–17 are missing. In Germany, *National Recommendations for Physical Activity and Physical Activity Promotion* (16) recommends as little as possible and a maximum of 60 min daily sitting, using a screen media or SB. Guidelines for ASPs also recommend a screen time of <60 min (13–15). Screen time should be limited to homework, research, or digital learning (14). The California Department of Education also recommends a maximum 60 min of SB in ASPs (13).

Several studies investigated PA and SB in the school context, especially considering full-day school's ASPs: Beets et al. (17) showed in their study with more than 1,000 elementary school children attending 97 ASPs in South Carolina, USA, operated by the Young Men's Christian Association (YMCA), that only one quarter reached the 30-min guideline of PA in ASPs. On average, children spent 21.4 min in MVPA and 64.3 min in SB at baseline. In the study, ASP staff qualification was also investigated with the assumption that trained staff can increase students' MVPA during ASPs. Regarding children's overall PA in combination with ASP's, PA helps to identify active periods within 1 day. De Meester et al. (10) investigated daily PA of 1,526 Belgian students and compared participants of extracurricular school-based sports offerings with non-participants via questionnaire. Participants were significantly more physically active than non-participants, even after controlling for outer school sports participation. They concluded that ASP participation is linked to higher PA levels. Therefore, full-day school may contribute to an active and healthy lifestyle. Pau et al. (18) measured PA and SB via accelerometry in 169 Italian elementary school children. They compared full-day and half-day school children's PA and SB in different time periods. In the afternoon time period, where ASPs take place for full-day attendants, children spent significantly less time in SB and more time in MVPA than did half-day school children spending the afternoon hours outside school. Van Stralen et al. (19) investigated in a cross-European cross-sectional survey (The ENERGY project) PA and SB during the school day. Ten- to 12-year-old European school children spent on average 65% of their time at school in SB and 5% in MVPA. Van Stralen et al. found significant differences in SB and MVPA for boys and girls. Boys showed less SB and higher amounts of MVPA than did girls. In Messing et al. (20) systematic review of reviews considering PA promotion among children and adolescents, few studies analyzed time in ASPs and identified these programs as effective health promoter. Regarding associations between PA and ASPs, especially programs focusing on PA and/or sports were categorized as effective. Other studies investigated PA and SB in students or in school, respectively, but without specific reference to full-day school or ASPs. Systematic reviews from Parrish et al.

(21) or Atkin et al. (22) provided an overview of studies and results in this field. The analyzed studies either took place during recess or lunch break (21) or examined additionally implemented short-term interventions to promote PA and reduce SB in school (22). For this reason, comparisons with these findings are limited to the field of PA and SB in ASPs in full-day schools.

Overall, most studies in this field analyzed children's daily PA and SB, without differentiating between times of the day. Research analyzing PA and SB in ASPs and its potential influence on daily PA as well as studies comparing full-day school and half-day school are rudimentary. Studies investigating PA and SB in German full-day schools accurately and with device-based measurements, such as accelerometry, are missing. Only one international study (18) compared full-day and half-day school children's PA and SB via accelerometry. Considering this state of studies, questions about full-day schools' or particularly ASP's contribution to children's PA and SB cannot be answered clearly. Further, a comparison between PA and SB in half-day and full-day school children is still pending. Against this background, this study has three major aims:

1. the description of PA and SB of children attending full-day schools during time spent in ASPs, and additionally, the comparison of PA and SB in ASPs with PA and SB during teaching hours and leisure time;
2. the comparison of full-day school and half-day school children's PA and SB during the afternoon hours; and
3. the investigation of the impact of full-day school specific factors on the achievement of WHO PA GL.

# MATERIALS AND METHODS

## Study Design

This study was part of the project *Physical Activity in Full-Day School Children* funded by the German Federal Ministry of Education, Youth and Sports Baden Württemberg from 2014 to 2018. The study was performed from May to July 2017 in elementary schools with either a mandatory or voluntary full-day school branch located in the federal state of Baden-Württemberg, Germany. To minimize weather condition-related differences in PA and SB, data were collected in spring and summer. Regional weather conditions (hours of sunshine, temperature, and daily rainfall) were documented and checked using data from the German Weather Service.

In the first step, 25 schools—officially registered, accredited, and therefore supported by the Federal Ministry of Education, Youth and Sports Baden-Württemberg in their first year as full-day school—were asked to join the study. Eleven schools (44%) agreed to participate. Overall, 1,620 children from grade 1 to 4 were enrolled in the 11 participating schools. In the second step, principals and class teachers handed out an information letter about the study. Parents were asked to fill out the included reply form to accept or decline their children's participation in the study. Regardless of their affiliation to half-day or full-day school, all children of grade 1 to grade 4 were invited to participate. Data were collected by accelerometry for device-based measurement of PA and SB and by paper–pencil questionnaire (23).

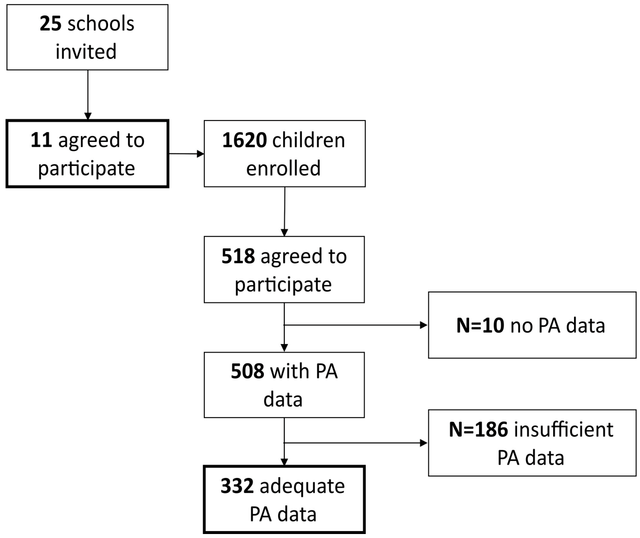


**FIGURE 1 |** Flow chart of the sample selection process.

## Participants and Data Collection

In total, 508 children were equipped with accelerometers and paper–pencil questionnaires. The test period was a regular week without special events (e.g., federal youth games, excursions, and sports meetings). Because of broken devices ($n = 10$) and lack of wear time ($n = 186$), the final sample included 332 children with adequate data for 5 consecutive school days (**Figure 1**). The reason to exclude students with insufficient data is based on the study of Rich et al. (24) determining minimum wear time for accelerometer data. A measurement reliability coefficient of 0.92 can be achieved by a wear time of at least 6 h/day on 5 days. Children's age ranged from 6.69 to 12.3 years with an average of 8.97 (SD = 1.2) years. Sex, organizational form of school, and grade level were well-distributed. **Table 1** shows detailed sample characteristics.

## Measures

Participating children wore a tri-axial accelerometer (ActiGraph® GT3X, GT3X+ or, GT3XBT, Acticorp Co., Pensacola, USA) at the left hip with an elastic belt. Robusto and Trost's (25) study highlighted a strong agreement between the different models of applied ActiGraph accelerometer monitors. Children were asked to wear the accelerometer as soon as they got up in the morning and only remove it during water-based activities, at night and in exceptional cases because of the

**Abbreviations:** PA, physical activity; SB, sedentary behavior; WHO, World Health Organization; ASP, after-school program; WHO PA GL, Global Recommendations on Physical Activity for Health; MVPA, moderate-to-vigorous physical activity; LPA, light physical activity; OR, odds ratio.

**TABLE 1 |** Sample and characteristics.

| *N* | 332 |
|---|---|
| Age (mean, SD) | 8.97 (±1.2) |
| Age (range) | 6.69–12.3 |
| Sex | |
| Female | 172 (51.8%) |
| Male | 160 (48.2%) |
| Organizational form | |
| Half-day school | 134 (40.4%) |
| Full-day school | 198 (59.6%) |
| Grade level | |
| 1st | 77 (23.2%) |
| 2nd | 88 (26.5%) |
| 3rd | 90 (27.1%) |
| 4th | 62 (18.7%) |
| Mixed-age classes | 15 (4,5%) |
| Students per school | 30.18 (±14.0) |

risk of injury, e.g., while performing contact sports such as martial arts.

Data collection by accelerometer was set to 10-s epoch length and started 1–2 h after distribution to avoid increased PA results because of curiosity for device and study. ActiLife Software v6.11.9 was used for data processing. Wear time validation was calculated using Troiano (26) defaults. Time intervals of at least 60 consecutive minutes of zero counts were defined as non-wear time. For PA level calculation and identification of SB, Pulsford's cut points for children (27) were used. Therefore, counts per minute of the vertical axis were classified as SB (SB < 100), light PA (LPA ≤ 2,240), moderate PA (MPA ≤ 3,840), and vigorous PA (VPA ≥ 3,841).

Socio-demographic data (date of birth and sex) were collected via paper–pencil questionnaire, which was an adapted version of the *Motorik-Modul activity questionnaire MoMo-AFB* (23). Children filled out the questionnaire together with their parents or guardians. In the questionnaire, parents and children were asked if the child attended full-day or half-day school. If attending full-day school, ASP end time or time leaving school should be specified for each day separately. Additional information about class and ASP schedules or other school-based information was given by the schools' principals or teaching staff.

## Data Preparation and Data Analyses

PA and SB data were divided into different time periods throughout the day and summarized for 5 consecutive school days from Monday to Friday. Individual timetables were created, based on class schedule and ASP attendance information. A typical school day was divided into teaching hours and leisure time for half-day school children and teaching hours, ASPs, and leisure time for full-day school children. To compare PA and SB in the afternoon hours between full-day and half-day school children, an additional time period named *non-teaching* time was created. Children attending full-day schools stay in school for extracurricular activities in ASPs. Leisure time with activities free of choice started after ASPs. *Non-teaching* time for full-day school children included ASPs and leisure time. Children in half-day schools left school after teaching hours. The remaining time awake was leisure time and therefore equal to *non-teaching* time. Valid wear time was checked for full day recording (as mentioned above) and double-checked for each period of the day to ensure at least 50% wear time in each time period. On average, daily wear time amounted to 11.92 (SD = 2.3) hours and 49.7% (SD = 9.5) for a whole day; 4.06 (SD = 0.7) hours in teaching hours, which equates to 89.3% (SD = 12.8) for daily teaching hours, 2.46 (SD = 1.0) hours and 91.6% (SD = 14.4) in ASPs, 6.72 (SD = 2.1) hours and 50.6% (SD = 13.5) in leisure time, and 7.75 (SD = 1.9) hours and 54.1% (SD = 12.5) in *non-teaching* time.

After raw data to PA and SB data with ActiLife® software were converted, Microsoft® Excel® for Office 365 MSO was used to prepare data.

Comparisons of children's PA and SB in different time periods (e.g., ASPs and leisure time) within the day were conducted by repeated measure factorial ANOVA with sex and grade as independent variables. Analyses comparing full-day and half-day school children or subgroups differentiated by school affiliation were fulfilled by one-way ANOVA, to identify the interaction effect between sex and grade, a factorial ANOVA was conducted. For multiple comparisons, Tukey's *post-hoc* test was used. Effect size eta squared was categorized based on Cohen (28): small, $\eta^2 < 0.06$; medium, $\eta^2 = 0.06$ to 0.14; and large, $\eta^2 > 0.14$. If sphericity was missing, Greenhouse–Geisser correction was applied. Correlations between variables were calculated via Pearson correlation coefficient. Prediction for school's organizational form attendance and WHO PA GL achievement was checked with chi-squared test for the whole sample. The subsample of full-day school children was analyzed by logistic regression to identify general (sex and age) and specific full-day school predictors (number of days per week in ASPs, duration of ASPs in minutes per day, minutes of MVPA in ASPs per day, and reaching the guideline of 20% MVPA in ASPs) as independent variables, which were given as odds ratio (OR) to achieve the WHO PA GL (dependent variable). Significance was assessed at $\alpha = 0.05$ for all analyses. All statistical tests were conducted using IBM® SPSS® Statistics (version 26).

# RESULTS

## Children's Physical Activity and Sedentary Behavior in After-School Programs

The following results refer to the subgroup of participants attending full-day school ($n = 198$) and taking part in ASPs on at least 1 and up to 5 days of the week. Over two thirds of students attending full-day school participate on three (31.8%) or four (37.4%) afternoons in ASPs. The number of days varies in the full range from one (6.6%) or two (7.1%), up to five (17.2%) days attending full-day school programs within a school week with an average of 3.52 (SD = 1.1) days weekly. On average, children spend 162.88 (SD = 57.0) minutes per day in ASPs.

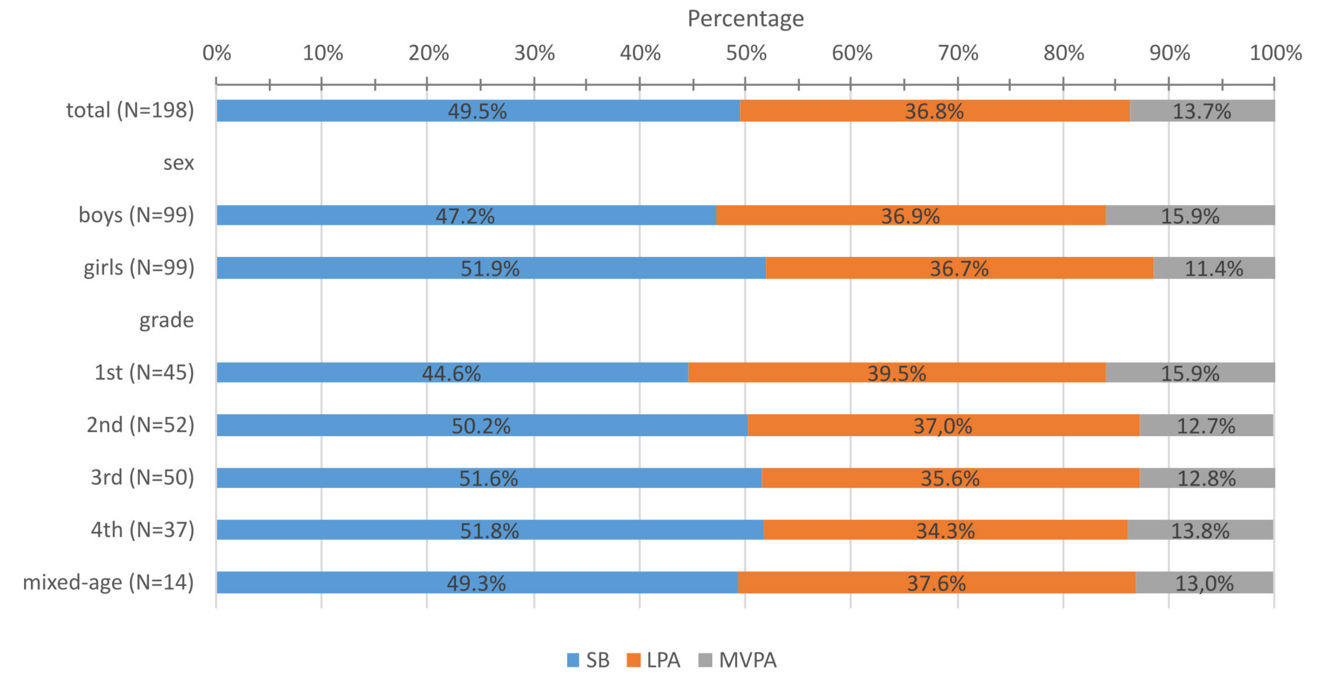


**FIGURE 2 |** Percentages of physical activity and sedentary behavior in after-school program time of full-day school children.

The maximum duration of ASPs time is 5 h/day. Summarizing all school days within 1 week, we found that children attend extracurricular activities in ASPs for 9 h 42 min (M = 582.45 min, SD = 285.7) on average.

**Figure 2** shows the constitution of SB, LPA, and MVPA in ASPs for the full-day school subgroup—differentiated by sex and grade (and therefore indirectly by age). In ASPs, factorial ANOVA reveals no significant interaction for grade and sex [$F_{(4,188)} = 1.32$, $p = 0.263$, $\eta^2 = 0.03$] in percentage of SB. Both factors individually show significant differences: boys' SB is lower than girls' [$F_{(1,198)} = 8.34$, $p < 0.001$, $\eta^2 = 0.04$]. Differentiated by grade, there is a significant difference of SB in ASPs [$F_{(4,198)} = 4.24$, $p = 0.003$, $\eta^2 = 0.08$]. Tukey's *post-hoc* multiple comparisons show that only first graders show significantly less SB than do second, third, and fourth graders. Considering the percentage of time spent in MVPA during ASPs, only sex shows a significant difference [$F_{(1,198)} = 28.19$, $p < 0.001$, $\eta^2 = 0.13$]. There are neither significant differences between grades [$F_{(4,198)} = 1.99$, $p = 0.107$, $\eta^2 = 0.04$] nor an interaction effect [$F_{(4,188)} = 0.65$, $p = 0.625$, $\eta^2 = 0.01$]. Significant differences with large effects are found for school affiliation in both percentage in SB [$F_{(10,198)} = 5.42$, $p < 0.001$, $\eta^2 = 0.23$] and MVPA [$F_{(10,198)} = 3.53$, $p < 0.001$, $\eta^2 = 0.16$]. *Post-hoc* results reveal that only one school stands out with a highly active ASP. This school is the only one in the sample where full-day school is mandatory for all children. PA and SB data of this school ($n = 27$) show that children spend on average 18.4% (SD = 8.2) of ASPs time in MVPA (overall: M = 13.7%, SD = 6.2), which differs significantly in comparison with four schools in a multiple comparison. In 39.0% (SD = 10.0) of ASP time, children of this school are sedentary (overall: M = 49.5%, SD = 9.9), which is significantly different to eight schools.

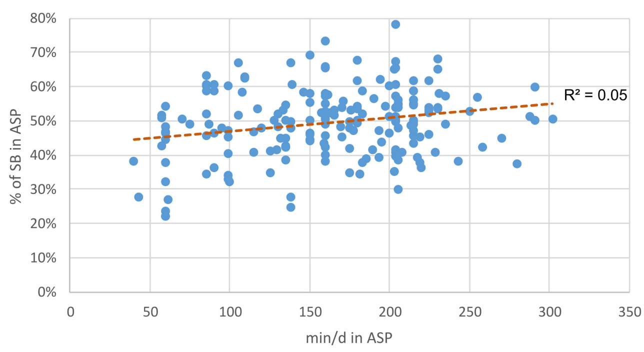


**FIGURE 3 |** Duration of after school program (ASP) correlated to percentage of time in sedentary behavior in ASP.

Children attending full-day school stay on average 2 h 43 min (M = 162.88 min, SD = 57.0) per school day at school for extracurricular activities in ASPs. Regarding the duration, there is a small positive correlation for SB ($r = 0.23$, $p = 0.001$) and a slightly negative correlation for MVPA percentages ($r = -0.15$, $p = 0.037$) as seen in **Figures 3**, **4**. This shows that children who spend more minutes per day in ASPs show a higher percentage of SB and a lower percentage of MVPA than do children who spend less time in ASPs.

