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Motor Skill Competence Matters in Promoting Physical Activity and Health

Lead Guest Editor: Zan Gao
Guest Editors: Xu Wen, You Fu, Jung Eun Lee, and Nan Zeng

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Editorial

Motor Skill Competence Matters in Promoting Physical Activity and Health

Zan Gao,[1] **Xu Wen**,[2] **You Fu**,[3] **Jung Eun Lee**,[4] **and Nan Zeng**[5]

[1]*School of Kinesiology, The University of Minnesota, 208 Cooke Hall, 1900 University Ave. SE, Minneapolis, MN 55455, USA*
[2]*Department of Sports Science, College of Education, Zhejiang University, Hangzhou, China*
[3]*University of Nevada at Reno, Reno, NV, USA*
[4]*Department of Applied Human Sciences, University of Minnesota, Duluth, MN, USA*
[5]*Prevention Research Center, Department of Pediatrics, University of New Mexico Health Sciences Center, 2703 Frontier Ave. NE, Research Incubator Building (RIB) Suite 120 Albuquerque, NM 87131, USA*

Correspondence should be addressed to Zan Gao; gaoz@umn.edu

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Children's low physical activity and health-related physical fitness levels may increase their risk of developing chronic diseases such as type II diabetes and hypertension [1, 2]. Participating in daily physical activity regularly is imperative in enhancing children's motor skill competence early in life and health promotion across the lifespan [3, 4]. As known, the development of motor skill competence has been posited to be an important predictor for increased levels of children's health-related physical fitness and physical activity behaviors, as well as improved health outcomes [5–9]. Motor skill competence has been defined as common fundamental motor skills and goal-oriented movements including large muscle groups or the whole body [10]. In general, motor skill competence consists of three major components: locomotor skills (i.e., the ability to move the body through space like running, jumping, and hopping), object control skills (i.e., the ability to move and manipulate objects in space like kicking, throwing, and catching), and stability skills (ability to maintain postural control like balancing, rolling, and stopping) [11].

Cross-sectional studies showed that children's motor skill development is positively linked to their health-related physical fitness, enjoyment, and perceived competence [12, 13]. Longitudinal studies also have shown that children's motor skill competence resulted in sustained levels of physical activity and health-related fitness over time [14]. Thus, the study of correlates and determinants of motor skill competence, physical activity, and sedentary behavior across the lifespan has become an emerging trend in the field, as, increasingly, researchers have conducted investigations in this area of inquiry in the past decade.

In response, we invited investigators to contribute original research articles and review articles that would stimulate continuing efforts to understand the relationships between motor skill competence, physical activity, health-related physical fitness, and health outcomes among various populations. In this special issue, novel findings from seven separate studies from multiple countries are presented. These studies attempted to (1) systematically review the effects of physical activity programs on motor skills and health outcomes in pediatric populations; (2) investigate the effectiveness of physical activity programs on individuals' motor skill competence; (3) provide empirical evidence concerning the relationships among individuals' motor skill competence and physical activity, physical fitness, and academic achievement; (4) test the validity of children's movement skill quotient based upon classroom environment; and (5) offer directions for future research studies in this area of inquiry.

D. J. McDonough et al. [15] synthesized 25 randomized controlled trials (RCTs) examining causal evidence regarding the effects of physical activity interventions on children's motor skill development. They found that 20 RCTs reported significant improvements in motor skill performance as a result of physical activity participation. In detail, 18 studies examined traditional physical activity interventions and 7 studies examined exergaming-based physical activity

interventions, 15 and 5 of which observed statistically significant improvements in children's motor skill development, respectively. Of note, some limitations of this review (e.g., heterogeneity of measurement protocols and assessment tools in testing motor skills) are discussed. Thus, the authors advocated for future RCTs to employ a priori power analyses and long-term follow-up measurements, to explore the dose response and moderating relationships between physical activity and motor skill development in childhood, and to utilize homogenous assessment instruments to allow for more rigorous, quantitative syntheses. J. Yin et al. [16], on the other side, reviewed RCT studies that compared high-intensity interval training with moderate-intensity continuous training on health outcomes among children and adolescents. In this meta-analysis of 16 RCTs that included 543 participants published from 2005 to 2019, children and adolescents demonstrated a significantly higher peak VO_2 level after participating in high-intensity interval training compared to moderate-intensity continuous training. However, no differences were reported between modalities on the outcome variables such as maximum heart rate, fat mass, free fat mass, weight, body mass index (BMI), waist circumference, blood pressure, glycemia, insulinemia, total cholesterol, high-density lipoprotein, low-density lipoprotein, triglycerides, homeostatic model assessment of insulin resistance, hemoglobin A1c, and leptinemia. The authors suggested that more large-scale RCT studies should be conducted to further investigate the effects on young individuals' health outcomes between high-intensity interval training and moderate-intensity continuous training.