For children attending full-day school, ASP (SB: M = 49.5%, SD = 9.9; MVPA: M = 13.7%, SD = 6.2) time is significantly

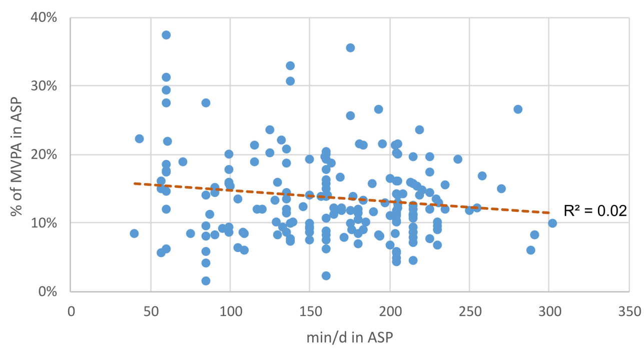


**FIGURE 4 |** Duration of after school program (ASP) correlated to percentage of time in moderate-to-vigorous physical activity (MVPA) in ASP.

the most active and least sedentary time of the day than are teaching hours (SB: M = 61.6%, SD = 7.0; MVPA: M = 8.4%, SD = 2.9) and leisure time (SB: M = 57.9%, SD = 7.6; MVPA: M = 10.1%, SD = 3.5) with the highest percentage of MVPA and lowest percentage of SB. Considering SB, interaction effects of the repeated measure factorial ANOVA are significant for the time periods differentiated by sex, but not by grade or by sex and grade. For percentages of MVPA, significant interaction effects can be found for sex as well as grade, but not for grade and sex (see **Tables 2**, **3**). Descriptive data can be found in **Supplementary Tables A, B**.

## Comparison of Full-Day and Half-Day School Children's Physical Activity and Sedentary Behavior in the Afternoon Hours

During *non-teaching* time children attending full-day schools (M = 256.84 min, SD = 76.45) spend significantly less minutes in SB than children in half-day schools (M = 276.60 min, SD = 89.0): $F_{(1,332)} = 4.67$, $p = 0.031$, $\eta^2 = 0.01$. The difference in minutes of MVPA in the *non-teaching* time is not significant; half-day school children (M = 47.57 min, SD = 19.59) spend 1.7 min less in MVPA than children attending full-day schools (M = 49.26 min, SD = 18.60): $F_{(1,332)} = 0.63$, $p = 0.427$, $\eta^2 < 0.01$. Considering girls and boys separately, the affiliation to school's organizational forms do not differ in boys' SB [$F_{(1,160)} = 0.33$, $p = 0.570$, $\eta^2 < 0.01$) or MVPA [$F_{(1,160)} = 0.33$, $p = 0.565$, $\eta^2 < 0.01$). The difference in minutes of SB in the *non-teaching* time for girls aggregates to almost 30 min. Girls in half-day schools show SB for 290.47 (SD = 87.19) minutes and girls in full-day schools for 260.73 (SD = 85.29) min [$F_{(1,172)} = 5.02$, $p = 0.026$, $\eta^2 = 0.03$). As reported for boys' PA, there are no significant differences in girls' MVPA [$F_{(1,172)} = 0.06$, $p = 0.801$, $\eta^2 < 0.01$). Regarding subgroups divided by grade, there is a difference in second graders: half-day school children in second grade spend significantly more time in SB during *non-teaching* time than full-day school children [$F_{(1,88)} = 5.75$, $p = 0.019$, $\eta^2 = 0.06$). For all other grades, differences in SB and PA between full-day and half-day school children are not significant.

**TABLE 2 |** Differences of percentages in time spent in sedentary behavior (SB) in different periods of the day in full-day school children ($n = 198$).

| | Test for difference | p | $\eta^2$ |
|---|---|---|---|
| Setting[a] | $F_{(1.87,351.47)} = 138.86$ | < 0.001 | 0.43 |
| Setting × grade[a] | $F_{(7.48,351.47)} = 1.89$ | 0.066 | 0.04 |
| Setting × sex[a] | $F_{(1.87,351.47)} = 4.03$ | 0.021 | 0.02 |
| Setting × grade × sex[a] | $F_{(7.48,351.47)} = 1.43$ | 0.189 | 0.03 |

[a]*Sphericity not given, Greenhouse–Geisser correction.*

**TABLE 3 |** Differences of percentages in time spent in moderate to vigorous physical activity (MVPA) in different periods of the day in full-day school children ($n = 198$).

| | F | p | $\eta^2$ |
|---|---|---|---|
| Setting[a] | $F_{(1.66,312.60)} = 83.94$ | < 0.001 | 0.31 |
| Setting × grade[a] | $F_{(6.65,312.60)} = 2.38$ | 0.024 | 0.05 |
| Setting × sex[a] | $F_{(1.66,312.60)} = 8.41$ | 0.001 | 0.04 |
| Setting × grade × sex[a] | $F_{(6.65,312.60)} = 0.70$ | 0.667 | 0.02 |

[a]*Sphericity not given, Greenhouse–Geisser correction.*

## The Global Recommendations on Physical Activity for Health: The Influence of Specific Full-Day School and General Variables

In this study, 59.9% of participants reach the recommended 60 min of MVPA daily according to the WHO PA GL (11). A chi-squared test shows that significantly more boys (73.8%) than girls (47.1%) can be categorized as active in the meaning of the WHO ($\chi^2(1) = 24.53$, $p < 0.001$, $\varphi = 0.27$). Attendance to full-day or half-day school does not show any significant difference in the percentage of children reaching the WHO PA GL: full-day school 62.1%, half-day school 56.7% ($\chi^2(1) = 0.97$, $p = 0.324$, $\varphi = 0.05$).

The logistic regression model with six predictors reaches a likelihood of 79.1%. The OR is displayed in **Table 4**. Sex as a significant predictor in this model shows that boys are more than twice as much likely (OR = 2.16) than girls to reach the WHO PA GL. Age and number of days per week attending ASPs do not show any significant predictions. The likelihood to reach the WHO PA GL decreases (OR = 0.98) when duration of ASPs increases. Vice versa, an increased number of minutes of MVPA in ASPs helps to increase the likelihood of reaching the guideline (OR = 1.26). Reaching the ASP guideline of 20% MVPA of total time in ASPs does not show a significant influence on the dependent variable.

# DISCUSSION

## After-School Program as Highly Active Time of the Day

Germany's change from the traditional half-day to a full-day school system may bring along changes in children's lifestyle, leisure time, and PA as well as SB habits. Hence, the first aim

**TABLE 4 |** Logistic regression and odds ratio (OR) for reaching the Global Recommendations on Physical Activity for Health (WHO PA GL).

| Variable | OR | 95% CI | | *p*-value |
|---|---|---|---|---|
| | | Low | High | |
| Sex (ref. girl) | ref. | | | 0.048 |
| Boy | 2.16 | 1.01 | 4.63 | |
| Age | 0.94 | 0.67 | 1.31 | 0.696 |
| Number of days per week in ASP (ref. 1 day) | ref. | | | 0.605 |
| 2 days | 4.18 | 0.50 | 35.19 | 0.188 |
| 3 days | 2.05 | 0.39 | 10.73 | 0.394 |
| 4 days | 2.51 | 0.47 | 13.44 | 0.281 |
| 5 days | 1.46 | 0.24 | 8.83 | 0.684 |
| Duration of ASP (min/day) | 0.98 | 0.97 | 0.99 | < 0.001 |
| Minutes of MVPA in ASP (min/day) | 1.26 | 1.16 | 1.36 | < 0.001 |
| Reaching the guideline of 20% MVPA in ASP | 0.39 | 0.08 | 2.01 | 0.259 |

*Total assumption:* $\chi^2(9) = 84.91$, $p < 0.001$. *Effect size: Nagelkerke's* $R^2 = 0.48$.

of this study was to describe and analyze PA and SB in ASPs of children attending full-day schools and compare the results considering ASPs with other times of the day. Girls as well as children in higher grades show more SB and less MVPA in ASPs than boys or children in lower grades, respectively. These well-known differences (29) may lead to a policy of organizing ASPs in full-day schools: it is essential to offer various activities in ASPs to address all children independent of sex or age. In elementary schools, age-appropriate activities, specifically for older children in grades 3 and 4, may motivate this age group to be physically active and by this decrease their SB time. Additionally, results showed that ASP time is characterized by high percentages of MVPA as well as low percentages of SB. ASPs therefore depict the most active time of the day in comparison with teaching hours or leisure time. Three points may explain this highly active time: first, at German full-day schools, most ASP activities involve sports, games, or play. Almost every school provides at least one PA-based offer within its full-day school program (8, 9). Second, children attending ASPs have access to facilities that allow or promote PA, e.g., schoolyards. Access to facilities promotes PA and therefore reduces SB (30, 31). In the case of full-day schools, availability and access to the schoolyard or in some cases the school's own gym may help to encourage children for PA (32). Third, leisure time at home is often characterized by SB in the form of screen usage (33). At school, screen usage is restricted to educational purposes, which the *National Afterschool Association* (14) also recommends for ASPs. Time for highly active offers in ASPs seem to be limited. Prolonged attendance in ASP correlates with a higher percentage of time spent in SB. One reason might be full-day schools' organization. In this sample, federal requirements ask for 7–8 h in school on 3–4 days. Further, many full-day schools offer privately organized and fee-based voluntary childcare exceeding after-school hours. In this time beyond the federal required ASPs, less children are present. Consequently, there is less variety of organized activities, and the possibility to play freely with other children that brings along PA decreases. The lack of peers or offers therefore may be reason for the higher percentage of SB in prolonged ASPs. Furthermore, there may be an infrastructural reason for less PA and more SB in prolonged ASPs: schools and sports clubs typically share facilities. As sports clubs' activities take place in the later afternoon hours, the availability of gyms and playing fields (e.g., soccer pitches or athletics fields) for activities in ASPs is limited. This double usage of sports facilities is a limiting factor for extracurricular activities in ASPs (34) in general and in prolonged ASPs in particular. Because of these reasons, it can be assumed that staying in full-day schools for an extended time may involve an unorganized and SB-based waiting for pickup by parents or guardians.

## Comparison of Full-Day and Half-Day School Children's Physical Activity and Sedentary Behavior

The second major aim of this study was to compare PA as well as SB of children in full-day and half-day schools during the afternoon hours in the *non-teaching* time period. Children attending full-day schools showed less SB than children in half-day schools in the afternoon hours. For the same time period, this study did not find significant differences in MVPA. The results can confirm Pau et al. (18) results regarding lower SB, but not regarding higher MVPA among full-day school children in comparison with half-day school children. According to Dahlgren and Whitehead's (4, 5) model, living conditions and the social network are different in full-day and half-day school children's *non-teaching* time. On the one hand, in ASPs, peers and space for free play or organized extracurricular activities are available. This enables full-day school children to spend their time less sedentary and more active in ASPs as compared with half-day school children who potentially spend the early afternoon at home. On the other hand, referring data of this study, Spengler et al. (35) showed that full-day school children are less engaged in organized sports outside school than are half-day school children. Furthermore, weekly duration of training in sports clubs is significantly higher in half-day school children compared with full-day school children. This may explain that there is no significant difference in MVPA between children attending full-day and half-day schools in the afternoon hours. Against this background, it seems that Züchner and Arnoldt's (36) hypothesis considering the changes in children's sports club activities in connection with full-day school attendance can be accepted: a shift of PA in leisure time from sports club activities to ASPs for full-day school children seems possible. ASPs may be a chance to increase MVPA and decrease SB of children who do not participate in organized sports activities in their leisure time (10). With the aim to reduce SB and increase PA, three policies seem promising: first, half-day school children could join ASPs to reduce their SB in the early afternoon, independent of participation in organized sports. Second, children attending ASPs in full-day schools should be motivated to participate in club sports or to join free play in the late afternoon. And third, schools should provide an obligatory PA time during ASPs but in accordance to a designated duration of ASPs. Therefore, a guideline for PA and SB in ASPs should include both absolute and relative values as recommendations for PA and SB. This finding can also decline critics' assumption that full-day school will only increase SB.

## After-School Program in Full-Day Schools and the Global Recommendations on Physical Activity for Health

The third aim of this study was to identify potential and specific full-day school factors that influence the achievement of WHO PA GL. The schools' organizational form did not influence reaching the boundary value of 60 min MVPA daily. Analyzing predictors identified gender in favor of boys, shorter duration of ASPs, and higher number of minutes of MVPA in ASPs as beneficial to reach WHO PA GL. The gender effect in favor of boys is comparable with that of the study of Beets et al. (29). Combining these findings, quantity and quality of ASPs are relevant for children's PA and should be adjusted. This means that beyond the obligatory lunch (federal requirements) and time for homework, ASPs should provide time to be active in extracurricular activities. Prolonged attendance without activities may lead to sedentariness and by this decreases the possibility to reach WHO PA GL.

## Future Research and Practical Implications

Future research should investigate children's PA and SB longitudinally. PA and SB development or changes over time comparing different organizational forms could be displayed. Transitions from half-day to full-day school or vice versa may bring along changes in lifestyle habits, sports club participation, and other factors influencing daily PA and SB. This study's results considering PA and SB only show children's behavior in spring and summer season with mostly good weather conditions. Comparisons between other seasons of the year or the influence of weather conditions for full-day and half-day school children's PA and SB would be interesting, too. This study analyzed device-based measured PA and SB via accelerometry. ASP content was not observed. To identify offers in ASPs that lead to higher or lower PA, ASP content should be analyzed in combination with PA and SB data. As research in physical education classes explains quality of teaching content and staff qualification, these aspects should be investigated in ASPs likewise. Examining the optimal duration and content of ASPs benefitting children's daily PA and SB requires multiple findings regarding the abovementioned topics. Including children's and parents' or guardians' socioeconomic status may (a) help to identify specific subgroups or (b) highlight the school's organizational form influence on children's PA and SB. Compared with sports clubs, full-day schools with optional sports activities reach more children. A potential influence of socioeconomic issues on children's sports activities may be much smaller in full-day schools' ASPs than in organized activities in sports clubs. Additionally, activities in ASPs could have a recruitment effect on club sports (36).

Findings of this study may lead to the following practical implications: time in ASPs should be limited in duration and not exceed the late afternoon. Full-day schools should offer a variety of extracurricular activities in ASPs for the time children stay in school. Children attending full-day school should still have the possibility to participate in organized sports, e.g., organized by sports clubs. Therefore, full-day schools and sports clubs should cooperate. Because of a lack of teachers, providing extracurricular activities for the whole time in ASPs is a problem for many schools. Including sports club coaches in ASPs may help to offer more activities during ASPs and at the same time enable sports clubs' recruitment of interested children to participate in organized sports. The compliance of PA-based ASP guidelines may help to lead children not engaged in organized sports to more PA and less SB.

## Strengths and Limitations

A strength of this study is the device-based measurement of PA and SB via accelerometry with a sample size of $N = 332$ distributed over 11 elementary schools. Accelerometer-based PA and SB data underlies the chosen algorithms to calculate wear time and cut points. Algorithms used in this study were chosen by best fitting arguments. Comparisons with studies using other algorithms should be done carefully (37). Although, Robusto and Trost (25) as well as the producer postulate that the ActiGraph® models used in this study are completely compatible, a doubtless comparison of data seems to be only possible using totally identical device models. This study was conducted in the federal state of Baden-Württemberg, Germany. Therefore, the sample is not representative and is subjected to regional conditions. Schools' participation was voluntary. It can be assumed that schools declined their participation because of bad circumstances, e.g., schoolyards under construction, shortage of teachers, or the apprehension to achieve bad results and to be marked as *low PA school*. Further, children's participation was voluntary. The relatively low participation rate (31.8%) may be attributed to the considerable effort for parents, managing questionnaire completion, and accelerometer recording for a whole week. Although parents were informed about privacy and the Federal Ministry's approval of the study, data collection via accelerometry might still be seen critically by some parents.

## DATA AVAILABILITY STATEMENT

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

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Commitee of the University of Konstanz (approval number: 08/2019). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

## AUTHOR CONTRIBUTIONS

AK and FM coordinated the whole project and developed the study design. AK collected data and wrote the paper with substantial contributions from CM and MS. AK and CM performed the data preparation and statistical analysis. MS performed the final proofreading. All authors provided feedback on drafts and approved the final manuscript.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2020.00463/full#supplementary-material

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BRIEF RESEARCH REPORT
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# Representative Percentile Curves of Physical Fitness From Early Childhood to Early Adulthood: The MoMo Study

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**Introduction:** Monitoring of physical fitness in youth is important because physical fitness is a summative indicator of health. From a developmental and preventive perspective, physical fitness levels are relatively stable from childhood to early adulthood. Thus, it is important to monitor physical fitness on a population based level being able to intervene at early stages (1). In order to reliably assess and evaluate the physical fitness of youth, a reliable system of standard values based on representative data is required. The aim of this analysis is to report sex- and age-specific physical fitness percentile curves from childhood to early adulthood in a nationwide sample in Germany.

**Methods:** We use data from the nationwide representative Motorik Modul (MoMo) Study in Germany (data collection wave 1: 2009–2012; age: 4–23 years; $n = 3,742$; 50.1% female). Physical fitness was assessed by means of the MoMo test profile covering four dimensions of physical fitness (strength, endurance, coordination, and flexibility) and including eight physical fitness items. Percentile curves were fitted using the LMS transformation method of Cole and Green.

**Results:** Standardized age- and sex-specific physical fitness percentiles were calculated for eight items: ergometric endurance testing, standing long jump, push-ups, sit-ups, jumping side-ways, balancing backwards, static stand, and stand and reach test. The physical fitness curves differ according to gender and the fitness dimension. Physical fitness improvements with age are linear (e.g., max. strength) or curvilinear (e.g., coordination) and have their stagnation points at different times over the course of adolescence.

**Discussion:** Our results provide for the first time sex- and age-specific physical fitness percentile curves for Germany from 4 to 17 years. Differences in curve-shapes indicating a timed and capacity-specific physical fitness development. Nationwide German physical fitness percentiles can be useful in comparing different populations (e.g., cross-country), reporting secular trends, comparing special groups, and to evaluate physical fitness interventions.

**Keywords: health-related, performance, skill-related, LMS, reference, monitoring, Germany, youth**

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## INTRODUCTION

Physical fitness levels play a major role in overall healthy child and youth development (2). Representing powerful biomarkers of health status already in early childhood, especially the maintenance of satisfactory fitness levels is highly connected with current public health issues as physical development (3), the prevention of diabetes, obesity (4), cardiovascular disease risk factors (5), cancer and mental health (2, 6). Therefore, it is important to monitor population fitness levels longitudinally to being able to intervene at an early stage (7, 8). The importance of such monitoring has also been shown by critical decreases in physical fitness levels in a large world-wide sample (9).

The specific selection of appropriate definitions, assessments and subsequent test interpretations are important in the scientific as well as practical fields of human health and sports sciences. The construct of physical fitness consists of two components (10): on the one hand, health-related fitness includes cardiovascular endurance, strength endurance, explosive muscular strength, body composition as well as flexibility (10). On the other hand, skill-related fitness is defined as agility, balance, coordination, speed, power and reaction time (10). Physical fitness can be accessed via laboratory as well as field tests. Although laboratory tests using sophisticated material are capable of providing very objective and detailed outcomes, these tests are not suitable for comprehensive monitoring of physical fitness levels in large scale studies across cities, states or countries. Here, single field tests assessing specific fitness domains are often utilized and gathered in standardized test batteries to comprehensively cover physical fitness [e.g., FitnessGram (11), Eurofit (12), German Motor Performance Test 6–18 (13)]. Among various widely known and broadly used single test items, the MoMo Motor Performance Test (14) was compiled using the most widely used single item tests in Europe in order to broadly and longitudinally assess physical fitness from early childhood to early adulthood.

In Germany, it has been shown that certain physical fitness components are relatively stable between cohorts from childhood to early adulthood while others increase or decrease (3, 15). In order to successfully monitor physical fitness levels over time in a representative manner, it is necessary to provide up-to-date normative data of the specific test items. Many researchers, but also physical education teachers or sport coaches assess physical fitness from their students and need valid and simple possibilities judging their physical fitness performance (16). Therefore, this study aims to provide up-to-date age- and sex-related percentile curves of persons aged four to 17 years for frequently used test items:

(1) Ergometric endurance testing, (2) standing long jump, (3) push-ups, (4) sit-ups, (5) jumping side-ways, (6) balancing backwards (7) static stand, and (8) stand and reach test.

## METHODS

The study was conducted according to the Declaration of Helsinki. Ethics approval was obtained by the University of Konstanz (Wave 1). The Federal Commissioner for the "data protection" and "freedom of information" was informed about the study and approved it.

### Participants

Data were obtained from the nationwide German Motorik-Modul study (MoMo). The MoMo study is an in-depth module study of the German Health Interview and Examination Survey for Children and Adolescents which was conducted by The Robert Koch-Institute (RKI, Berlin) since 2003 (17, 18). The MoMo study provides nationwide representative data on the physical fitness and physical activity status (19). The study was set up in 2003 (2003–2006 MoMo Baseline). Two consecutive survey waves were conducted until now: MoMo Wave 1 (2009–2012) and MoMo Wave 2 (2014–2017). Children and adolescents were invited to the physical fitness tests at central locations within close proximity to their homes in the 167 cities and municipalities.

The data of 3,284 children and adolescents (1,644 female, 1,646 male) aged 4–17 years were reported in figures below while LMS curve modeling used data of persons till 23 years ($N = 3{,}742$; male 49.9% $N = 1{,}868$; female 50.1% $N = 1{,}874$) from the MoMo Wave 1 survey (2009–2012) was used to model physical fitness percentiles of children and adolescents. We have modeled the percentile curves up to 23 years, as the model fit for the percentile curves become better and more accurate with more data and thus over a larger age range. From the age of 17 years on, however, our sample is no longer representative for Germany, so we report only the data up to 17 years. Characteristics of the whole sample including individual level of socioeconomic status (SES) (20), BMI (21), and type of residential area (22) differentiated by age group and sex are shown in **Supplement Table 1** in the Supplement Material.

Detail information about mean values of all physical fitness tests for age groups and gender can be found here (23).

### Sampling

To ensure a diverse sample of German children and adolescents, a nationwide, stratified, multi-stage sample with two evaluation levels was drawn (24).

First, a systematic sample of 167 primary sampling units was selected from an inventory of German communities that were stratified according to the BIK classification system that measures the level of urbanization and the geographic distribution (17). The probability of any community being picked was proportional to the number of inhabitants younger than 18 years in that community. Second, an age stratified sample of randomly selected children and adolescents was drawn from the official registers of local residents. At the second measurement point (KiGGS Wave 1 study), 12,368 children and adolescents participated (18). This sample built the population for the MoMo Wave 1 subsample. 6,076 from KiGGS Wave 1 were randomly assigned to MoMo Wave 1. From those, 3,994 participated in MoMo (65.7%). After excluding participants without a valid physical fitness test (one test item was sufficient), a total of 3,742 children and adolescents 4–23 years remained for this analysis.

## Representativeness

Weighting procedure was used to account for potential bias in outcome variables caused by selective unit nonresponse (24). In the first step, inverse probability weights were applied via logistic regression to eliminate differences in outcome variables between the MoMo subsample and the weighted representative KiGGS sample. In the second step, the MoMo subsample was stratified using data of the German Micro Census 2010 to ensure representativeness of the target population (German children and adolescents aged 4–17 years) regarding sex, age, region, migration background, and education level (25).

## Material

The MoMo Motor Performance Test (14) was developed in order to broadly cover the construct of physical fitness. The physical fitness tests were carried out in the time frame from 8 a.m. to 6 p.m. Trained testing stuff conducted the tests with the children and adolescents in a one-to-one supervision. Testing always start with the coordination tasks followed by the strength tasks and at the end the endurance test on the bike ergometer was carried out. The duration of the test is about 60 min. The test items originated from common validated test profiles and were pretested, optimized, discussed with experts, and documented in a comprehensive test manual (14). The overall reliability was calculated using the standardized total value and results in a correlation of $r = 0.97$ ($p = 0.00$) and no significant difference in mean value. The objectivity (tested using different test directors) is very good ($r = 0.98$ to 0.99), the percentage difference is less than one percentage point for all test items (26). It consists of eight items covering health-related (i.e., endurance, strength endurance, lower body explosive muscular strength, and flexibility) and skill-related fitness domains (i.e., balance, coordination), which are covered by the following test items:

*Cardiovascular endurance* was assessed using a static bicycle ergometer test. It measures the aerobic endurance capacity of participants using a sequential step test design. The test is started at a calculated input load of 0.5 watt/kg body weight and a cadence of 70 revolutions per minute (rpm). Each load level is held for two minutes. Then the load is increased by 0.5 watts per kilogram of body weight. Each level is shown on a digital display. For the assessment of the performance the power at a heart rate of 170 bpm (Physical Working Capacity [PWC170]) were used. The test stops at three occasions: (1) if there is a pulse of above 190 (participants up to 10 years) or above 180 (participants from 11 years), respectively, (2) if the cadence falls below 50 rpm for more than 20 s, or (3) if participants want to stop due to subjective exhaustion. Children aged 4–5 years did not participate in the test.

*Strength endurance* is assessed for upper extremities as well as body core via sit-ups and push-ups. Firstly, participants perform sit-ups to cover body core strength endurance in a lying position with bent legs. The test instructor fixes the feet on the ground. The fingertips touch the temples in order to avoid pulling the neck. At each sit-up, participants need to touch the knees with their elbows without lifting the basin. Subjects repeat as many correct sit-ups as possible in 40 s. Secondly, push-ups were performed in order to cover upper extremities strength endurance starting with hands together at the lower back. In a first step, participants push their body up with a plank body angle. When the arms are straight, subjects touch one hand with the other hand and return the starting position with constant body control. The resulting variable is the number of repeated correct push-ups in 40 s. Children aged 4–5 years did not partake in these two tests.

*Explosive muscular strength* of the lower extremities is assessed via standing long jump. Participants start at a line, which is marked on a tartan mat. It is important that subjects jump using both legs together and do not fall backwards after landing the jump. Otherwise, the jump has to be repeated. Two jumps were performed while the maximum jump is counted.

*Coordination including Balance* is assessed via jumping sideways, static stand and balancing backwards. For the jumping sideways task the test instructor creates two adjacent 50 cm squares with 5 cm lines. Participants have to jump from one to the other square like a pendulum jumping with both legs without touching the boundaries. After a 1-min pause, subjects have a second trial. The test instructor counts the number of correct jumps in 15 s.

*Balance* is assessed via static stand and more dynamic balancing backwards. Firstly, static jump measures sensomotoric regulation of precision tasks on a 3 cm broad beam. Participants have to balance on the beam without touching the own leg, the beam or the ground. Test instructor counts the number of mistakes in one minute. Secondly, balancing backwards assesses dynamic whole-body balance on three differently broad. Subjects have two trials each on a 6 cm, on a 4.5 cm, and on a 3 cm beam. Test instructor counts the number of steps from each participant before touching the ground while reaching a maximum of eight steps per beam (total max. 48 steps).

*Flexibility* of the lower extremities is assessed via stand and reach. Stand and reach specifically measures the flexibility of the lower back and hamstring muscles. Test instructors measure the level of the fingers with the feet recording to zero. Negative values are associated with not being able to reach one's own toes while positive values are related to reaching further than the toes. Participants have to stay in the final position for two seconds in order to avoid swinging execution of the task. Subjects have two trials for this test.

## Data Analysis: LMS Curves

Age- and sex-specific percentile values (P5, P10, P15, P30, P50, P70, P85, P90, and P95) were calculated and percentile curves were fitted using the LMS transformation method of Cole and Green (27). The LMS method summarizes the changing distribution by three curves representing the median (M), coefficient of variation (L), and skewness (S) (expressed as a Box-Cox power). Using penalized likelihood the three curves can be fitted as cubic splines by non-linear regression, and the extent of smoothing required can be expressed in terms of smoothing parameters or equivalent degrees of freedom (27). The values of L, M and S were constrained to change smoothly with age, and the fitted values can be used to construct any required percentile curves (28). All analyses were performed with LMS chartmaker pro (V. 2.3). When modeling some extreme values resulted

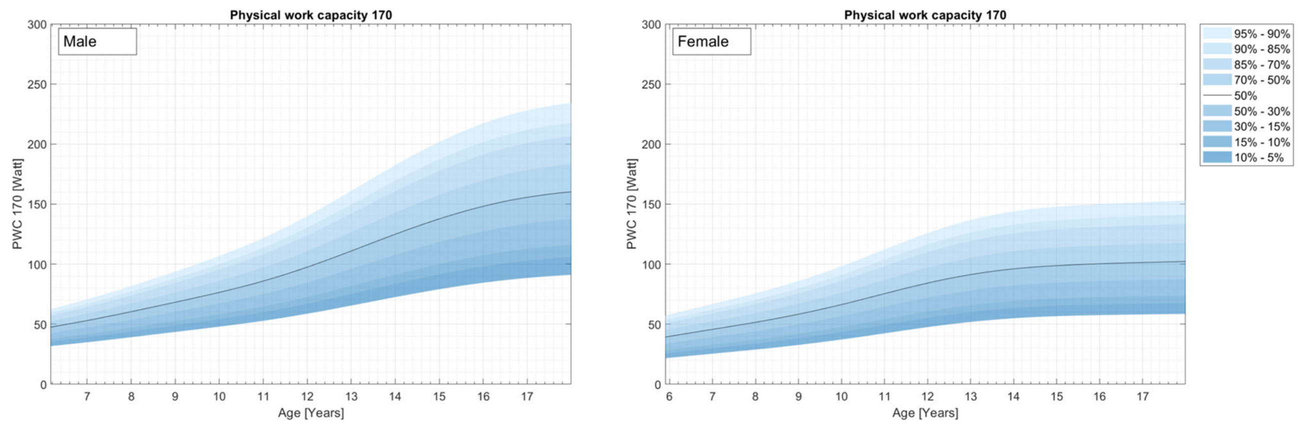


**FIGURE 1 |** Cardiovascular endurance curves (Physical Work Capacity 170, ergometric bicycle test) for the representative sample of German boys and girls aged 4–17 years.

in the sample of computational instabilities in the application of the method. For this reason, values were excluded which exceeded plus and minus three standard deviations. The number of degrees of freedom for the splines is considered optimal, following a recommendation by Cole (29), if the model's deviance (P Deviance and SBC Black Bayesian Criterion) with a further increase of 1° of freedom does not improve by more than 8. In addition, a visual quality control was conducted: Empirical and fitted centiles plotted on top of each other. This is an accurate technique in which the observations are divided into age groups (half-yearly). Empirical centiles are computed for each group, and these are plotted together with the fitted curves. If everything is right, the fitted curves should be close to the point estimates (that is, within sampling error). Quantile–quantile plot (Q–Q plot) of the $z$-scores were also applied. The display plots the quantiles of the theoretical distribution (on the horizontal axis) against those of the empirical distribution (on the vertical axis).

# RESULTS

Physical fitness indicators for 3,742 children and adolescents from a representative (for 2010) nationwide German sample were used to develop percentile curves for male (49.9%) and female (50.1%) students aged 4–23 years. **Supplement Table 1** and **Figures 1–4** demonstrate the distributions and corresponding standardized age-based percentiles of all items separated for male and female subjects. We present figures to reproduce the shape of the percentile curves but at the same time provide the data basis for concrete physical fitness comparisons using the data in the tables for practical use.

## Cardiovascular Endurance

The results for cardiovascular endurance can be found in **Figure 1** and **Supplement Table 2**.

Although the lowest percentile curves for fitness are relatively flat, a steady increase in mean aerobic performance is seen as children enter adolescence. On average, girls had a maximum fitness between ages 14 and 15 years, while boys, on average, had a maximum fitness between 15 and 16 years. Both sexes demonstrated a slight decrease after these peaks.

## Strength

### Sit-Ups

Results for strength are represented in **Figure 2** and **Supplement Tables 3–5**.

There is a steady increase in mean strength performance from childhood to adolescence. On average, girls had a maximum fitness between ages 11 and 12 years, while boys, on average, reach their maximum performance probably at the 17–18 years. The girls demonstrated a slight decrease after the peak.

### Push-Ups

For females, the lowest percentile curves for fitness are relatively flat. On average, girls had a maximum strength performance at the age of 11 years (3). Boys also demonstrate a steady increase in mean strength performance over childhood and adolescence for all percentile curves except for the highest percentiles. The female percentile curve demonstrates a slight decrease after the peak for the highest percentiles or a stabilization for the other percentile curves.

### Standing Long Jump

There is a steady increase in mean strength performance of the standing long jump from childhood to adolescence for both sexes. On average, standing long jump performance in girls stabilizes at the age of 11 years, while boys, demonstrate a steady increase. Both sexes demonstrated no decrease in this timespan.

### Coordination Including Balance

**Figure 3** and **Supplement Tables 6–8** show the results for coordination including jumping sideways, static stand, and balancing backwards.

### Jumping Side-Ways

There is a steady increase in mean jumping sideways performance from childhood to adolescence for both sexes. On average, performance stabilizes

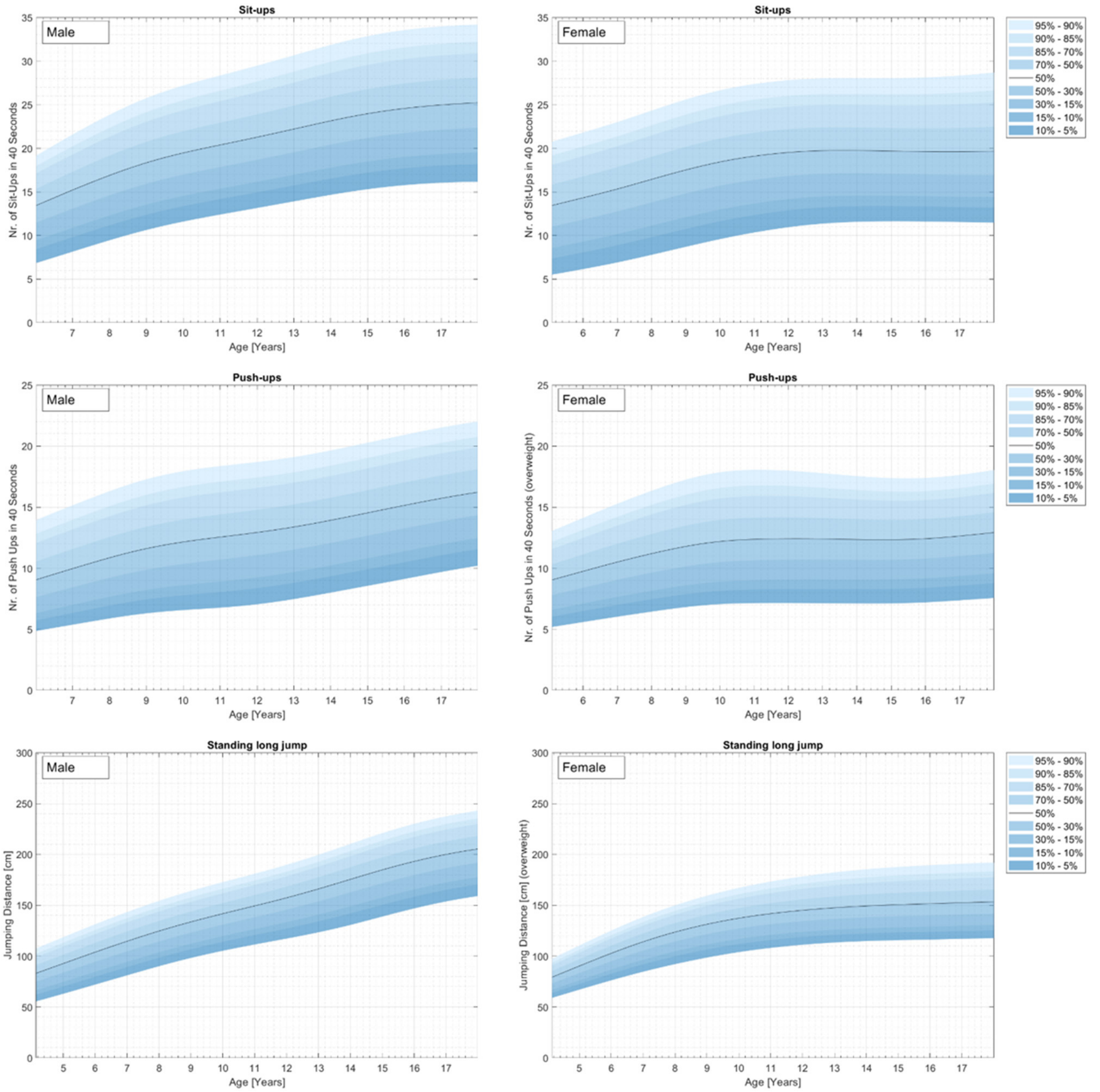


**FIGURE 2 |** Strength curves for the representative sample of German boys and girls aged 4–17 years for the testitems Sit-ups (top), Push-ups (middle), and Standing long jump (bottom).

for both sexes at the age between 12 and 14 years. Both sexes demonstrated no decrease in this timespan.