To gain empirical evidence, H. Wang et al. [17] tracked young children's motor skill development over time and investigated the determinants from home environments. The Test of Gross Motor Development tool (version 2) was used to assess 268 children's locomotor and object control skills, as well as self-reported behavior and home environments. During the follow-up, children's locomotor and object-control skills continued to grow, with an annual growth rate of 20% and 30%, respectively. Specifically, the scores of 5 locomotor skills and 2 object control skills were significantly higher in the 3–4-year-old group than in the 4–5- and 5–6-year-old groups. Girls' locomotor skills developed at a significantly higher rate than those of boys. Furthermore, 3-year-old boys performed significantly better than girls on object-control skills. Determinants of children's motor skill development in middle-income families include the frequency of playing with friends and the frequency of bicycling, skateboarding, dancing, running, and jumping. Family income, parents' education level, and family activity area were not significantly associated with the improvement rate of motor skills. In addition, more opportunities to play with friends and engage in a variety of sports activities could promote children's motor skill development. Meanwhile, M. Batez et al. [18] examined the relationships between motor competence, physical fitness, and academic achievement in young children. The Körperkoordinationstest Für Kinder and the EUROFIT battery of tests were applied to measure motor competence and physical fitness, respectively, in 130 elementary school children in Serbia. Academic achievement was assessed based on the grade point average (GPA) score. It was found that the GPA scores significantly correlated with almost all motor competence and physical fitness measures. The results of regression indicated that only plate tapping and sit and reach could significantly predict the GPA score. The authors concluded that academic achievement is generally associated with physical fitness and motor competence in children. Plate taping and sit and reach were accounted as the most important predictors for academic achievement. The study may contribute to further understanding of the link between motor competence, physical fitness, and academic achievement.

On the other lifespan spectrum, degenerative changes such as muscle loss, weight gain, and osteoarthritis occur in seniors during the aging process, which increase the risk for falling and cognitive decline among older adults. Thus, actions are needed to prevent and treat degenerative changes in this population. To this end, J. Adamczyk et al. [19] conducted a RCT to examine an exercise-based intervention on older women's physical functioning. A total of 73 participants were recruited and randomly assigned to either the intervention group or the control group. The intervention group was required to participate in a Jaques-Dalcroze eurhythmics exercise program for 12 weeks, twice a week for 45 minutes each session, whereas the control group was asked to maintain regular activity patterns. Dynamic agility was determined by the Timed Up and Go test for both single-task and dual-task as the primary outcome. After 12 weeks of exercise intervention, the authors observed that only the dual-task scores were significantly higher in the intervention group, compared to the control group. The finding supports Jaques-Dalcroze eurhythmics as an effective intervention form to improve physical functioning in women over 65 years of age.

Working with an athletic population, W.-D. Chang et al. [20] examined the relationships between various motor ability tests and sports injury risk among 32 athletes who either played volleyball, basketball, or handball in school sports teams for at least 3 years. The tests were functional movement screen, star excursion balance test, agility T-test, and vertical jump test, and the differences in the test scores were compared between groups with high- and low-injury risk. No significant differences were observed in the functional movement screen, balance test, agility T-test, and vertical jump between high-risk and low-risk groups. Additionally, a series of moderate-to-good correlations were observed for deep squat, inline lunge, hurdle step, rotary stability of functional movement screen, and various components of the balance test. Researchers concluded that junior athletes with a functional movement screen score of less or equal to 14 or a balance test score difference of 4 cm or greater have a higher risk of sport injury, and these moderate correlations between functional movement screen and balance test scores may be due to similar movement patterns required among these tests.

As known, a reliable and valid assessment tool is essential for evaluating children's movement skills in daily physical education environments. J. Chang et al. [21] examined the validity of the Children's Motor Skills Quotient used in the

Figure 1: Spiral of engagement (Stodden et al., 2008).

physical education setting. A total of 734 children completed the 14 test items (e.g., jumping, sliding, catching, throwing, crawling, running, bouncing, rolling, and kicking) which were evaluated by six raters. Rasch analysis was used to verify the fitting statistics, project difficulty, and functional differences of the items of the Children's Motor Skills Quotient. The findings showed that the instrument met the assumptions of the Rasch model, including the unidimensionality, local independence, person measure, and item difficulty hierarchy. The instrument also demonstrated adequate interrater reliability and internal consistency. The differential item functioning demonstrated a number of items showing different probabilities across sex and age. Overall, the Children's Motor Skills Quotient seemed to have appropriate testing items with an appropriate rating scale structure for measuring 6-9-year-old children's movement skills in the physical education environment.

1. Challenges and Opportunities

According to Competence Motivation Theory [22], there is a positive relationship between one's behavior and motor skill competence and perceived competence. In particular, successful skill/task mastery (e.g., sports-specific motor skill competence development) will enhance one's perceived competence, which in turn, facilitates other motivated behaviors (e.g., engaging in physical activity) and performance on physical tests (e.g., motor skill competence and fitness testing scores) [5]. Compiling the literature has observed a trend such that many children who have lower physical activity-related perceived competence (e.g., confidence in playing football) avoid physical activity opportunities because (1) they feel less physically competent compared to their peers [23] and (2) they are ashamed/embarrassed to demonstrate low motor skill competence. Since these children have fewer athletic skills and, therefore, less movement opportunities, they will be less motivated to participate in physical activities or sports activities which, compared to their more advanced peers, will be less fun for them [24]. Indeed, cross-sectional and longitudinal studies suggested that the relationships between children's motor skill competence and physical activity, and fitness might be mediated by their perceived competence [25]. However, it is still unclear whether this mediating effect of perceived competence is prevalent among young children who possess high levels of perceived competence and low levels of motor skill competence, concurrently. Furthermore, the maintenance or development of motor skill competence can be achieved by regular participation in physical activity and high levels of physical fitness [25]. However, whether or not perceived competence mediates the effect of physical activity and health-related physical fitness on future motor skill competence has yet to be examined, thereby creating the need for future research on this topic among young children. Figure 1 shows two feedback loops for the preceding engagement (i.e., negative or positive). In detail, a "positive spiral of engagement" suggests a positive trajectory for physical activity and physical fitness with high motor skill competence, whereas a "negative spiral of engagement"

suggests that low motor skill competence may lead to lower levels of perceived competence, thus decreasing physical activity and fitness over time, and, ultimately, poor future motor skill competence in children. Participation in innovative and fun physical activity promotion programs (e.g., active video game programs [5]) may facilitate the development of motor skill competence, promote these recursive relationships, and may even have the potential to influence the lifespan trajectories of young children's physical activity and health-related physical fitness.

Getting a greater and deeper understanding of children's determinants and correlates of physical activity behaviors and motor skill competence is a multidimensional process involving many cultural, environmental, psychosocial, and behavioral constraints, which may influence individuals' physical activity and fitness trajectories across the lifespan [26–28]. For example, studies that investigated the relationship between physical environment and motor skill competence have yielded inconclusive results, with some showing higher motor skill competence in rural children in comparison with their urban counterparts [29], whereas others reported opposite findings [30]. The discrepancies may be due to the fact that other dimensions, such as social support and perceived competence, are imperative in improving children's motor skill development [31].

Additionally, it is vital to develop novel physical activity promotion programs to foster healthy lifestyle behaviors in young children, which will result in increased physical activity and fitness levels across time with the ultimate goal of promoting health and preventing chronic diseases [5, 6]. As can be seen, investigating the longitudinal sustainability and the impact of novel physical activity interventions on the different dimensions of children's health is needed in future studies, which will help us better understand how innovative physical activity intervention programs can be utilized in communities, homes, and schools to promote a healthy lifestyle throughout the lifespan. Additionally, few studies have examined the longitudinal relationships among young children's physical activity, motor skill competence, screen time, sleep, and other social-ecological variables [32, 33]. Thus, researchers may need to put more emphasis in this area of inquiry, particularly longitudinal research in early childhood. Finally, while the interconnectedness among physical activity, motor skill competence, and cognitive functions have been evident in the past decades [34], it appears that there is a lack of understanding concerning the contextual specificity of these variables [35, 36], which warrants more research on this topic.

Conflicts of Interest

We declare that none of the Guest Editors have a conflict of interest.

Zan Gao
Xu Wen
You Fu
Jung Eun Lee
Nan Zeng

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Research Article

Relationship between Motor Competence, Physical Fitness, and Academic Achievement in Young School-Aged Children

Maja Batez,[1] Živan Milošević,[2] Ivan Mikulić,[3] Goran Sporiš,[3] Draženka Mačak,[1] and Nebojša Trajković[4]

[1]*Faculty of Sport and Physical Education, University of Novi Sad, Serbia*
[2]*Sports Diagnostic Center, Šabac, Serbia*
[3]*Faculty of Kinesiology, University of Zagreb, Croatia*
[4]*Faculty of Sport and Physical Education, University of Niš, Serbia*

Correspondence should be addressed to Nebojša Trajković; nele_trajce@yahoo.com

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Children in schools are facing many academic challenges. Moreover, there is constant pressure on children and parents to maximize academic achievement. We aimed to determine the relationship between motor competence, physical fitness, and academic achievement in young school-aged children. Participants were 130 elementary school children (mean ± SD 8.60 ± 0.61 years; 51 boys and 79 girls) from Serbia. The KTK (Körperkoordinations Test für Kinder) battery of tests was used to assess the motor competence in children; children' physical fitness was assessed using the EUROFIT battery of tests, while academic achievement was assessed based on the children's GPA (grade point average) scores at the end of the school year. Pearson's r showed the weak to moderate relationships between the GPA and motor competence and physical fitness measures. The GPA correlates positively and significantly with almost all motor competence and physical fitness measures, but negatively with BMI ($p \leq 0.05$). However, the hierarchical linear regression indicated only the plate tapping and sit and reach as the significant predictors of the GPA. Although both tests positively affect the GPA, the plate tapping ($B = -0.22$, $p = 0.02$) tends to influence the GPA more than the sit and reach test ($B = 0.18$, $p = 0.04$) after adjusting for effects of motor competence ($B = 0.19$, $p = 0.03$), age ($B = -0.01$, $p = 0.89$), and BMI ($B = -0.19$, $p = 0.03$). This study provides evidence demonstrating that academic achievement is generally associated with physical fitness and motor competence in children. However, plate taping and sit and reach were accounted as the most important predictors for academic achievement.