## Static Stand

There is a steady decrease in mean ground contact from childhood to adolescence for both sexes up to 10–12 years. After that, performance stabilizes. There is a ceiling effect for the high percentiles.

## Balancing Backwards

There is a steady increase in mean balancing performance from childhood to adolescence for both sexes. On average, performance stabilizes for both sexes at an age of 9 years. Both sexes demonstrated no decrease in this timespan.

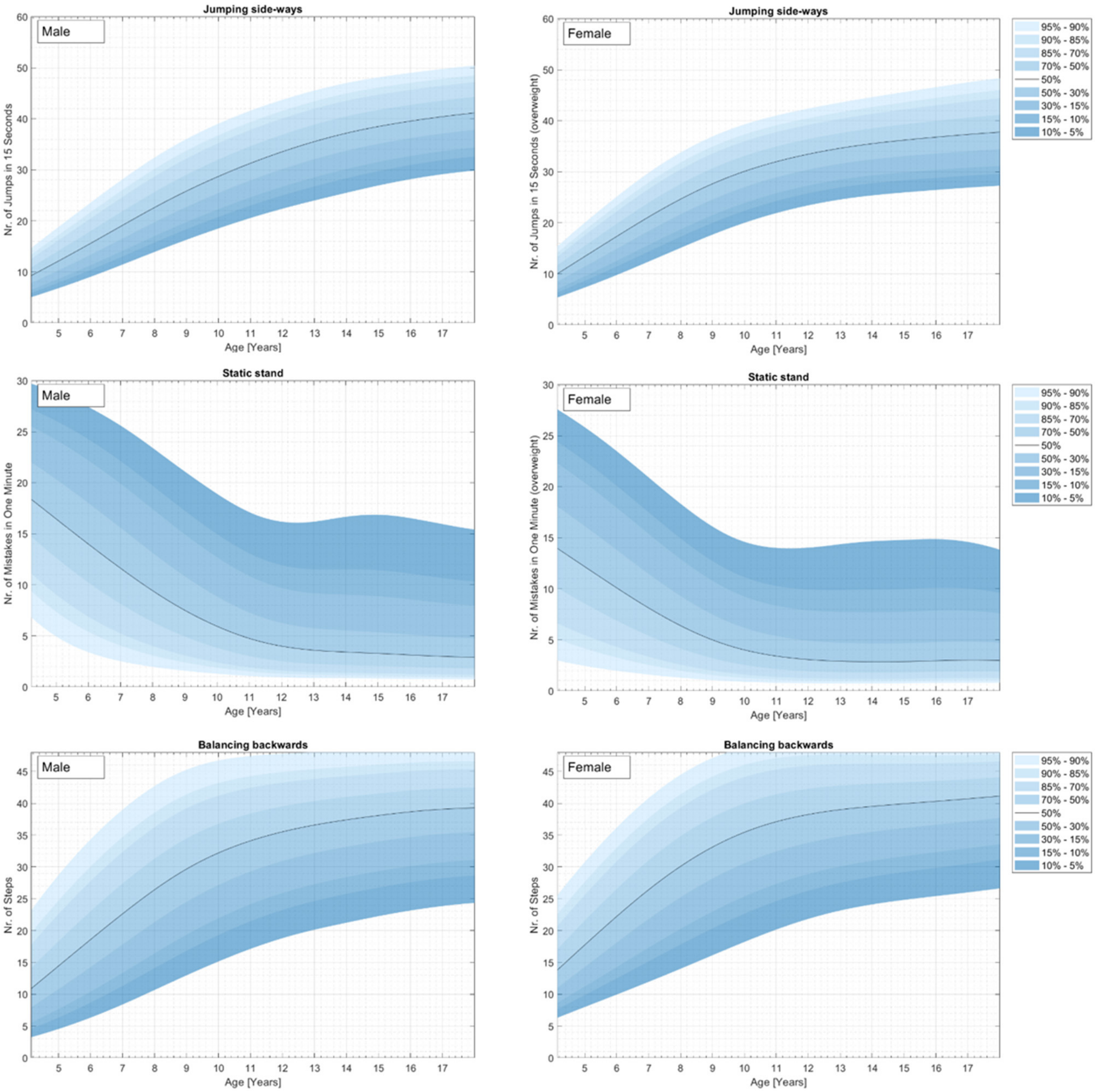


**FIGURE 3 |** Coordination curves for the representative sample of German boys and girls aged 4–23 years for the test items jumping side-ways (top), static stand (middle), and balancing backwards (bottom).

## Flexibility

Results for flexibility are represented in **Figure 4** and **Supplement Table 9**.

### Stand and Reach

In mean, both sexes demonstrate relatively flat percentile curves. Percentiles show a siccors effect with increasing age between the low and the high percentile curves. The low percentile curves decrease steady whereas high percentile curves increase steady from childhood to adolescence.

## DISCUSSION

Poor physical fitness levels are associated with negative health trajectories from early childhood to adulthood e.g., (2, 4, 6). Therefore, it is an important public health goal to improve

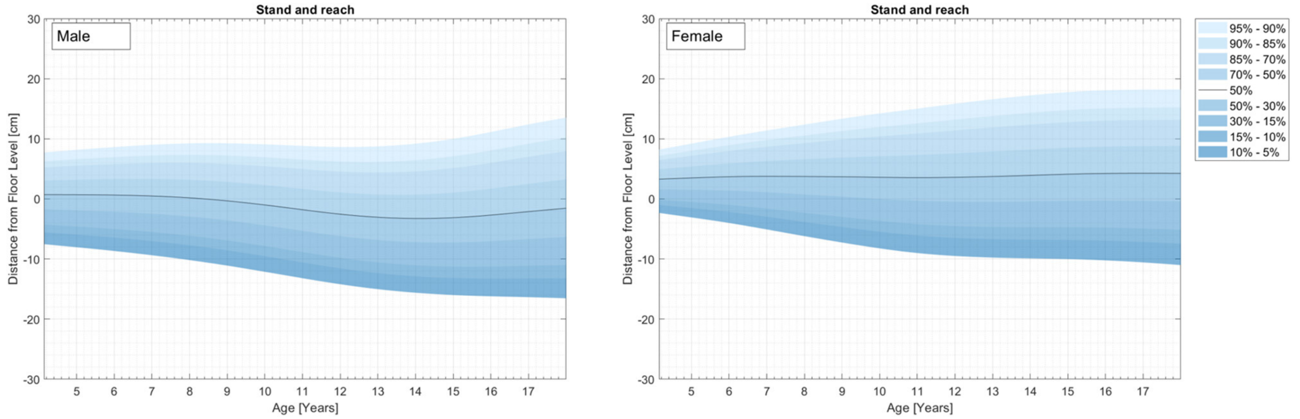


**FIGURE 4 |** Flexibility curves (Stand and reach) for the representative sample of German boys and girls aged 4–23 years.

and maintain physical (i.e., skill-related and especially health-related) fitness levels of children and adolescents as well as their physical self-concepts in order to foster physical activity behavior, e.g., (30, 31). In this regard, public health as well as politics need reliable and valid assessments and representative normative data in order to validly classify people's current fitness level according to their sex and current age. Unfortunately, these normative data did not exist for all fitness assessments and representative samples so far. Therefore, the aim of this study was to provide normative LMS percentile curves for several physical fitness parameters for typical developed German children and adolescents. Using LMS curves provides several advantages for representative normative data. Firstly, the sample size of each age group can be relatively small as the age and sex dependent groups were in the current study, because each age group benefits from adjacent age groups which increases overall accuracy and power of the normative data. Secondly, these adjacent age groups increase the developmental character of the normative data for longitudinal analyses purposes as it has been established for BMI (32) and Bioelectrical Impedance percentiles (33). This is clearly a benefit but also a limitation of this study, because smoothing algorithms might damage the validity of the data under specific circumstances. Therefore, the LMS curves were examined in-depth theory-driven.

Fitting MLS percentile curves for Germany (MoMo Wave 1, 2009–2012) enables us to compare the physical fitness in Germany with other nations which have percentile curves and using same test items. As an example for using our percentile curves we conducted a comparison for the test item standing long jump, as a highly standardized test item, with current European standard values of Tomkinson et al. (34). Boys (9–17 years) in Germany perform worse than their European peers in almost all age groups (e.g., boys 17 year. German P50 = 200,00 cm, European P50 = 205.8 cm). The standing long jump performance of German girls (9–17), on the other hand, is comparable to the European peer group (1). There are some other countries presenting physical fitness percentile curves [Australia: (35), Spain: (36), US Wisconsin: (37), Europe: (34)]. These percentile curves partly allow comparisons between countries, but these comparisons must be interpreted with caution, since the test items, the survey periods, and the samples differ. At first sight, physical fitness levels of populations have a continuous character rather than dichotomous (strict criterion-based "healthy" or "non-healthy"). Hence, it is intuitive to expect most information about children within very detailed percentiles and such population-based percentile distribution curves (and values) can be seen as very useful for public health cross-sectional assessment and prospective evaluation of interventions. However, from a test theoretical point of view (i.e., considering measurement error, test instructor effects, etc.), motor test performance should be interpreted in validated categorization system (or in percentile ranges) instead of single percentile values, because development is rarely truly (38–41). In this regard, percentile curves were provided based on internationally comparable values (i.e., percentiles 5, 10, 20, 30, 50, 70, 80, 90, and 95 as well as interim curves) which have successfully been shown for the measurement of physical fitness across childhood (32, 34, 42).

How "high" the level of physical fitness should be has not been sufficiently researched so far, but it is assumed that certain threshold values of physical fitness should be reached by every child to ensure growing up healthy. Some authors give a fitness level of less than percentile 5 as an indicator of health risks and thus define this value as the boundary between "healthy" and "increased risk for diseases" e.g., (33, 43). The problem with this definition might be that it is based on standard values and do not provide information regarding how the values relates to health (44). The only health-related fitness test that tries to circumvent this problem is the FitnessGram test battery (11) and the $VO_2$max test (45). However, the test items used at Fitnessgram correspond to the type of test used in the MoMo study (e.g., push-up, sit-up, etc.), but they differ in terms of their execution and/or duration. As a result, the health-related fitness cut-off points defined in the FitnessGram cannot be transferred to the MoMo study. However, the determination of cut-off points and so define thresholds on the basis of the MoMo study is in progress, e.g., we are working on the conversion of the PWC 170 values of our study into VO2max values via ergonizer software for sports medical performance diagnostics. The aim is to use the thresholds identified by Ruiz et al. (45) in their systematic literature search for studies that determined a cardiorespiratory fitness cut point that predicted cardiovascular disease risk in children and adolescents.

In Conclusion, we present LMS coefficient relating to representative physical fitness percentile ranges in order to provide cut-offs for children with positive but also negative fitness values. The new LMS curves are available by year from age 4 to 17 years. These LMS coefficient make it easy to compare children's physical fitness levels within one age branch, but also between age brands and longitudinally. We recommend to use these new, rather than old, LMS curves to transform children's raw performances into standard values that enable the identification of children especially in the peripheral areas (16). Finally, we emphasize that the presented normative data should be regularly updated and put in to context with older data to monitor trends in physical fitness performance.

## DATA AVAILABILITY STATEMENT

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

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Karlsruhe Institute of Technology. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

## AUTHOR CONTRIBUTIONS

CN and TU drafted the initial manuscript and reviewed and revised the manuscript. CN and DO coordinated and supervised data collection. CN, DO, and SS modeling the percentile curves. AWol, AWor, and KB conceptualized and designed the study. AH-D supervised data collection and critically reviewed the manuscript for important intellectual content. All authors have read and approved the submitted manuscript.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2020.00458/full#supplementary-material

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# Can Functionalised Play Make Children Happy? A Critical Sociology Perspective

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The functionalisation of play basically stems from the diagnosis of a global childhood inactivity crisis, the so-called "children's obesity pandemic." Hence, in the context of the activity-related guidelines, children's play appears no longer to be unproductive and purpose-free. It is rather considered an anti-obesity tool that will help children to meet physical activity recommendations. It is questionable whether such a functionalised tool can also provide what has been called the salience of the pleasures of free-play for children. Furthermore, a "normalization" of functionalised practices of play, in turn, could stigmatize children who do not or cannot adhere to these practices. Based upon this background, this paper will take a critical sociology perspective to analyse the functionalisation and medicalisation of children's play in an individualized, mediatized, and pedagogised society. In this sense, the paper aims to pay attention to how the primary goal of play in the sense of "simply make children happy" has given way to the goal of making them healthy and functional.

**Keywords: children's play, individualization, functionalization, digitalization, child health, medicalisation, physical activity monitoring**

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## INTRODUCTION

Play has been perceived as so important to optimal child development that it has been recognized by the United Nations High Commission for Human Rights. According to the UN Convention on the Rights of the Child, every child has the right "to rest and leisure, to engage in play and recreational activities" (1). At the same time, current research reports a decline in play among children in the Global North, particularly for middle-class, female, younger, and ethnic-minority children (2).

Historical analyses have highlighted that childhood play is a natural human trait, but its extent depends on socio-cultural conditions in which people live. During many historical eras, such as post-hunter-gatherer societies, in the ages of agriculturalization, or following the industrial revolution, children had only limited opportunities to play because they had to spend most of the daytime working (3). Playing nevertheless occurred, whenever possible, sometime intertwined with labor, without parental or generally adult supervision and direction. Children's play tended to be free and spontaneous; in rural regions it took place in fields, streams, and farmyards, in urban regions it tended to be located in vacant lands and parks (4). However, it was not until the Age of Enlightenment, with the discovery of childhood as an independent phase of life, that children's play was recognized as a human developmental necessity (5).

Children's play, as we know it today, is a phenomenon of modern society. Authors such as Chudacoff (4) have identified the mid-1950s as "golden age" of children's play in North America and potentially the Global North in general. After World War II, children tended to be free from long working hours. Generally, children's play was positively attributed, which was also reflected in the development of supportive environments, such as parks and other playgrounds. However, this "golden age" did not last long. Starting already in the mid 1950s, children's play has been continuously declining. Part of this decline has been attributed to the role of adults and their control and supervision of children's activities (3).

In the following, we will take up the challenge of understanding and explaining this decline and its consequences for public health. Understanding and explaining changes in play requires a broader perspective. Thus, we will apply a critical sociological lens to analyze occurring changes in play. We follow an understanding of children's play as *free play,* as an "activity that is freely chosen and directed by the participants and undertaken for its own sake, not consciously pursued to achieve ends that are distinct from the activity itself" (3). Our central assumption is that free play of children has been increasingly replaced by playful activities which are functionalized in the sense that they are aimed at fulfilling a purpose that is outside the activity. Hence, we argue against the background of the notion that children's leisure lives are reframed (6) in the sense that the basic intention of play to "simply make children happy" (7) has given way to the goal of making them healthy and functional.

In building our argument, we will first provide a critical reflection about four recent trends in today's society that have had an impact on children's play: (i) individualization, pedagogisation, and protection, (ii) indoor- and setting-orientation (iii) mediatisation and digitalization, as well as (iv) medicalisation. Following the critical reflection of those trends, we will discuss the potential consequences of functionalisation to the pleasures linked to free play. We will conclude the paper by arguing for a more holistic understanding of free play to be integrated into physical activity promotion and monitoring in public health.

## TRENDS IN CHILDREN'S PLAY

### Individualization, Pedagogisation, and Protection

In principle, modern meritocratic societies are characterized by the fact that social advancement is not *per se* predetermined by social background. However, the chances of professional success are—among other factors—limited by qualifications and skills, which have to be developed. In this sense, children find themselves in a "state of permanent endangerment" (8). This has consequences, both at the micro- and at the macro-level (9). At the macro-level, the development of talents in each individual has become a central goal of education policy. Hence, the design of learning environments has increasingly focused on a methodically and didactically professionalized promotion of individual strengths and self-development (10). We observe that this pedagogical aspiration has been extended to the earliest childhood, for example, in foreign language courses for 3-months-old babies or special toys for highly gifted toddlers. We call this a "pedagogisation" that also impacts the way in which a child's social sphere is organized at the micro-level. Children's life worlds have become "pedagogised" in order to limit the risks of uncertain biographies and to offer children and adolescents the best possible start in life.

One consequence is that performance pressure already starts in early childhood. The pedagogisation of children's life worlds also causes so-called "helicopter parents" to hovering over their children, eagerly trying to support them wherever they can in order to solve their problems and promote their success (11, 12).

With regard to the spatial structure of these life-worlds, childhood in today's societies tends to be characterized by functionalized "islands." Children and adolescents commute between separate islands throughout the day, from daycare or school to selected enrichment activities, including individual and collective extracurricular sporting, cultural, and leisure opportunities (2). This island structure of the children's life worlds makes children's life dependent on continous parental support. If parents want to provide their children with the broadest possible support for development, they have to transport them from one island to another: from school to the sports club, to the music school, and even to the playdate with friends. Consequently, parents take control over both children's everyday and leisure-time activities as well as their everyday and leisure-time mobility.

As a result of these societal processes of individualization and pedagogisation, time and significance given to schooling and other adult-directed school-like or enrichment activities have increased (3, 13). Increases in time spent at school, pre-school, and kindergarten have come along with decreases in break times. Play tends to take place within structured settings such as P.E. and supervised breaks, daycare and after school care in clubs or recreation centers. Due to the fact that these scheduled activities do not necessarily provide links between each other, children mostly do not have relationships to other children that go beyond the functionalized islands. Furthermore, the pedagogisation of children's lifestyles considerably restricts the opportunities to autonomously explore social spaces in between the specialized islands. Consequently, the time children spend play freely has continuously decreased over the last decades. Data indicates that the time children spent in free play decreased by about 25% in the USA, already between the 1980s and late 1990s (14). Instead, children's games have become functionalised. To promote children's development in the best possible way, they serve a predetermined purpose, take place at a fixed location, and are instructed by professionals (15).

At the same time, parent-children interaction with regard to children's play has changed. For the 1990s, Valentine and McKendrick showed that, due to adult restrictions and parental rules, children's freedom declined significantly for outdoor play and travel in their neighborhoods (16, 17). Several studies have provided more insights on parenting styles to free play, particularly free unsupervised outdoor play. Parenting styles have become of interest to popular media as well as research, and multiple hyper-parenting styles have been identified (18). The already mentioned "helicopter parents" tend to be overly involved and protective parents who supervise their children's activities and often intervene in their children's affairs and make decisions for them (12, 19, 20). Janssen (18) referred to further parental styles, introduced by other authors, that hinder children's autonomy: "Little emperor" parents focus on providing all material goods available to and craved by children. "Tiger moms" strive for extraordinary achievement among their children. Finally, parents characterized by "concerted cultivation" provide children with a plethora of extracurricular activities aimed at giving the children socio-cultural advantages compared to their peers.

Hyper-parenting styles have influenced children's outdoor play (21). Studies showed that more fear for children's safety is linked to less free play (21–25). In this regard, the desire to prevent potentially risky situations is a main barrier toward the exploration of unknown spaces by the children. Consequently, games that had been perceived as normal in earlier generations are now considered dangerous (26). Fear and danger might either lead parents to eliminate children's play, such as to completely forbid unsupervised outdoor play, or to modify play by putting it under parental supervision, accompanying children in every while playful activity or limiting play to the own backyard (27).

## Mediatisation and Digitalization

The consequences of individualization and pedagogisation for children's play are amplified by mediatisation and digitalization. It is not only that parents can use media and digital gadgets to constantly supervise their children's play and their locations (28). In today's Global North, the children's world itself is shaped by information and communication technologies. Due to the digitalization of life-worlds, socio-spatial conditions of growing up have fundamentally changed. Internet-based communication technologies have become a natural part of everyday life. According to Statista, almost every adolescent over 11 owns a smartphone in Germany (29). For some adolescents, smartphones have become so important for coping with everyday life that they perceive these devices as a parts of their own body (30).

With regard to the structures of everyday communication, instant messaging (e.g., WhatsApp, Snapchat, iMessage, or Hangout) has become much more important for the communication with peers than phone calls (31), potentially also more important than face-to-face communication. Digitalization boosts the individualization of everyday communication (9). Communication via WhatsApp or Snapchat does not rely on instantly responding to messages, as it is the case with analog face-to-face communication. Messages are read and answered, when it suits the recipients. Digitalization also impacts social relationships. Emotions are expressed by emoticons and emojis. Facial expressions and nonverbal gestures, fundamentally important for analog communication, play a minor role in digitalized communication.

In a digitalized society, adolescents do not communicate less. However, it is different *how* they communicate. Social negotiation processes play a less important role. In many cases, it is no longer important to "read" body language. The social restrictions of digitalized everyday communication may lead to deficits in adolescents' development of social skills which are relevant for playing games in analog worlds (32). The shift toward digital activities might also minimize positive effects associated with offline events, such as opportunities to increase social capital, build and enlarge networks as well as transform relationships to a deeper level (33).

On the other hand, the internet enables us to transcend concrete geographic space. The ability to communicate virtually independent of time of day and location provides the opportunity to create virtual "meeting places" (34). In this sense, digitalized communication offers participation and inclusion in an otherwise fragmented lifeworld by creating a second "virtual" reality, including new playgrounds and meeting places. At the same time, certain multiplayer online role-playing games might allow for digital social interaction and positive effects on social capital (35). Those might result in new friendships that can deepen through shared interest whereas non-playing offline friends might get neglected.

The trend toward digitalization will ultimately result in a, at least partly, transfer of play into virtual playfields or arenas. Especially virtual playfields are nowadays increasingly used to promote physical activity among children.

## Medicalisation

One consequence of individualization and mediatisation of children's play is the trend toward creating games for children to serve health-related purposes. Behind the development of exergames or serious games is the idea that children who tend to be inactive can be motivated to exercise via playful and enjoyable activities. The WHO, for example, states that "for children who are currently inactive, progressive increase in activity to reach the target through additional time for free active play will have health benefits" (36). With similar intent, a clinical report by the Committee on Psychosocial Aspects of Child and Family Health and the Council on Communications and Media of the American Academy of Pediatrics (37) emphasizes the health-related benefits of play even aims aim to provide information "to write a prescription for play at well visits to complement reach out and read" (37).

This "medicalization of play" basically stems from the diagnosis of a global childhood inactivity crisis, the so-called "children's obesity pandemic." Hence, in the context of the activity-related guidelines, children's play is primarily discussed to tackle the problem of inactivity (38–40). In this regard, the Active Healthy Kids Global Alliance developed a matrix for national report cards on children's core physical activity, initiated by Active Healthy Kids Canada in 2004 (39). The matrix considers "active play" as one indicator of core physical activity (41). So far, Active Healthy Kids research working groups from 49 countries have adopted the procedure and presented national report cards. For Germany, Demetriou et al. (38) have very recently presented the German report card and concluded that $<25\%$ of children and adolescents play actively for several hours per day.

The flipside of this well-meant trend is that children's play no longer appears to be unproductive and purpose-free. It is rather considered an anti-obesity tool that will help children reach the recommended 60 min of physical activity per day (36). Data already has indicated that functionalised play could become a privileged and exclusive support activity for some children only. Middle-class children in England participate to a higher degree in functionalised play activities, such as extracurricular sporting and leisure activities, than working-class children, even though parents of both classes value such activities in similar ways (2). A relevant factor in this regard is the ability to incorporate functionalised play into the life-worlds of families. Since this transfer seems to work better in middle-class families, functionalised playing activities in these families can compensate the loss of free unstructured play to a higher degree than working-class families in England (2). Hence, a "normalization" of functionalised practices of play could stigmatize children who do not or cannot adhere to these practices (42).

Furthermore, it is questionable whether a functionalised anti-obesity tool can also provide what Sutton-Smith has called the salience of the pleasures of free play for children (7).

## CAN FUNCTIONALIZED PLAY PROVIDE THE PLEASURES OF CHILDREN'S FREE PLAY?

Data already indicates that the restriction of free play may have a negative impact on the general well-being of children (43, 44). Free play is an activity that is (a) voluntary, (b) open and uncertain, (c) separated from everyday life, (d) unproductive and self-sufficient, (e) regulated, and (f) fictional (45).

First, *voluntary participation* is indispensable for play, one cannot really be forced to play. Play only takes place "when the players have a desire to play, and play the most absorbing, exhausting game in order to find diversion, escape from responsibility and routine" (45). Play thus represents a space of action sought for its own sake. Play enables the actors to satisfy their current needs for action and to experience the joy of immediate activity. Play is an activity that is motivated by the quality of life, excitement, satisfaction, and joy experienced in the course of action. People can become absorbed in play, fully immerse themselves in the activity, receive intensive feedback about their own abilities, find a pleasure-oriented approach to (physical) culture and thereby experience a feeling of initiative and causation through play. Second, the *openness and uncertainty* of the outcome is a further characteristic of play. Particularly for children and adolescents, the uncertainty—which is often difficult to bear—and the associated risk of failure seem to be dimensions of play that promote individual development and growth. Playing confronts children and adolescents with multiple challenges and it supports to establish a relational relationship between someone's world of experience and the person's relevant environment. While playing, children exhibit a multitude of social behaviors and interactions, and take up various social status roles (46). These roles mirror to a certain extent the life-worlds, in which the children are growing up. Third, play is *a separate activity* that takes place in a special world that is clearly distinguishable from the world of day-to-day life. Play takes place in its own time and space. Ideally, nothing is created through playful activity that is of significance outside that activity. In this sense, play is, fourth, an *unproductive activity* that is sufficient in itself but in contrast to the ordinary day-to-day life. Fifth, since cultural ideas and conventions have an effect on how to play, play appears to be a *regulated activity*, but its rules may well conflict with the legal or day-to-day regulations of the living environment. Due to the conscious "as-if" character of the activity, play is, sixth, also a *fictional activity* whose "unreality" stimulates dedicated playing and the experience of joy both during as well as after play.

In principle, children's play can contribute to the development of intrinsic motivation and competence, decision-making and problem-solving skills, self-control and emotional regulations, friendship skills and social capital (3). Children's free play also embodies the dynamic of the dramatic increase and decrease of tension. Hence, play allows to practice the drama of interpersonal relationships in a protected environment in a casual way (47). As such, play plays an important role in Piaget's process of accommodation and assimilation and also serves for empowerment.

The fact that children's play particularly contributes to the experience of joy makes it such a valuable tool for public health programs. From the perspective of critical sociology, however, it is questionable, whether activities like "energetic play" (36), "free active play" (36), "active play" (38, 41) or "active outdoor play" (39, 48), which are implemented as parts of public health programs, are indeed fun for the children. The use of these terms in the context of public health is not neutral. Rather, it can be regarded as a sign of objectification and functionalisation in the current discourse on play in public health and physical activity promotion (26). Making "active play" or "active free play" a research object and promoting it as part of public health concerns may (re-)define the way play is understood and experienced. From the perspective of a sociology of the child, Alexander et al., among others, have already hinted at the underlying paradox in this discourse: advocating, promoting and discussing children's play might reshape it into a new form that is purpose-driven and thus no longer free and intrinsically motivated (6). In this sense, a highly pre-structured, functionalised playing activity bears the risk that it no longer primarily aims at what Sutton-Smith identifies as the main function of free play of children: that it simply "makes them happier" (7).

From the perspective of critical sport sociology, a more reflective discussion of functionalized play is needed that pays attention to the current "reframing of children's leisure lives" (6). Such a critical reflection should particularly focus on the potential harmful consequences of transforming a leisure activity that allows risk-taking and provides fun (which is what childhood should be about in the first place) into a much more constrained, managed, and supervised intervention.

The functionalisation of play in the field of health promotion has a particularly interesting dynamic in the form of so-called "serious games." Marsh (49) defines serious games as follows: *"Serious games are digital games, simulations, virtual environments and mixed reality/media that provide opportunities to engage in activities through responsive narrative/story, gameplay or encoun- ters to inform, influence, for well-being, and/or experience to convey meaning. (...) Serious games are identified along a continuum from games for purpose at one end, through to experiential environments with minimal or no gaming* *characteristics for experience at the other end."* These games are developed, designed, marketed and distributed by companies. Within the framework of the serious games, health-related content is taken up and integrated into an exciting story, which should ensure a sustainable motivation for healthy behavior. At the same time, the companies are oriented toward selling the games and thus primarily follow a market logic. To the extent that business enterprises, due to their market interest, integrate algorithms into the games that create dependency on playing or even play addiction, the health promotion intention is thwarted. Thus, e-games may deviate from the idea of free children's games in two respects: On the one hand, the games are pre-programmed, methodised and internationalized to a large extent. In this regard, one can also expect effects of social inequality. In milieus, in which physical activity is considered a relevant instrument to foster the development of children, functionalised e-games will probably be given to children, while milieus that are far away from movement will become impoverished in terms of physical activity. On the other hand, the attempt to encourage children to consume these games in a sustainable way and—linked to this—to buy updates or new versions, prevent adolescents from freely deciding for or against the game. Given that the particularly motivating health-promoting e-games for children are most at risk to cause dependency, guidance of children becomes of central importance.

Current statistics on the media behavior of children during the COVID-19-pandemic show how important supervision of children's use of digital technologies is. According to a recent German FORSA survey with 500 children on behalf of a large German health insurance, 95 percent of all parents report that their children spent significantly more time in front of PCs and smartphones during time of school lockdowns (50). In this regard, it is not only the use of communication technologies, social media, streaming services or e-games, but also the massive upswing of digital learning that leads to an increase of time spent sedentarily. Only in a small percentage of the children, this behavioral change is compensated by physical activity, for example by more outdoor activities in gardens or parks (38 percent). A Facebook Messenger survey on behalf of ParentsTogether with over 3,000 parents came to a similar conclusion in the USA (51). The average time spent online has doubled for kids during the crisis. Almost half of the children spent more than 6 h online per day (compared to only 8.29% before), 26% of kids even spent more than 8 h online (compared to 4% previously) during the lockdown. The most prominent platforms and apps used by children whose parents completed the survey were mostly non-educational: YouTube (78.21%), Netflix (49.64%), and TikTok (33.41%) (51).

## CONCLUSIONS

The functionalisation of play in the context of health promotion basically attempts to resolve a paradox: to integrate the motivational characteristics of free play into an actually unfree setting. This idea is well-intentioned and principally aimed at promoting the best interests of children. However, so far there has been no empirical evidence on its actual outcome. In a highly digitalized social world characterized by functionalization, isolation, and commercialization, there are hardly any spaces left in which children can have development-promoting experience without adult guidance. Serious games that are designed to promote a healthier behavior in children are therefore not necessarily the best answer on global health challenges. This is even more true when considering the potential opposite effects to those intended, namely if serious games increase the children's sedentary time. From a critical-sociological perspective, there is another interesting dynamic in the functionalization of play in form of e-games. Implicitly, this dynamic means that public health authorities delegate some of their responsibility for the promotion of citizens' health (comparable with similar tendencies in the field of education) to commercial enterprises whose interests by no means fully coincide with the tasks of public institutions. One could therefore say that governments do not fulfill their obligation to secure collective goods for society but that they leave gaps to be filled by commercial enterprises.

The question remains what public health strategies can be recommended to promote "healthy and development-promoting" play? Instead of pre-structured games, some of which take place on the computer, public health should rather aim to create stimulating movement environments in which children can act freely, invent their own rules, test these rules, measure each other, learn to cooperate, i.e., to make use of the socialization potential of sport and movement, which is neglected in guided, controlled worlds. This includes, firstly, the appropriation and questioning of norms and, secondly, the ability to develop design possibilities where social norms are lacking. Secondly, this includes learning the ability to act autonomously and to apply social norms in a reflective and flexible manner, both of which are a prerequisite for the development of an "ego-strength." Thirdly, this also includes developing the competence to weigh self-interest against group interests in less pre-structured game worlds and to be able to make decisions that meet social obligations without neglecting one's own goals. PA-promoting free play areas should ideally be linked locally to schools and kindergartens to ensure that all children are reached. These areas should not be supervised and it should be left to the children themselves how and what they play. If one considers the socially contagious effects of free play, then it is to be expected that children will get moving.

Monitoring children's play then could focus on the infrastructures of settings in which free play should take place. Thereby, the design for the settings should also make sure to differentiate target groups in alignment with how they are affected from the decline of PA and to which degrees.

Parents who are involved in children's life, public health professionals, and researchers who are interested in understanding and monitoring children's play can bring back happiness to children's play. In this regard, children's play need to be contextualized in a holistic way. Parents, professionals, and researchers need to put children's perspectives and experience at center. From this perspective, the monitoring of play environments for children should primarily focus on whether play can "simply make children happy" (45). If this works, one can ultimately also expect benefits with regard to the children's physical, mental, and social health.

## DATA AVAILABILITY STATEMENT

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

## AUTHOR CONTRIBUTIONS

AF had the idea for the paper. AF and AT wrote and edited the draft article. All authors contributed to the article and approved the submitted version.

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# Trends in Neuromotor Fitness in 10-to-12-Year-Old Dutch Children: A Comparison Between 2006 and 2015/2017

*Manou Anselma[1]*, Dorine C. M. Collard[2], Anniek van Berkum[1], Jos W. R. Twisk[3], Mai J. M. Chinapaw[1] and Teatske M. Altenburg[1]*

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Children with a low level of neuromotor fitness are less skilled to participate in sports activities. Moreover, lower levels of neuromotor fitness are related to adiposity, lower cardiovascular health, and poor self-esteem in children. The aim of this paper was to determine neuromotor fitness in 10–12-year-old Dutch children over a 10-year period. Test scores measured in 2015/2017 ($N = 533$ in 2015, $N = 941$ in 2017) were compared with scores of same-aged children measured in 2006 ($N = 1986$). Neuromotor fitness was assessed using the MOPER fitness test battery, including speed and agility, strength, flexibility, and coordination and upper-limb speed. Data were analyzed using multilevel linear regression models and tobit regression analyses in case of skewed distributions with an excess of zeros. Analyses were stratified by age and gender, and adjusted for level of urbanization. Children in 2015/2017 performed significantly worse on speed and agility ($\beta = 0.8$ to 1.1 s), significantly better on coordination/upper-limb speed ($\beta = -1.0$ to $-0.6$ s), and–except for 12-year-old girls–significantly worse on flexibility vs. children in 2006 ($\beta = -3.4$ to $-1.8$ cm). Additionally, upper-body strength was significantly worse among 10-year olds ($\beta = -3.2$ to $-2.5$ s) while leg strength was significantly worse among 11-year-olds in 2015/2017 vs. 2006 ($\beta = -1.8$ to $-1.7$ cm). Trunk strength was worse among 11- and 12-year old boys ($\beta = 1.1$ to 1.2 s). In line with a previously observed downward trend in neuromotor fitness among children (1980–2006), we found worse scores on speed and agility, and flexibility in 2015/2017 vs. 2006, stressing the need for interventions aimed at improving neuromotor fitness in order to promote physical activity and future health.