1. Introduction

Motor development and cognitive development have been studied separately, and they have generally been viewed as independent phenomena, although occurring in the same organism over the same time period. However, recently, motor development and cognitive development showed to be much more interrelated than what has been previously stated [1]. Recent studies have increasingly indicated the positive effects of motor competence and physical fitness on health status in children [2–5]. Moreover, the strength of relationship between motor competence and health status tends to increase from childhood to adolescence [6]. Most of the research on children's academic achievement has been focusing on physical activity showing the beneficial effects on academic performance [7–10]. Having in mind that the development of motor skill competence is a primary underlying mechanism that promotes engagement in physical activity and fitness [11], we think that similar relationship between motor competence, physical fitness, and academic achievement was logical. However, studies that examined the association between physical activity, motor competence and physical fitness, and academic achievement showed contradictory results, especially in the directionality of association [12]. Apart from this well-known effect, a large number of authors produced research on the effect of the level of motor skills on the cognitive abilities and academic achievement in the children.

The results of the study by Abdelkarim et al. [13] lead to a conclusion that encouraging motor competence in the prepubescent children during their elementary school years is associated with better academic achievement. This was confirmed by several other studies indicating the positive effects of motor competence on academic achievement [7, 12, 14–20]. Regarding physical fitness, Sardinha et al. [21] showed in their longitudinal study that an improvement in fitness in children increases the probability of higher academic achievement. This was confirmed by a recent systematic review by Donnelly et al. [9]. However, the authors stated that studies examining the associations among fitness and academic achievement showed inconsistent findings and that numerous elements of fitness are still unexplored.

Highly demanding curriculum requirements that schools, teachers, and parents put before children since the very start of their elementary education do not leave much time for exercise and improvement of fitness. In Serbia, it is obligatory to have two classes (2×45 min) of physical education per week, which is not sufficient enough to accomplish high level of motor competence and physical fitness. A possible relationship with academic achievement would put significantly more impact on exercise during their stay in school. Therefore, it is necessary to point out the importance of motor competence and physical fitness in younger children due to inconsistent findings [14] concerning the connection and the contribution to better academic achievement. Moreover, it is not defined which distinct academic domains are connected with physical fitness and academic achievement. Accordingly, the purpose of this paper is to examine the relationship between motor competence, physical fitness, and academic achievement in young school-age children.

2. Materials and Methods

2.1. Subject. This cross-sectional study included 130 elementary school children (Table 1). All children attended a standard school program in primary school from the territory of the city of Sabac (urban area), Republic of Serbia. We randomly selected four elementary schools and one class within each school. All students and their parents consented to participate in the study. The inclusion criteria were that children were healthy without any musculoskeletal injury or diseases. Ethical approval was obtained from the University Ethics Board at the Faculty of Sport and Physical Education in Novi Sad (reference no. 46-10-06/2020-1).

2.2. Procedures. All assessments were performed in accordance with the ethical standards laid down in the Declaration of Helsinki. The assessments included body height and weight, academic achievement, the Körperkoordinations Test für Kinder, and the Eurofit Physical Fitness Test Battery test. All assessments were conducted as part of the project "Bring sports to schools-Grow healthy" which is approved by the Serbian Ministry of Education, Science, and Technological Development (ref. no. 601-00-54/2012-15), which is under implementation on the territory of the city of Sabac (Republic of Serbia). The members of the "Sports Diagnostic Center of Sabac," professors of physical education and sports sciences, assessed measures of physical fitness and motor competence. The Körperkoordinations Test für Kinder and the Eurofit Physical Fitness Test Battery tests were performed in the school gyms in the form of circuit exercises.

Table 1: Sample characteristics.

	Total	Boys ($N = 51$)	Girls ($N = 79$)
Age (years)	8.60 ± 0.61	8.60 ± 0.63	8.59 ± 0.60
Height (cm)	138 ± 0.08	139 ± 0.08	137 ± 0.08
Weight (kg)	33.43 ± 8.53	34.50 ± 8.36	32.32 ± 9.15
BMI (kg/m^2)	17.32 ± 3.29	17.81 ± 3.30	17.04 ± 3.49

Values are mean ± SD. BMI: body mass index.

The participants were informed about the purpose and the technique of the tests and were given clear instructions on how to do the tests precisely, quickly, and consistently, in accordance with the factor being measured. Each test item was accompanied by specific instructions orally presented to each of the participants. Trials were allowed for each test item to allow for a familiarization with the tests. Following the familiarization, the participants performed the tests and the corresponding results were recorded.