**Keywords: physical activity, secular trend, youth, neuromotor fitness, MOPER fitness test**



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## INTRODUCTION

Physical fitness is defined as "a set of attributes that people have or achieve", which are health- and skill-related attributes that aid performing physical activity (1). Health-related physical fitness consists of aerobic and neuromotor fitness. Neuromotor fitness comprises the components flexibility, coordination, muscle strength, muscle endurance, and speed of movement (1). Better fitness in children is associated with improved future health (2, 3). There is strong evidence for an inverse relationship between neuromotor fitness components and adiposity, cardiovascular health, bone health, and self-esteem (3). Furthermore, children with low levels of neuromotor fitness can experience difficulties with participating in sports activities as they do not have the physical skills required for the complex movements in sports (4). Children who do not participate in sports are also less likely to participate in sports through adolescence and into adulthood (5, 6), thereby increasing the risk for negative health outcomes at all ages (2, 7, 8). Therefore, it is worrisome that worldwide declining trends in childhood physical fitness scores are observed. A systematic review showed a decline in aerobic fitness scores in 6–19-year-old children from 27 countries between 1970 and 2003 (9). Studies on neuromotor fitness showed similar results (10–14). Lower muscular fitness scores in children were observed in different studies on various tests: 10-year-old English children scored lower on handgrip, sit-ups and bent-arm hang in 2008 vs. 1998 (12); Canadian children scored lower on sit-and-reach and handgrip in 2007/2009 vs. 1981 (11); Lithuanian 11–18-year-old children scored lower on standing broad jump, sit-and-reach, and bent-arm hang in 2012 vs. 1992 (14); and Czech children aged 8–9 and 12–13 scored lower on standing broad jump and sit-ups in 2013 vs. 1986 (13). Lower neuromotor fitness scores were also observed on bent-arm hang, sit-and-reach, $10 \times 5$ meter run, leg-lift, and plate-tapping in a large sample of Dutch 9–12-year-olds in 2006 vs. 1980 (10). However, it is unknown how this trend developed since 2006, as no data on neuromotor fitness of Dutch children have been published since.

The current paper compares neuromotor fitness scores of the same sample measured in 2006 with scores of 10–12-year-old Dutch children measured in 2015 and 2017, to gain insight in neuromotor fitness trends in the Netherlands in the last decade. As the last decade has seen many interventions aiming to improve physical activity of children in the Netherlands (15, 16), the current study can provide insight into the effectiveness of these efforts on neuromotor fitness of children and required future policy directions.

# MATERIALS AND METHODS

## Recruitment & Participants

For this study, data from three different studies were combined: baseline data collected in 2006 from the "iPlay" -study (10), data from a cross-sectional study in 2015, and baseline data collected in 2017 from the "Kids in Action" project. The iPlay-study included 2,208 children (aged 9–12 years) from 40 primary schools throughout the Netherlands. The original focus of the iPlay-study was to develop and evaluate a program to prevent sport and physical activity related injuries. More details on the study protocol and results are reported elsewhere (10, 17). The cross-sectional study performed in 2015 included 1000 children (aged 9–12 years) from 18 primary schools in and around the city of 's Hertogenbosch, the Netherlands. The original focus of this study was to determine the neuromotor fitness levels of children in order to indicate which children had a low fitness level. The Kids in Action study included 656 children (aged 9–12 years) from eight primary schools in and around Amsterdam, the Netherlands. The original focus of Kids in Action was to engage 9–12-year-old children from a low socioeconomic neighborhood in the co-creation of interventions to improve their physical activity and dietary behavior. The eight participating schools were located in neighborhoods of low socioeconomic position (18). In all three studies recruitment of children was conducted via schools. In 2015 and 2017, the MOPER test was conducted as part of a regular physical education class and therefore all children attending the respective physical education class participated in the test. In 2006 all children in grades 7 and 8 were eligible to participate in the study, and those who participated in the study took part in the fitness test. In 2017, four intervention schools were approached and all schools participated. Control schools were contacted ($N = 22$) until four schools agreed to participate (19). Parents of eligible children received a letter containing information on the study and a form to decline their child's participation (passive consent; participation rate 99.1%). In 2015, the MOPER test was conducted as part of the physical education class at 18 primary schools by the "care sport connector" working at the schools. The care sport connector links sports to several other sectors such as care and education. Data from all children participating in those physical education classes were obtained. Because the MOPER test was used as a student monitoring system in school, informed consent was not obtained. In 2006, 520 primary schools were invited to participate in the iPlay-study of which 40 primary schools were included. Parents of eligible children from grades 7 and 8 received a letter containing information on the study and a form to decline their child's participation (passive consent; participation rate: 99.9%). As the three studies only included a small number of children under the age of 10 and over the age of 12 years, these children were not included in the analysis. The Medical Ethics Committee of the VU Medical Center approved the iPlay (2006.129) and Kids in Action (2016.366) study.

## Measurements

### Procedures

All three studies used the same, standardized protocol of the Motor Performance (MOPER) fitness test (20). The MOPER fitness test consists of eight items in total: $10 \times 5$ meter run, leg-lifting while laying down, plate-tapping, bent-arm hang, sit-and-reach, arm pull, standing high jump, and a 6-min run test. The MOPER fitness test is considered a valid and reliable measurement tool in children aged 9–18 years (21). The average test-retest coefficient was 0.57 for the high-jump and at least 0.74 for the other items in 9–11-year old boys and girls (21). Assessment of structural validity showed low correlations between test items—correlation coefficients ranging from 0.1 to 0.4—indicating that each item measures a unique characteristic of children's neuromotor fitness (21). In the "Kids in Action" study, the arm-pull test was interchanged for a hand-grip test and in both the "Kids in Action" and "iPlay" study, the 6-min run test was not conducted for practical reasons. Therefore, these tests were not included in the analysis. **Table 1** presents a description of the included items of the MOPER fitness test and their metric units.

**TABLE 1 |** Description of the MOPER fitness test items used in this study.

| Item | Characteristic | Description | Unit |
|---|---|---|---|
| 1. 10 × 5 meter run | Speed and agility | 10 times running between 2 lines with a five meters distance as fast as possible, 2 attempts | s |
| 2. Plate-tapping with one hand | Coordination and upper limb speed | Tapping two plates alternately with the dominant hand 50 times as fast as possible, 2 attempts | s |
| 3. Bent-arm hang | Upper body strength | Hanging from a horizontal bar with bended arms as long as possible, 1 attempt | s |
| 4. Standing high jump | Explosive leg strength | Jumping up from a standing position as high as possible, 2 attempts | cm |
| 5. Leg-lifting while laying down | Trunk and leg strength | Lifting outstretched legs 10 times while laying on back as fast as possible, 1 attempt | s |
| 6. Sit-and-reach | Flexibility | Reaching from sitting position with outstretched legs and arms as far as possible, 3 attempts | cm |

The MOPER test was conducted during a physical education lesson in the school's gym. In 2006 the MOPER was conducted at the beginning of the school year (September), in 2015 and 2017 at the end of the school year (April-May). The children had no previous experience with the test and were not familiarized with the test items. Trained researchers, physical education teachers and/or sports instructors conducted the tests. The participating children were divided into groups of two to four children and they performed the test items one by one. The participants performed the MOPER test bare foot and were encouraged by the instructors to perform optimally.

### Covariates

Children's age and gender were obtained prior to the MOPER test. Urbanization was included as a confounder as it has been associated with neuromotor fitness in children (22). Data on the degree of urbanization of the school's neighborhood was obtained from Statistics Netherlands (23). The classification of population density in a neighborhood was divided into five categories: extremely high density (>2,500 addresses per km$^2$), high density (1,500–2,000 addresses per km$^2$), moderate density (1,000–1,500 addresses per km$^2$), low density (500–1,000 addresses per km$^2$), and extremely low density (<500 addresses per km$^2$).

### Statistical Analyses

Descriptive characteristics and fitness test data were analyzed using means, standard deviations or medians and 25$^{th}$-75$^{th}$ percentiles, and frequencies. For the fitness data first assumptions of normality, linearity, homoscedasticity and the absence of multicollinearity were checked.

The data collected in 2015 and 2017 were combined to increase the sample size. The comparison between the 2006 and 2015/2017 fitness test scores was made using multilevel linear regression analyses for normally distributed variables. The multilevel analyses accounted for the hierarchical structure of the data by adjusting for the clustering of children's test results within schools (24), e.g., due to different physical activity programs or culture between schools. The residuals of two tests were not normally distributed. The "leg-lifting" scores were log-transformed resulting in a normal distribution of the residuals, and therefore multilevel linear regression analyses were used. Due to the skewed distribution and excess of zeros, differences in "bent-arm hang" were analyzed using tobit regression analysis. All analyses were stratified by age and gender, to provide insight in possible age- and gender-specific trends. Analyses were adjusted for the degree of urbanization of the school's neighborhood. Betas (β) and 95% confidence intervals (CI) are reported; the betas of the log-transformed data have to be interpreted as a ratio. *Post-hoc* power calculations showed that the sample size is sufficient to detect a difference of 3-8% as statistically significant. The statistical analyses were conducted using IBM SPSS Statistics 22.0.

## RESULTS

Children were on average 10.8 (SD = 0.7) years old (51% girls) in 2006 and 11.0 (SD = 0.8) years old (52% girls) in 2015/2017. In the 2006 sample, 41% of children attended a school in a high or extremely high density neighborhood, while this was 62% in the 2015/2017 sample.

**Table 2** (girls) and **Table 3** (boys) provide the results of all fitness tests (mean and standard deviation, median and interquartile range, beta and confidence interval), stratified by age. Both girls and boys in all age categories performed significantly worse on the "10 × 5 meter run" in 2015/2017 vs. 2006 and significantly better on "plate-tapping". Girls and boys in 2015/2017 ran about 1 s (β ranging from 0.8 to 1.1 s, depending on age and gender) slower than girls and boys in 2006, and were almost a second (β ranging from −1.0 to −0.6 s) faster on "plate-tapping". "Sit-and-reach" scores were significantly worse in 2015/2017 vs. 2006 in girls (β ranging from −3.4 to −1.8 cm) and boys (β ranging from −2.8 to −2.3 cm), except for 12-year-old girls. Girls and boys in all age categories performed worse in 2015/2017 vs. 2006 on the "bent-arm hang" test, but this was only significant in 10-year-old girls (β = −3.2 s) and boys (β = −2.5 s). 11-year-old girls (β = −1.8 cm) and boys (β = −1.7 cm) scored significantly worse on "standing high jump" in 2015/2017 vs. 2006.

11- and 12-year-old boys scored significantly worse on "leg-lifting" in 2015/2017 vs. 2006 (β of log-transformed data = 1.1 and 1.2 s). In girls, no significant differences were found.

## DISCUSSION

This study investigated differences in neuromotor fitness in Dutch 10–12-year-old children in 2006 vs. 2015/2017. Children scored worse in most age and gender categories in 2015/2017 on speed and agility ("10 × 5 meter run") and flexibility ("sit-and-reach"). 10-year olds scores worse on upper body strength ("bent-arm hang") and 11-year-olds on explosive leg strength ("standing

**TABLE 2 |** MOPER fitness test scores for girls in 2006 and 2015/2017, stratified by age.

| **Girls** | **10-year-olds** | | | **11-year-olds** | | | **12-year-olds** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **2006** | **2015/2017** | **%** | **2006** | **2015/2017** | **%** | **2006** | **2015/2017** | **%** |
| 10x5 meter run (s)[1] $\bar{x}$ (SD) | 20.1 (1.5) | 21.2 (1.8) | +4.9 | 19.9 (1.5) | 20.9 (2.0) | +5.0 | 19.8 (1.6) | 20.7 (2.1) | +4.5 |
| β (95% CI)[2] | **1.0 (0.6; 1.4)*** ** | | | **0.9 (0.6; 1.3)*** ** | | | **0.8 (0.3; 1.4)** ** | | |
| *n* | 372 | 222 | | 516 | 329 | | 109 | 213 | |
| Bent-arm hang (s)[3,4] $\tilde{x}$ (IQR) | 6.0 (3.0–14.0) | 5.0 (1.0–10.0) | −16.7 | 6.0 (2.0–13.0) | 4.0 (1.0–10.0) | −33.3 | 6.0 (2.0–12.0) | 4.0 (1.0–11.0) | −33.3 |
| β (95% CI)[2] | **−3.2 (−5.2; −1.1)** ** | | | −0.8 (−2.4; 0.7) | | | −0.8 (−3.3; 1.6) | | |
| *n* | 372 | 224 | | 521 | 330 | | 109 | 213 | |
| High jump (cm)[3] $\bar{x}$ (SD) | 35.8 (6.3) | 34.6 (6.4) | −3.4 | 37.3 (6.3) | 35.2 (6.5) | −5.6 | 37.5 (6.4) | 36.4 (6.3) | −2.9 |
| β (95% CI)[2] | −0.6 (−2.2; 0.9) | | | **−1.8 (−2.9; −0.8)** ** | | | −1.4 (−3.0; 0.7) | | |
| *n* | 373 | 224 | | 520 | 330 | | 109 | 213 | |
| Leg-lifting (s) [1,4,5] $\tilde{x}$ (IQR) | 16.3 (13.9–19.1) | 14.8 (13.2–17.6) | −9.2 | 16.5 (14.2–19.9) | 15.9 (13.9–20.0) | −3.6 | 16.3 (13.8–21.0) | 15.4 (13.3–18.3) | −5.5 |
| β (95% CI)[2] | 1.0 (0.9–1.1) | | | 1.0 (1.0–1.1) | | | 1.0 (0.9–1.1) | | |
| *n* | 369 | 223 | | 519 | 330 | | 107 | 212 | |
| Sit-and-reach (cm)[3] $\bar{x}$ (SD) | 30.4 (6.0) | 28.4 (7.1) | −6.6 | 30.2 (6.2) | 26.8 (7.3) | −11.3 | 29.1 (6.6) | 28.1 (7.7) | −3.4 |
| β (95% CI)[2] | **−1.8 (−3.2; −0.4)*** | | | **−3.4 (−4.4; −2.4)*** ** | | | −1.1 (−3.0; 0.7) | | |
| *n* | 373 | 224 | | 515 | 330 | | 109 | 213 | |
| Plate-tapping (s) [1] $\bar{x}$ (SD) | 15.2 (1.8) | 14.6 (2.0) | −3.9 | 14.4 (1.8) | 13.7 (2.0) | −4.9 | 14.1 (1.7) | 13.2 (1.8) | −6.4 |
| β (95% CI)[2] | **−0.8 (−1.3; −0.3)** ** | | | **−0.7 (−1.1; −0.4)*** ** | | | **−0.9 (−1.4; −0.3)** ** | | |
| *n* | 372 | 224 | | 521 | 330 | | 109 | 213 | |

*[1] A lower value indicates a better test score [2] 2015/2017 vs. 2006 [3] A higher value indicates a better test score [4] Data not normally distributed, therefore the median ($\tilde{x}$) and interquartile range (IQR) (25th-75th percentiles) are provided [5] Data have been log-transformed, therefore the β should be interpreted as a ratio. Bold is significant, by *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.*

high-jump"). In contrast, children in 2015/2017 performed better on coordination/upper limb speed ("plate-tapping") vs. 2006.

In contrast to a Dutch study comparing neuromotor fitness scores of children between 2006 and 1980 (10), the current study found no significant differences on trunk and leg strength ("leg-lifting") and improved scores on coordination and upper limb speed ("plate-tapping") in 2015/2017 vs. 2006 in most age and gender groups. A possible explanation for the improved "plate-tapping" scores could be the increase in computer use and gaming (25). Playing certain video games can promote fine motor skills and movement coordination (26), which may have contributed to children's improved "plate-tapping" scores. The item "leg-lifting" showed only worse scores in 11- and 12-year-old boys. In 2006 vs. 1980 all age and gender categories scored significantly worse on upper body strength ("bent-arm hang"), while in the current study significant worse scores were only found in 10-year olds in 2015/2017 vs. 2006. Lastly, in 2006 vs. 1980 children in all age and gender categories scored significantly better on explosive leg strength ("standing high-jump"), while the current study only found significantly worse scores in 11-year-olds.

Previous studies evaluating motor fitness of children over a longer time period showed mixed results. Several studies in Europe and Canada observed worse scores on most items of the motor fitness tests over the past two decades (11, 12, 27). In contrast, one study in Portuguese children demonstrated better scores on speed, trunk strength, and flexibility in 2013 compared to 1993, and no changes in explosive leg strength (28). The authors contributed the improvements to more access to and participation in organized sports of Portuguese children over this time period. The Dutch study comparing neuromotor fitness scores of children between 2006 and 1980, found worse neuromotor fitness scores in 2006 on upper body strength, flexibility, speed and agility, trunk and leg strength, and coordination and upper limb speed (10). The current study again shows significantly worse scores in 2015/2017 vs. 2006 on speed and agility, and flexibility in boys aged 10–12 years and girls aged 10 and 11 years. The declines on these test-items were small, for example only about 1 s on the "10 × 5 meter run," but differences are comparable to and in some instances larger than reported in the study comparing scores from 2006 to 1980 in the Netherlands (10). Our finding that the downward trend in certain neuromotor fitness scores from 1980 to 2006 has continued from 2006 to 2015/2017, may have important implications for physical activity enjoyment and participation and as a result future health (29).

The downward trend over the last decades in children's neuromotor fitness may be related to downward trends in children's motor competence (30). A study funded by the Dutch ministry showed lower levels of motor competence (balancing, swinging on a rope, aiming at a high target, catching and throwing a small ball via the wall and playing tennis against a wall) in Dutch children from 2006 vs. 2016 (31). The Dutch government responded to these alarming results by implementing several policies to improve children's motor competence (32), such as the recent adoption of an amendment that obligates Dutch primary schools to provide at least 2 h of physical education per week (33). In the past decade a number of Dutch policies have focused on improving physical activity and/or motor competence

**TABLE 3 |** MOPER fitness scores for boys in 2006 and 2015/2017, stratified by age.

| Boys | 10-year-olds | | | 11-year-olds | | | 12-year-olds | | |
|---|---|---|---|---|---|---|---|---|---|
| | **2006** | **2015/2017** | **%** | **2006** | **2015/2017** | **%** | **2006** | **2015/2017** | **%** |
| 10 × 5 meter run (s)[1] $\bar{x}$ (SD) | 19.7 (1.5) | 20.7 (2.2) | +5.1 | 19.4 (1.6) | 20.4 (2.2) | +5.1 | 19.2 (1.5) | 20.1 (2.0) | +4.7 |
| β (95% CI)[2] | **0.9 (0.4; 1.4)**** | | | **1.0 (0.5; 1.5)***** | | | **1.1 (0.5; 1.6)***** | | |
| *n* | 366 | 205 | | 459 | 298 | | 153 | 204 | |
| Bent-arm hang (s)[3,4] | 9.0 (4.0–20.0) | 5.0 (1.0–10.0) | −44.4 | 9.0 (4.0–18.0) | 7.0 (2.0–16.0) | −22.2 | 10.0 (4.0–21.0) | 7.0 (1.0–15.8) | −30.0 |
| $\tilde{x}$ (IQR) β (95% CI)[2] | **−2.5 (−5.0; −0.0)*** | | | −1.5 (−3.5; 0.6) | | | −2.9 (−5.9; 0.1) | | |
| *n* | 365 | 205 | | 458 | 298 | | 153 | 204 | |
| High jump (cm)[3] $\bar{x}$ (SD) | 36.8(5.8) | 35.8(6.3) | −2.7 | 38.6(6.5) | 36.8(6.7) | −4.7 | 39.6(6.5) | 39.2(7.0) | −1.0 |
| β (95% CI)[2] | −0.8 (−2.2; 0.5) | | | **−1.7 (−3.0; −0.4)**** | | | −0.5 (−2.1; 1.2) | | |
| *n* | 367 | 205 | | 460 | 298 | | 153 | 204 | |
| Leg-lifting (s)[1,4,5] $\tilde{x}$ (IQR) | 16.4 (14.2–20.0) | 15.8 (13.4–19.8) | −3.7 | 16.7 (13.9–21.4) | 16.8 (13.9–21.0) | +0.6 | 16.4 (13.9–20.8) | 17.2 (13.5–22.3) | +4.9 |
| β (95% CI)[2] | 1.0 (0.9–1.1) | | | **1.1 (1.0-1.2)*** | | | **1.2 (1.0-1.4)*** | | |
| *n* | 363 | 205 | | 449 | 298 | | 147 | 203 | |
| Sit-and-reach (cm)[3] $\bar{x}$ (SD) | 27.0 (6.4) | 24.6 (6.5) | | 25.4 (6.9) | 22.7 (6.8) | −10.6 | 25.5 (7.1) | 23.6 (6.6) | −7.5 |
| β (95% CI)[2] | **−2.3 (−3.4; −1.2)***** | | −8.9 | **−2.8 (−4.0; −1.6)***** | | | **−2.3 (−4.1;−0.5)*** | | |
| *n* | 365 | 205 | | 459 | 298 | | 153 | 204 | |
| Plate-tapping (s)[1] $\bar{x}$ (SD) | 15.6 (1.9) | 14.6 (1.9) | −6.4 | 14.8 (1.8) | 14.0 (2.0) | −5.4 | 14.1 (1.9) | 13.4(1.8) | −5.0 |
| β (95% CI)[2] | **−1.0 (−1.4; −0.6)***** | | | **−0.7 (−1.1; −0.3)**** | | | **−0.6 (-1.1; −0.2)*** | | |
| *n* | 367 | 205 | | 59 | 298 | | 153 | 204 | |

*[1] A lower value indicates a better test score [2] 2015/2017 vs. 2006 [3] A higher value indicates a better test score [4] Data not normally distributed, therefore the median ($\tilde{x}$) and interquartile range (IQR) ($25^{th}$-$75^{th}$ percentiles) are provided. [5] Data have been log-transformed, therefore the β should be interpreted as a ratio. Bold is significant, by *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.*

of children. Practical implications of our results are that upper-body strength and flexibility need specific attention in physical education or physical activity interventions. Implementing internationally standardized tests as part of the school curriculum could provide more insight in time trends and risk groups, and consequently lead to better tailored interventions. Future research has to determine the effects of implemented policies on children's neuromotor fitness and motor competence, as well as physical activity levels and health indicators.

A major strength of this study is the large sample size, including 1986 children in the 2006 sample and 1,474 in the 2015/2017 sample. The use of the same fitness test items and a standardized measurement protocol further strengthens this study as non-standardization of tests has been a problem in previous studies (11). Lastly, the current study compares neuromotor fitness levels in children in 2015/2017 vs. 2006 and such recent data was not available yet. A major limitation of this study is that no data was available at both the individual and school level on potential covariates such as physical activity level, socioeconomic position, cultural background, and BMI, while these could have influenced the results. The schools neighborhoods for example differed in the percentage of people with a non-Western background, with ∼11.4% in 2006 and 23.1% in 2015/2017 (34). We adjusted for the degree of urbanization of the school's neighborhood, as that was the only data available. Unfortunately, we could also not adjust for BMI. A previous study including the 2006 MOPER data showed that even when children with overweight and obesity were excluded from the analyses, most declines in children's neuromotor fitness scores from 1980 to 2006 remained significant (10). This suggests that the inferior neuromotor fitness scores found in current generations are not only due to the higher prevalence of overweight, however, we could not verify this in the current study.

## CONCLUSIONS

The current study found that the previously observed downward trend in most components of neuromotor fitness among 10–12-year old Dutch children from 1980 to 2006 continued from 2006 to 2015/2017. Persistent low scores were found on most strength components and worsened scores on speed and agility and flexibility (with the exception of 12-year-old girls for the latter item) in 2015/2017 vs. 2006. This downward trend in neuromotor fitness can have important implications on physical activity enjoyment and participation and thereby future health. Therefore, improving children's neuromotor fitness from an early age should be a larger public health priority and be reflected as such in local and national policy.

## DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors for scientific research.

## ETHICS STATEMENT

The iPlay (2006.129) and Kids in Action (2016.366) study were approved by the Medical Ethics Committee of the VU Medical Center. Written informed consent for participation was not provided by the participants' legal guardians/next of kin because: in 2015, the MOPER test was used as a student monitoring system in school and therefore informed consent was not obtained; in 2006 and 2017, parents of eligible children received a letter containing information on the study and a form to decline their child's participation.

## AUTHOR CONTRIBUTIONS

TA, MC, and MA designed the 2017 study. MA coordinated and led data collection in 2017 with AB assisting the data collection. DC and MC designed the 2006 study with DC coordinating and leading data collection. AB conducted the data cleaning and assisted in the first draft of this manuscript. MA wrote the manuscript with DC, MC, and TA providing critical input and feedback. JT assisted with the data analysis. All authors contributed to the article and approved the submitted version.

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# Secular Trends of Physical Fitness in Twenty-Five Birth Cohorts of Slovenian Children: A Population-Based Study

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In Slovenia, the national SLOfit surveillance system of the somatic and motor development of children and youth has been enabling researchers to observe the developmental trends of the entire population of school-aged children since 1987. The national database currently incorporates over 7.2 million sets of measurements of eight fitness tests and three anthropometric measurements. Since 1991, as in the rest of the world, in Slovenia, there is a common perception that the physical fitness of contemporary children is in decline and below the level of the physical fitness of the previous generation's childhood fitness. Our paper examines the trends of physical fitness in 26 birth cohorts of 7–10-year-olds. The analysis shows that the secular trends of physical fitness in boys and especially in girls have been positive and that the level of physical fitness of recent birth cohorts exceeds the national average of physical fitness of the 1989–2019 period. At the same time, the analysis reveals that the distribution of physical fitness has been changing from almost normal in the cohorts born in the first half of the 1980s, toward positively skewed in the subsequent cohorts born before the year 2000, and bimodal distribution in the later cohorts, indicating growing inequality and polarization of the motor development of children.

**Keywords: physical fitness, children, secular trends, cohort, SLOfit**



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## INTRODUCTION

There is a common perception that the physical fitness of children has declined over the last few generations due to growing sedentary behavior, lack of habitual physical activity, and the easy availability of energy-rich food. This perception, however, is based on a great deal of anecdotal and lay speculation since the evidence, deriving from longitudinal cohort studies of secular trends in physical fitness is scarce and the existing evidence inconclusive. The assessments of the secular trends of physical fitness of children have been distinctly understudied and have been mostly derived from temporal studies, relying mostly on cross-sectional designs, usually comparing only individual or joint age-groups of children at two or three time-points, predominantly comparing data on relatively small samples of one or several age-groups, and using a variety of different test batteries (1–14). Some studies of secular trends have been focusing only on the components of in aerobic fitness (15–17), while others focused only on the components muscular fitness (18–22).

We were unable to identify any study that used the cohort design of population data for the assessment of the secular trends in general physical fitness, which is why there is a lack of evidence on the actual secular trends of distribution of physical fitness comparing one generation of children to the other at multiple time points.

When studying secular trends of physical fitness, it is not sufficient to observe only the changes in the central tendency but also the changes in its distribution among the observed groups. We were, however, unable to identify any study of secular trends in physical fitness that addressed the problem of secular changes in its distribution; this is mainly due to a lack of national monitoring systems for the development of physical fitness that could regularly provide population data or at least nationally representative large datasets on the annual level.

In recent years, Hungary (23), Portugal (24), and Finland (25) have introduced national monitoring systems for the assessment of children's somatic development and functional capacity, but several years of measurements are required before they will be able to assess the secular trends of children's physical fitness in at least a few age groups of schoolchildren, since none of the systems covers the entire age-span of the school-going population. In Slovenia, however, the SLOfit national surveillance system for somatic and motor development of children and youth, implemented in 1982 (26), already enables the analyses of secular trends of childhood physical fitness of several generations on the population level.

The purpose of this study is not merely to analyze temporal trends bit to assess the actual secular trends of general physical fitness of Slovenian children (between ages 7 and 10) in 26 birth cohorts, born from 1983 until 2008, on the population data of the 1991–2019 period. In addition, the analysis attempts to assess whether the statistical distribution of physical fitness remained normal throughout generations with the entire population experiencing similar trends, or the distribution became skewed due to growing differences, reflected in the polarization of results at both extremes.

## MATERIALS AND METHODS

### Participants

The analysis included 1,953,847 measurements of children (girls $n = 953{,}001$, boys $n = 1{,}000{,}847$) from 26 birth cohorts. Children from every birth cohort were measured annually at ages 7, 8, 9, and 10. The oldest cohort was born between January 1, and December 31 in 1983 and the youngest in 2008. In 2019, the youngest cohort was in primary school grade 5. The number of boys and girls in individual birth cohorts at age 10 are visible in **Figure 1**. After the breakup of Yugoslavia, Slovenia experienced a decrease in natality rates, which was reversed after 2003 and is also reflected in the number of children measured. The average response rate was around 94%, ranging from 88.7% in the 1986 birth cohort to 97.7% in the 2008 cohort. The difference in response rates between girls and boys was negligible and did not exceed 0.3% on the average.

### Instruments

#### Physical Fitness Assessment

The SLOfit test battery was used to assess the level of physical fitness of every child. This battery includes three anthropometric measurements (height, weight, and triceps skinfold thickness) and eight fitness tests (arm plate tapping, standing broad jump, backwards obstacle course, sit-ups in 60 s, stand and reach, bent-arm hang, 60-m dash, and 600-m run) (27).

Since each fitness test indicates a specific component of physical fitness, we used the Physical Fitness Index (PFI) based on the results of all fitness test as a single indicator of general physical fitness. A similar approach, utilizing a single indicator (Physical Fitness Indicator) based on the percentage of change of physical fitness, was utilized in two recent studies of physical fitness trends in Chinese populations (10, 13). In our case, PFI provides information about the percentile ranking of every child in the population of all Slovenian children in the 1989–2019 period ($N > 7.2$ million). To calculate the PFI, percentile scores of all eight fitness tests were calculated for each age-group, separate for boys and girls. Then, the mean percentile value of the eight fitness tests was calculated, each test contributing equally to PFI. The results of fitness tests were not adjusted to weight, height, triceps skinfold thickness, or BMI. The mean of eight fitness tests for every child was again ranked, and percentile score of PFI established on the entire population of the Slovenian children in the 1989–2019 period. In this way, the results of all individual tests for every child were ranked against the results of all children of same age and sex from 1989 onwards.

### Procedure

The SLOfit national surveillance system of somatic and motor development is a part of the Slovenian educational system. Its primary purpose is to provide teachers insight into the status of the somatic and motor development of their pupils to better plan and implement the PE lessons and other curricular and extracurricular sporting activities. All primary and secondary schools in Slovenia are required to organize and carry out annual assessments of the somatic and motor development for all children, with parental consent. The physical fitness tests are administered annually every April in the children's schools by physical education teachers according to the uniform national protocol and standardized equipment (27). All the schools in Slovenia send children's measurement results to the Laboratory for Physical and Motor Development Diagnosis at the Faculty of Sport, University of Ljubljana, where the data are cleaned, analyzed, and evaluated; feedback reports sent back to schools. The results of every child are rigorously checked using specially designed software, with all the ambiguities communicated back to the PE teachers and subsequently corrected. All PE teachers in Slovenia are educated at the Faculty of Sport and are thoroughly trained in the SLOfit measurements and data management, which are also regulated by the education legislation at the national level. In this way, the SLOfit system has been able to limit the individual influences of the observers on the results and sustain a high and homogeneous level of quality of data collection through the years.

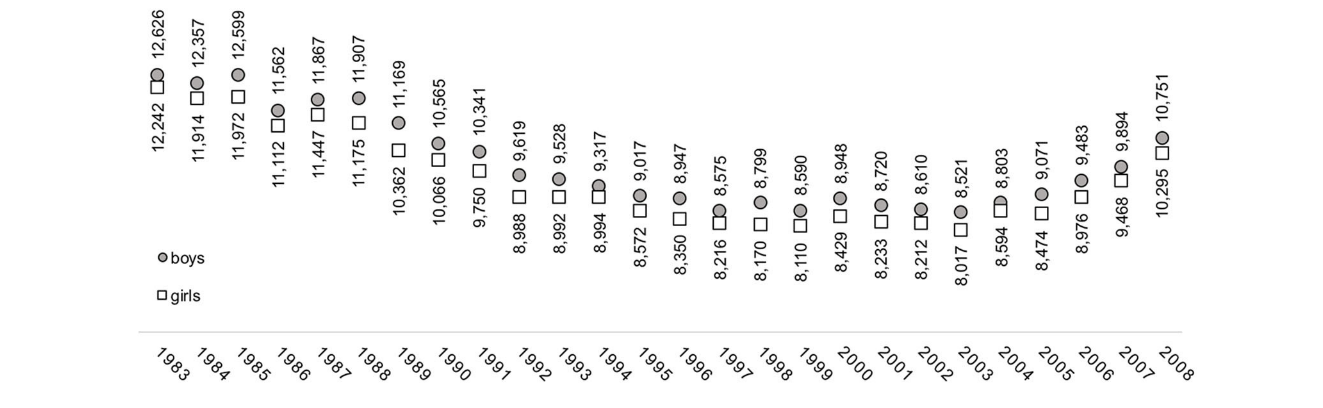


**FIGURE 1 |** The number of boys and girls in the analyzed birth cohorts at age 10.

The longitudinal cohort data with repeated measures were obtained from the SLOfit database to perform an exploratory analysis of secular trends of physical fitness. The selected age-span between 7 and 10 was used to minimize the effects of pubertal growth on physical fitness. Prior to the implementation of the 9-year primary school in the 1999/2000 school year, children in Slovenia had been entering primary school at age 7, but with the 9-year primary school, the admission age was changed to 6. The cohorts born before 1991, therefore, have data available only from age 7 onwards, which is why the data from age 6 was not included in the analysis.

## Statistical Analysis

The SPSS 26.0 for Mac statistical package was used to carry out the data analysis (Armonk, NY: IBM Corp.). The Kolmogorov–Smirnov test and Levene's test were used to determine the nature of the data. They provided scores below 0.05, whereby a decision was made to produce non-parametric statistics. The Generalized Linear Models (GLMs) method was used (28) to compare the secular trends of physical fitness in 26 birth cohorts. We used the AIC method of goodness of fit to construct the comparison model. GLMs with linear variable response distribution were selected, with model-based estimator of co-variance matrix. Wald Chi-square statistics with confidence interval type, and maximum likelihood estimation method was used to build the interaction model between the birth cohorts as a factor and PFI as dependent response variable to assess the secular trends in boys and girls. No tests for random effects were performed. Since PFI is a percentile value, calculated separately for every age and sex, we did not include the two variables in the model as covariates. Results were considered significant if $P < 0.05$. To assess the secular changes in the distribution of PFI in different birth cohorts, we produced histograms, and visually inspected the shape of distribution separately in boys and girls.

# RESULTS

**Tables 1**, **2** show the statistics of the GLMs for boys and girls, respectively, which show significant differences in physical fitness between the youngest birth cohorts and the majority of older birth cohorts. They show that after the decline of physical fitness in the birth cohorts from the 1990s, the trends improved in the cohorts from the 2000s.

For boys, there was no significant difference in PFI between the 2008, 1983, 1986, and 2006 cohorts, while all other cohorts, except for the 2007 birth cohort, had significantly lower PFI than the 2008 reference cohort ($P < 0.005$) (**Figure 2**). The 2000 birth cohort in boys experienced the poorest development of physical fitness while the first cohort that again exceeded the average national PFI of the 1989–2019 period was the 2004 birth cohort.

For girls, the positive secular trend of PFI was much more pronounced and started improving in the 1991 birth cohort (**Figure 2**), but there were significant differences in PFI between the 2008 birth cohort and all other birth cohorts except for the cohort born in 2007 ($P < 0.010$). All the birth cohorts of girls until 2001 were below the average national PFI of the 1989–2019 period, but all younger birth cohorts achieved the level of PFI above the national average. The lowest level of PFI in girls was observed in the 1990 birth cohort.