2.3. Academic Achievement. The data on the children's grade point average (GPA) scores at the end of the school year were taken from the school records upon approval by the elementary schools' principals. We accounted two mandatory subjects for the GPA, the Serbian language and mathematics. According to the rulebook [22] on student assessment in Serbian schools, the grades are numerical. The student was evaluated on the basis of oral examination of achievement, written examination of achievement, and practical work and in accordance with the course program. Numerical grades are as follows: outstanding (5)—a student who achieves outstanding progress in mastering the subject program and completely independently fulfilling the requirements; very good (4)—a student who achieves significant progress in mastering the subject program and completely independently fulfilling the requirements; good (3)—a student who achieves progress in mastering the subject program and completely independently fulfilling the requirements; acceptable (2)—a student who achieves minimal progress in mastering the subject program and fulfilling with the help of the teacher the requirements that are determined in most of the basic level of achievement; and insufficient (1)—a student who does not achieve minimal progress in mastering the subject program and does not meet the requirements even with the help of the teacher.

The students must have four grades during one semester, in order to determine their final grade. The final grade is as follows: outstanding (5), if the arithmetic mean of all individual grades is at least 4.50; very good (4), if the arithmetic mean of all individual grades is from 3.50 to 4.49; good (3), if the arithmetic mean of all individual grades is from 2.50 to 3.49; acceptable (2), if the arithmetic mean of all individual

grades is from 1.50 to 2.49; and insufficient (1), if the arithmetic mean of all individual grades is less than 1.50.

2.4. Motor Competence. The Körperkoordinations Test für Kinder (KTK) battery test was used to assess the level of motor competence [23]. The KTK battery consists of four test items: (1) walking backwards three times along three different wooden beams (a maximum of 72 steps), (2) single-leg hopping over a 5 cm high foam obstacle (a maximum of 78 points for both legs), (3) lateral jumping over a low obstacle within a 15-second time frame two times (a sum of jumps over two trials), and (4) lateral movement across the floor using 2 wooden platforms for 20 seconds (a sum of relocations over two trials). The raw performance score of each test item was converted into a standardized motor quotient (MQ) adjusted for age and gender according to the normative data tables. Likewise, the sum of all four item MQs was transformed into an MQ total. The battery of tests was customized for 5- to 15-year-olds, with high reliability (reliability coefficient from 0.90 to 0.97 for the total battery of tests) and validity ($r = 0.60$-0.80 for the intercorrelation of KTK subtests) [24, 25].

2.5. Physical Fitness. The range of children's motor skills was assessed using the Eurofit Physical Fitness Test (EUROFIT) battery tests [26]. Each item test was performed two times, and a better result was recorded. A plate tapping test was used to estimate the reaction rate. The subject moves the preferred hand back and forth between the discs (which placed with their centers 60 cm apart on the table) over the hand in the middle as quickly as possible. This action is repeated for 25 full cycles (50 taps). The time taken to complete 25 cycles is recorded. The test was performed twice, and the best result is recorded. A standing long jump test was used to estimate the explosive leg power. The subject stands behind a line marked on the ground with feet slightly apart. The subject attempts to jump as far as possible, landing on both feet without falling backwards. The measurement is taken from the take-off line to the nearest point of contact on the landing (back of the heels). The "sit-ups in 30 seconds" test was used to estimate the abdominal and hip flexor muscles. On the command "Go," the subject raises the chest so that the upper body is vertical and then returns to the floor. For each sit-up, the back must return to touch the floor. The maximum number of correctly performed sit-ups in 30 seconds is recorded. A 10×5 m shuttle run test was used to estimate the speed and agility. When instructed by the timer, the subject runs to the opposite marker, turns, and returns to the starting line. This is repeated five times without stopping (covering 50 meters in total). At each marker, both feet must fully cross the line. Record the total time taken to complete the 50 m course.

2.6. Data Analysis. Statistical analysis was carried out using SPSS (v19.0, SPSS Inc., Chicago, IL, USA), and data are presented as mean ± SD unless otherwise stated. Data were log-transformed analysed but reported raw for the sake of clarity when the Kolmogorov–Smirnov test failed to confirm normality.

The t-test for independent samples analysed the mean differences between boys and girls in the study outcomes. If Levene's test did not assume equal variances, we used the t-test with a Satterthwaite approximation for the degrees of freedom. By the visual inspection of a residual scatter plot, we confirmed homoscedasticity.

Pearson's correlation coefficients (r) were used to investigate associations among motor competence, physical fitness, and academic achievement. The degrees of statistically relevant Pearson's correlation are defined in the bivariate linear relationship as weak (±0.10), moderate (±0.30), and strong (±0.50) [27]. The correlation matrix was inspected to assess multicollinearity ($r \geq 0.8$) [28].

Finally, we modelled a GPA using a hierarchical linear regression building approach. Hence, three sequential linear regression models evaluated a relative influence (B, standardized coefficient) of motor competence (block 2) and physical fitness measures (block 3) on an academic achievement, while controlling for age and BMI effects (block 1). Overall fit of the academic achievement model in the function of motor competence and physical fitness measures (adjusted for age and BMI) is represented by the coefficient of determination (R^2) and adjusted coefficient of determination (adjusted R^2). We compared the models using change statistics (in R^2 and F) from block 1 to block 2 and from block 2 to block 3. The level of significance was set at $p \leq 0.05$.