Although the analysis refutes the commonsensical speculations of declining general physical fitness and evidence about the positive secular trend, the changes in the distribution of PFI tell another interesting story (**Figure 3**). Namely, with every generation of boys and girls after 1983, the distribution of PFI deviated from the normal one toward the bimodal distribution with pronounced extremes, which evidence about a worrying trend of increasing inequality and polarization of physical fitness development in recent cohorts. More evidence of growing inequality is the growth of the share of children at both extremes of the distribution, specifically, those with poor physical fitness below the 5th percentile of the 1989–2019 period, and those with extraordinary physical fitness above 95th percentile (**Figure 4**). For boys and girls, the share of children with extremely low PFI was growing with every birth cohort until the year 2000 but has afterwards started to decline, although it is still higher than in the generations born in the 1980s. In contrast, the share of children with extremely high PFI has been growing with almost every generation, which has been especially expressed in girls. The share of girls with extremely high PFI in the most recent five generations has doubled in comparison with

**TABLE 1 |** GLMs statistics for boys.

| Birth cohort | *B* | SE | 95% Wald CI | | Hypothesis test | |
|---|---|---|---|---|---|---|
| | | | Lower | Upper | Wald Chi-Square | Sig. |
| (Intercept) | 51.057 | 0.1466 | 50.769 | 51.344 | 121,269.658 | 0.000 |
| 1983 | −0.094 | 0.2046 | −0.495 | 0.307 | 0.213 | 0.645 |
| 1984 | −0.591 | 0.2044 | −0.991 | −0.190 | 8.352 | 0.004 |
| 1985 | −0.925 | 0.2031 | −1.323 | −0.527 | 20.752 | 0.000 |
| 1986 | −0.092 | 0.2063 | −0.496 | 0.313 | 0.198 | 0.657 |
| 1987 | −1.247 | 0.2048 | −1.648 | −0.845 | 37.064 | 0.000 |
| 1988 | −0.850 | 0.2054 | −1.253 | −0.448 | 17.145 | 0.000 |
| 1989 | −1.717 | 0.2086 | −2.126 | −1.308 | 67.755 | 0.000 |
| 1990 | −1.830 | 0.2114 | −2.244 | −1.416 | 74.920 | 0.000 |
| 1991 | −2.031 | 0.2123 | −2.447 | −1.615 | 91.479 | 0.000 |
| 1992 | −1.391 | 0.2162 | −1.814 | −0.967 | 41.356 | 0.000 |
| 1993 | −2.145 | 0.2169 | −2.570 | −1.720 | 97.795 | 0.000 |
| 1994 | −2.454 | 0.2177 | −2.881 | −2.028 | 127.115 | 0.000 |
| 1995 | −2.084 | 0.2183 | −2.512 | −1.657 | 91.178 | 0.000 |
| 1996 | −2.387 | 0.2181 | −2.814 | −1.959 | 119.734 | 0.000 |
| 1997 | −2.398 | 0.2194 | −2.828 | −1.968 | 119.427 | 0.000 |
| 1998 | −2.893 | 0.2198 | −3.324 | −2.463 | 173.215 | 0.000 |
| 1999 | −2.898 | 0.2205 | −3.330 | −2.466 | 172.747 | 0.000 |
| 2000 | −3.095 | 0.2174 | −3.522 | −2.669 | 202.646 | 0.000 |
| 2001 | −1.969 | 0.2192 | −2.398 | −1.539 | 80.695 | 0.000 |
| 2002 | −2.368 | 0.2193 | −2.798 | −1.938 | 116.598 | 0.000 |
| 2003 | −1.704 | 0.2200 | −2.135 | −1.272 | 59.936 | 0.000 |
| 2004 | −0.747 | 0.2181 | −1.175 | −0.320 | 11.735 | 0.001 |
| 2005 | −1.123 | 0.2166 | −1.548 | −0.699 | 26.900 | 0.000 |
| 2006 | −0.256 | 0.2137 | −0.675 | 0.163 | 1.432 | 0.231 |
| 2007 | 0.642 | 0.2113 | 0.228 | 1.056 | 9.226 | 0.002 |
| 2008 | 0[a] | | | | | |

[a] *2008 is a reference cohort.*

the 1983 generation, but overall, the overall share of boys and girls at both extremes rose by more than 70 per cent from 1983 to 2007 birth cohorts.

## DISCUSSION

Our findings suggest that children in Slovenia have been experiencing positive trends of general physical fitness development, which was much more pronounced in girls than in boys. In this sense, our results do not reflect the negative global temporal trends of children's physical fitness (29, 30).

Furthermore, our findings suggest that the distribution of PFI in different birth cohorts changed from almost normal into bimodal due to growing differences in the development of children, evidencing that a part of the population did not experience the same favorable development.

The average level of general physical fitness in Slovenian children has been increasing with almost every generation of boys who were born since the year 2000, and especially with almost every generation of girls, born in the post-Yugoslav period from 1991 onwards, which is in concordance and probably related to the recent finding that the trends of overweight and obesity among Slovenian children and youth have been in decline from 2010 onwards (31).

Although we were unable to identify any other study that compared the secular trends of general physical fitness between different generations, the findings of our study show the opposite trends than the majority of recent studies of secular and temporal trends from other countries (4, 5, 7–11, 13, 18, 21). Nevertheless, we identified two recent studies that showed somewhat similar results to our analysis. A study among the Portuguese school children established the positive trend of certain components of physical fitness in the period between 1993 and 2013 (6), but the secular trends in our study are most similar to the trends among German children, who experienced a slight positive increase in numerous physical fitness components in the 2003–2017 period (14). The similarity of our results with the secular trends in Germany was also observed in the more expressed positive trend among girls, which was in opposition to the findings of the above-mentioned recent studies in which the trends of physical fitness were most often more negative among girls than boys.

**TABLE 2 |** GLMs statistics for girls.

| Birth cohort | B | SE | 95% Wald CI | | Hypothesis test | |
|---|---|---|---|---|---|---|
| | | | Lower | Upper | Wald Chi–Square | Sig. |
| (Intercept) | 53.822 | 0.149 | 53.529 | 54.115 | 129,716.781 | 0.000 |
| 1983 | −4.294 | 0.208 | −4.701 | −3.886 | 426.668 | 0.000 |
| 1984 | −4.132 | 0.208 | −4.540 | −3.725 | 395.143 | 0.000 |
| 1985 | −5.506 | 0.207 | −5.913 | −5.099 | 704.600 | 0.000 |
| 1986 | −4.902 | 0.210 | −5.314 | −4.490 | 544.259 | 0.000 |
| 1987 | −5.820 | 0.209 | −6.229 | −5.411 | 777.780 | 0.000 |
| 1988 | −5.707 | 0.210 | −6.119 | −5.295 | 737.415 | 0.000 |
| 1989 | −7.015 | 0.215 | −7.436 | −6.593 | 1,063.253 | 0.000 |
| 1990 | −7.432 | 0.216 | −7.856 | −7.008 | 1,178.927 | 0.000 |
| 1991 | −6.628 | 0.218 | −7.055 | −6.200 | 922.504 | 0.000 |
| 1992 | −5.354 | 0.223 | −5.790 | −4.918 | 579.157 | 0.000 |
| 1993 | −5.794 | 0.223 | −6.230 | −5.358 | 677.419 | 0.000 |
| 1994 | −5.811 | 0.222 | −6.246 | −5.376 | 685.885 | 0.000 |
| 1995 | −5.500 | 0.224 | −5.939 | −5.061 | 603.873 | 0.000 |
| 1996 | −4.644 | 0.224 | −5.083 | −4.204 | 428.686 | 0.000 |
| 1997 | −4.242 | 0.225 | −4.683 | −3.802 | 356.548 | 0.000 |
| 1998 | −4.072 | 0.226 | −4.515 | −3.629 | 324.899 | 0.000 |
| 1999 | −4.704 | 0.227 | −5.149 | −4.260 | 429.917 | 0.000 |
| 2000 | −3.873 | 0.224 | −4.312 | −3.435 | 299.629 | 0.000 |
| 2001 | −3.783 | 0.225 | −4.224 | −3.342 | 282.201 | 0.000 |
| 2002 | −2.851 | 0.225 | −3.291 | −2.411 | 161.055 | 0.000 |
| 2003 | −1.709 | 0.226 | −2.151 | −1.266 | 57.272 | 0.000 |
| 2004 | −0.585 | 0.223 | −1.021 | −0.149 | 6.916 | 0.009 |
| 2005 | −1.710 | 0.223 | −2.147 | −1.273 | 58.758 | 0.000 |
| 2006 | −0.272 | 0.219 | −0.702 | 0.158 | 1.534 | 0.215 |
| 2007 | 0.314 | 0.216 | −0.110 | 0.738 | 2.109 | 0.146 |
| 2008 | 0[a] | | | | | |

[a] *2008 is a reference cohort.*

Despite the established positive secular trends of physical fitness in Slovenia, the changes in the distribution of PFI suggest a growing inequality in the opportunities for physical activity and polarization of physical fitness in the population, which could be connected to socio-economic reasons as was already evidenced in the studies of Danish children (2, 15) in which children from different socio-economic conditions experienced different trends of development. The almost normal distribution of physical fitness in the Slovenian cohorts, born in the first half of the 1980s who spent their pre-school period of life without computers and other screen technology, was rapidly changing into a positively skewed distribution with every new generation, resulting in growing numbers of children with low levels of physical fitness and diminishing numbers of children with high levels of physical fitness. In the 2010/2011 school year, Slovenia launched a national intervention program, Healthy Lifestyle, which provided two additional lessons of physical education per week to more than 30,000 children and significantly improved the perception of physical activity as a prerequisite of healthy development in the general public and also in schools that were not involved in the program. In the last decade, a large number of schools in Slovenia have also implemented other forms of "super-standard PE," resulting in increased time available for professionally guided physical activity within school settings. The Healthy Lifestyle program and other forms of additional PE were increasingly available to the cohorts of children born after the year 2000 and probably contributed to the improvement of physical fitness, but they did not add to the normalization of its distribution even if they have helped to improve the overall population median. In these cohorts, the positively skewed distribution of physical fitness became bimodal with a tendency toward negative skewness, evidencing the possibility to decrease the number of children with low physical fitness and increasing the number of children with excellent levels of physical fitness.

The methodology of our study differs substantially from the other existing studies of secular trends of physical fitness; it is also larger in scale and broader in scope than the previous studies, which make the direct comparison with other studies difficult but at the same time introduces a new perspective on the intra-generational change in physical fitness of children. By using a single indicator of physical fitness, incorporating most components of cardiorespiratory,

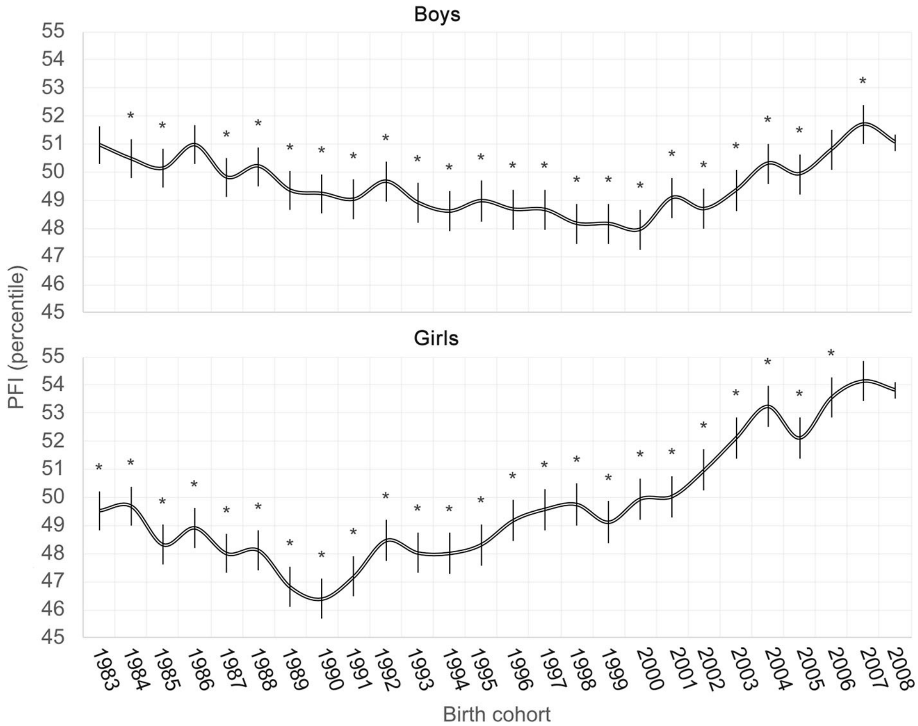


**FIGURE 2 |** Secular trends of physical fitness in boys and girls (*significant difference from the reference birth cohort of 2008).

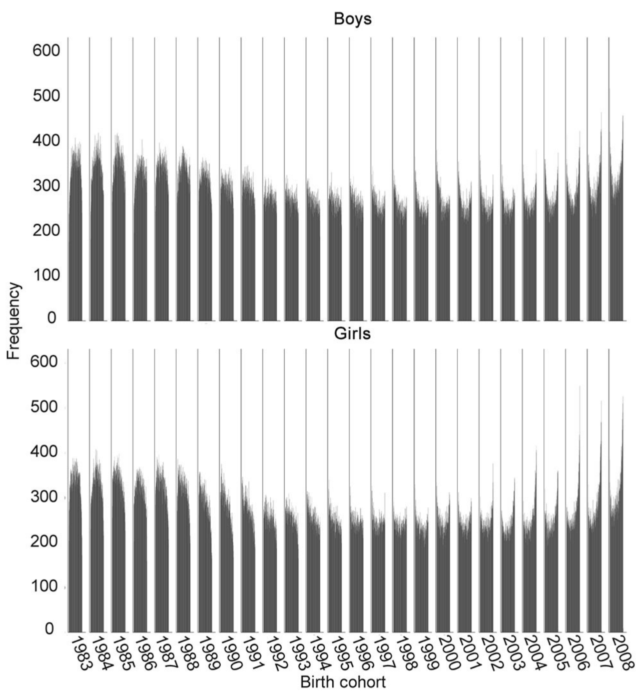


**FIGURE 3 |** Distribution of PFI in boys and girls (mean percentile, CI, *significant difference from the reference birth cohort of 2008).

muscular, and neuro-motor physical fitness, we attempted to surpass the limitations of looking only at a certain component of physical fitness. By looking at the physical fitness of individual birth cohorts throughout several years (7–10), we also attempted to avoid the limitations of looking only at a status of physical fitness of a cohort at only one time-point, which can be strongly influenced by individual differences in physical maturation. In comparison to the existing studies, our study does not focus only on the central tendency of the trend but also looks at the changes in the distribution of physical fitness, identifying a problem of growing inequality of physical fitness development.

The main strength of our study is its robustness due to the population data, its small probability bias due to high response rates, well-established test battery, highly qualified PE teachers performing the measurements, as well as its uniform measurement protocol and cohort design. However, it also has certain limitations. It uses one indicator of physical fitness as the aggregate of cardiorespiratory, muscular, and neuro-motor fitness, which can mask the negative trends in individual dimensions of physical fitness on behalf of positive trends in another dimension (for secular trends of individual fitness tests see **Supplementary Figures 1–8**). The analyzed data also do not enable the inclusion of various covariates that could reveal the causes of improved secular trends. The results are convincing and confirm that the physical fitness of children in

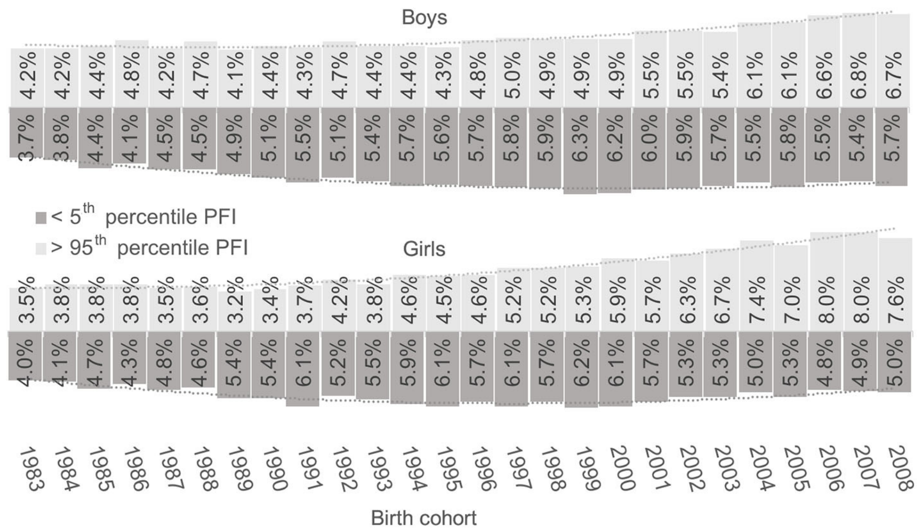


**FIGURE 4 |** Share of children above 95th and below 5th percentile of PFI per birth cohort.

Slovenia is improving, but they do not provide the answers about which environmental factors are the main cofounders and mediators of this improvement. Future research should, therefore, focus on studying the secular trends of physical fitness with different socio-economic indicators as covariates and should differentiate between children who were involved in interventions and sports training programs and those that were not. Although significant emphasis is placed on the assurance of the quality of data due to the high competence level of the PE teachers in measurement procedures, by standardized measurement conditions, and rigorous centralized data cleaning procedures, there are a large number of tests, a large number of schools, and a large number of children in a long period, which can compromise the quality of the data to some extent.

Lastly, the observed positive secular trends were studied only on the population of children between their ages 7 and 10 and do not provide information on the further development of their physical fitness in adolescence in adulthood.

## CONCLUSION

Our study attempted to assess the secular trends of physical fitness and changes in its distribution in 23 birth cohorts of Slovenian children. Our primary research questions attempted to determine whether the negative temporal trends, evidenced in the majority of other studies, have also been evident in the population of Slovenian children and whether the changes in the central tendency of physical fitness change were equally distributed throughout every cohort.

The PFI of Slovenian children, as an indicator of physical efficiency, encompassing cardiorespiratory, muscular, and neuromotor fitness, shows that the secular trends of physical fitness of children in Slovenia are positive and that the recent generations of girls are experiencing strong emancipation through participation in regular physical activity and sport. Their level of physical fitness is superior to that of their mothers, born more than 20 years ago. The most recent cohorts of boys also managed to reach the physical fitness level of their fathers despite the unfavorable, sedentary environment in which they have been living. This positive trend is in contrast to observed temporal global trends (29, 30, 32) but simultaneously confirms that the contemporary generations of children in Slovenia are in fact among the most physically active children in the world (33) and have been also experiencing declining trends of overweight and obesity (31), which is directly reflected in the level of their physical fitness.

In contrast, the positive trend has not been experienced by the entire population of children, and with every generation, the share of children at the extremes of the distribution curve has been growing.

Our findings suggest that the high quality level of physical education teaching in Slovenia, supported by evidence data, exceptional school sports infrastructure, and additional hours of PE, provided by the Healthy Lifestyle intervention or at the initiative of schools, provided more favorable conditions for the development of physical fitness of children. However, the findings also suggest that the problem of growing inequality in physical fitness development should be considered and effective solutions found to provide better opportunities for development to the children at the negative end of the distributional curve.

## DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: http://www.slofit.org/Portals/0/Clanki/Datasets/Secular_trends_SLO_fitness_anon.zip?ver=2020-08-15-135026-590.

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by National Medical Ethics Committee of the Republic of Slovenia (ID 102/03/15). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

## AUTHOR CONTRIBUTIONS

GS and ŽP conceptualized and designed the study, performed the statistical analysis, and wrote the first draft of the manuscript. ŽP organized the database. GJ wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.


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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2020.561273/full#supplementary-material

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

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