3. Results

Table 2 presents motor competence and physical fitness for the pooled sample and by gender. The t-test for independent samples showed no significant differences among boys and girls in the GPA ($t_{(144)} = -0.65$, $p = 0.51$), the KTK MQ ($t_{(144)} = -1.44$, $p = 0.15$), plate tapping ($t_{(144)} = -0.94$, $p = 0.35$), standing broad jump ($t_{(96.93)} = -0.92$, $p = 0.36$), sit-ups ($t_{(92.17)} = 0.94$, $p = 0.71$), 10×5 m shuttle run ($t_{(144)} = -1.16$, $p = 0.25$), and sit and reach ($t_{(144)} = -0.95$, $p = 0.35$).

The correlation matrix of Pearson's r showed the weak to moderate relationships between the GPA and motor competence and physical fitness measures. The GPA correlates positively and significantly with almost all motor competence and physical fitness measures, but negatively with BMI ($p \leq 0.05$). No multicollinearity was observed among the predictors. See Table 3 for the results from bivariate analysis.

A hierarchical linear regression yields that the full model of academic achievement was significant (block 3). The inclusion of the KTK MQ significantly improved the prediction of the GPA (change statistics: $R^2 = 0.03$, $F_{(1,142)} = 4.81$, $p = 0.03$) over and above age and BMI (block 1). However, the addition of physical fitness measures did not significantly enhance the prediction of the GPA (change statistics: $R^2 = 0.06$, $F_{(5,137)} = 1.85$, $p = 0.11$), although the plate tapping and sit and reach significantly influenced the GPA. The plate tapping tended to influence the GPA more than the sit and reach test. The full model of GPA is shown in Table 4.

Table 2: Sample characteristics and study outcomes in the pooled sample and among boys and girls.

	Total	Boys ($N = 51$)	Girls ($N = 79$)
GPA	4.64 ± 0.71	4.58 ± 0.56	4.72 ± 0.65
KTK MQ	85.13 ± 19.15	80.39 ± 16.69	86.10 ± 18.34
Plate tapping (s)[¥]	16.00 ± 2.56	16.43 ± 2.86	16.06 ± 2.31
Standing long jump (cm)	124.79 ± 25.21	124.73 ± 28.55	120.96 ± 21.28
Sit-ups (frequency)	17.03 ± 5.23	17.00 ± 6.33	16.67 ± 4.61
10 × 5 m shuttle run (s)[¥]	25.62 ± 3.07	25.39 ± 3.55	25.94 ± 2.84
Sit and reach (cm)	17.79 ± 6.28	18.47 ± 6.62	17.30 ± 6.01

Values are mean ± SD. [¥] Reverse scoring. GPA: grade point average; KTK MQ: motor quotient from the Körperkoordinations Test für Kinder.

Table 3: The correlation matrix showing Pearson's r for the motor competence, physical fitness, and academic achievement.

	GPA	Age	BMI	KTK MQ	Plate tapping (s)[¥]	Standing broad jump (cm)	Sit-ups (frequency)	10 × 5 m shuttle run (s)[¥]
Age	-0.01							
BMI	-0.19*	-0.03						
KTK MQ	0.22**	-0.17*	-0.21**					
Plate tapping (s)[¥]	-0.20**	0.35**	0.08	-0.26**				
Standing long jump (cm)	0.15*	-0.43**	-0.28**	0.48**	-0.34**			
Sit-ups (frequency)	0.09	-0.13	-0.25**	0.19*	-0.40**	0.46**		
10 × 5 m shuttle run (s)[¥]	-0.06	0.25**	0.19*	-0.37**	0.24**	-0.56**	-0.48**	
Sit and reach (cm)	0.14*	-0.03	0.10	0.08	0.15*	-0.07	-0.14*	-0.09

[¥]Reverse scoring. GPA: grade point average; BMI: body mass index; KTK MQ: motor quotient from the Körperkoordinations Test für Kinder.

Table 4: Linear regression models of academic achievement.

Predictors	GPA					
	Block 1		Block 2		Block 3	
	B	p	B	p	B	p
Age	-0.01	0.89	0.02	0.80	0.10	0.29
BMI (kg/m^2)	-0.19	0.03	-0.15	0.08	-0.16	0.07
KTK MQ			0.19	0.03	0.12	0.20
Plate tapping (s)[¥]					-0.22	0.02
Standing long jump (cm)					0.09	0.47
Sit-ups (frequency)					-0.02	0.85
10 × 5 m shuttle run (s)[¥]					0.10	0.36
Sit and reach (cm)					0.18	0.04
R^2	0.04		0.07		0.13	
Adjusted R^2	0.02		0.05		0.07	
F	2.38		3.37*		2.46*	

1 = males; 2 = females. [¥]Reverse scoring. GPA: grade point average; BMI: body mass index; KTK MQ: motor quotient from the Körperkoordinations Test für Kinder; B: standardized coefficient; R^2: coefficient of determination; F: F statistic. *Significant at $p \leq 0.05$.

4. Discussion

The aim of the study was to examine the relation between children's final GPA scores at the end of the school year and the results achieved on motor competence and physical fitness tests. The main findings of the present study are weak positive correlations between motor competence, physical fitness, and academic achievement (r from 0.14 to 0.22). The linear regression models showed positive association only for plate tapping ($B = -0.22$, $p = 0.02$) and sit and reach ($B = 0.18$, $p = 0.04$) after excluding the KTK MQ influence and adjusting for age and BMI effects. The obtained results indicate that gender was not the important predictor in this age group, showing the similar results for boys and girls in GPA ($p = 0.51$), the KTK MQ ($p = 0.15$), plate tapping ($p = 0.35$), standing broad jump ($p = 0.36$), sit-ups ($p = 0.71$), 10 × 5 m shuttle run ($p = 0.25$), and sit and reach ($p = 0.35$). As expected, the body mass index was negatively associated with GPA scores ($B = -0.17$, $p = 0.05$) in children.

There is sufficient evidence that children with low motor competence have a higher probability of having low academic achievement [17, 29–31]. The results of the present study indicate that motor development is positively related to successful academic achievement, supporting previously provided evidence about positive relationship between cognitive and motor developmental trajectories [1, 32–34]. Accordingly, highly developed motor abilities may facilitate cognitive function in children and thus contribute to better academic achievement, which is confirmed by other studies [31, 35]. Moreover, coordinative exercises are involved in

the activation of the cerebellum, influencing motor functions [36] and working memory [37] as well as attention [38]. In the end, better motor competence leads to better overall health, as has been shown in the case of physical fitness [39], which may further contribute positively to academic achievement [17]. However, after adjusting the motor competence influence on the GPA for BMI effect, regression analysis showed that KTK MQ could not significantly predict academic achievement. This could be due to smaller sample compared to other studies that examined the influence of motor competence on academic achievement. Moreover, the children in the present study showed very low level of KTK MQ (85.13), which could impact the association between motor competence and academic achievement. A recent study [40] confirmed that MQ KTK is actually stagnating (1.1%) or showing a delayed development (14.7%) of motor competence opposite to the reference sample [41]. Moreover, the same study showed statistically significant variability in trajectories of change in motor competence in individual children. Chagas et al. [29] in their recent study showed no significant associations between motor coordination and academic achievement in boys and girls. Therefore, longitudinal and prospective studies are needed in order to determine how better or worse motor competence can influence the academic performance of children throughout schooling.

By analysing the relationship between academic achievement and physical fitness, significant correlations were observed in the plate tapping test, standing long jump, and sit and reach test. However, the linear regression model showed positive association only for plate taping and sit and reach. Studies examining similar subjects also indicate a positive correlation between the plate tapping test and academic achievement [42]. According to Fernandes et al. [42], action systems [43] and anticipatory systems [44] involve different brain regions related to attentional control and visual processing and specific brain regions related to response selection and planning [45]. Moreover, it was stated that the deficit in visuospatial attention is related to motor and cognitive deficits found in children with developmental coordination disorder [46]. Altogether, the above-mentioned fact points to the importance of coordinative moves during plate tapping and accordingly to faster processing and longer retention of information during school. A positive correlation between academic achievement and fitness tests indicates that physically fit children have better academic performance. Most of the studies regarding physical fitness examined the association between aerobic fitness and academic achievement. A recent systematic review demonstrated positive relations between academic performance and aerobic fitness [9]. Results regarding relationship between the sit and reach test and academic achievement are inconsistent [20, 47]. Castelli et al. [20] found that flexibility was not related to general academic achievement, reading, and mathematics in third- and fifth-grade students. On the contrary, there was a positive correlation between sit and reach and mathematics scores [47]. The possible explanation could be because the association between fitness (sit and reach) and academic achievement may reflect the achievement orientation of motivated students [39]. Additionally, children's physical fitness may lead to a better overall health which can contribute positively to academic achievement [39]. Poor physical fitness at an early age may contribute to a negative path of academic development as indicated by Kantomaa et al. [48]. Several authors tried to give reasonable explanations regarding significant associations between physical fitness and academic achievement in children. However, the complexity of fitness and academic achievement relationship makes it difficult to specifically identify possible mechanisms. Hillman et al. [49] stated that fitter children have a more effective neuroelectric profile than less fit children on a stimulus discrimination task. Moreover, the motivation could have significant contribution for this significant relationship because children who perform better and enjoy in school may be more likely to exert more effort on academic tests and physical fitness [20]. In the end, weight status (BMI) was inversely associated with GPA scores in the current study. However, it could be speculated that the effect of weight status on academic achievement could be mediated by motor competence or physical fitness which was stated earlier [50]. This study did not comprise a large sample of participants, which may be deemed one of the drawbacks of the same. On the other hand, this study incorporated field tests where the motivation of the children played a significant role, in comparison with the laboratory tests which tend to produce more accurate results. It is safe to assume that inclusion of parameters such as parents' economic status, physical activity questionnaire, and availability of sport facilities near the place of residence would allow for a more comprehensive picture of the relationship between the motor skills of prepubescent children and their performance at school. Moreover, the motor competence and physical fitness influence on academic achievement was not adjusted for the intellectual ability effects. Future research should provide more evidence on the individual relationship of each subject to motor skills in order to discuss the causal relationships in more detail.

5. Conclusions

This study provides evidence demonstrating that academic achievement is generally associated with physical fitness and motor competence in children. However, when accounting motor competence and physical fitness in the regression model, plate tapping and sit and reach were the only significant predictors for academic achievement. More research is needed to fully understand the relationship between motor competence, physical fitness, and cognition in children and possible mediators that could influence the academic achievement in children. Nevertheless, this type of studies may help all the subjects involved in the process of education to recognize, understand, and design ways of facilitating creative and stimulating physical exercises both in and out of school. This primarily refers to creative and challenging motor tasks in the course of sensitive periods that may contribute to the development of self-confidence in children, improvement of memory, anticipation, and all other qualities that may result in better academic achievement.

Data Availability

The datasets analysed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors report no conflicts of interest.

Authors' Contributions

The authors alone are responsible for the content and writing of the paper.

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Review Article

Effects of Physical Activity on Children's Motor Skill Development: A Systematic Review of Randomized Controlled Trials

Daniel J. McDonough, Wenxi Liu, and Zan Gao

School of Kinesiology, University of Minnesota-Twin Cities, Minneapolis 55455, USA

Correspondence should be addressed to Zan Gao; gaoz@umn.edu

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Objective. This systematic review synthesized current randomized controlled trials (RCTs) examining casual evidence regarding the effects of traditional and exergaming-based physical activity (PA) interventions on motor skill development in typically developed children (i.e., those aged 6-12 years). *Methods*. We adhered to the PRISMA-P statement and searched electronic databases (Medline, PsycInfo, Web of Science, PubMed, ERIC, Scopus, and SportDiscus) from inception through July 2020. We screened for peer reviewed RCTs published in English between 2000 and 2020 examining the effect of PA on motor skill development in healthy children. *Results*. A total of 25 RCTs were included, 20 (80%) of which reported significant improvements in children's motor skill performance. Specifically, 18 studies examined traditional PA interventions and 7 studies examined exergaming-based PA interventions, 83% and 71% of which observed statistically significant improvements in children's motor skill development, respectively. *Conclusions*. Findings support the causal evidence regarding the effects of PA on motor skill development in children. Notable limitations of this review included heterogeneity of measurement protocols and assessment tools used to test children's motor skills across studies, a wide range of PA intervention dose across studies, and the lack of power analyses and long-term follow-up assessments in individual studies to discern appropriate sample sizes and long-term effectiveness, respectively. To further strengthen the evidence in this emerging field, we advocate for future RCTs to employ a priori power analyses, long-term follow-up measurements, and more exergaming-based interventions to allow for comparisons with traditional PA interventions, to explore the dose response and moderating relationships between PA and motor skill development in childhood, and to utilize homogenous assessment instruments to allow for more rigorous, quantitative syntheses.

1. Introduction

Currently in the U.S., approximately 33% of children and adolescents have opverweight or obesity [1]. The overweight and obesity epidemic has become a major public health challenge given weight-associated chronic diseases account for 70% of deaths and 85% of health care costs, annually [2, 3]. Physical inactivity is among the top contributors to this issue [4] as only about 25% of U.S. youth meet recommended physical activity (PA) levels [5, 6]. Fortunately, unlike other major contributing risk factors (e.g., pollution and medications), physical inactivity is a modifiable behavioral risk factor meaning this behavior can be changed [4]. Therefore, since PA and health behaviors are learned in the developmental years and track into adulthood [7], it is vital to establish lifelong, healthy PA habits during childhood. Because learning how to properly move is a necessary skill underlying PA behaviors in children [8, 9], interventions targeting the development of motor skills often precede those which target general PA promotion. However, given that less than 25% of children meet recommended PA levels [5, 6] and given the reciprocal determinism between PA and motor skills [8, 9], interventions have more recently focused on general PA promotion among these populations with the aim of increasing motor skills and ultimately increasing long-term PA adherence and health.

Motor skills have been operationally defined as sequences of learned movements that when combined yield smooth and efficient movements which leads to specific task mastery [10]. More broadly, fundamental motor skills include both fine and gross motor skills, the latter of which encompasses locomotor skills (e.g., running, hopping, and jumping), object control skills (e.g., kicking and throwing), and body coordination (e.g., balance control) [11]. Notably, however, these categories are not exclusive, and thus, motor skills from one category may take place concurrently with elements of other categories [12]. Cross-sectional and longitudinal evidence has supported the reciprocal and dynamic relationship between PA and motor skills [13–18], and compiling evidence has indicated the development of motor skills to improve various health indices in children including cardiorespiratory fitness, muscular strength and endurance, and perceived competence, to list a few [19, 20]. As such, the development and employment of PA interventions targeting improved motor skills in children have become an emerging field of inquiry [21].

Accordingly, as more PA interventions examining this relationship accumulate, more recent and thorough reviews are needed to discern the overall effectiveness of PA interventions on children's motor skill development. One such review was conducted in 2009 but included research designs other than randomized controlled trials (RCTs) and, therefore, was unable to infer causal relationships. Additionally, recent public health efforts have been aimed at integrating modern technologies into PA interventions to gauge children's interest [22], and given the rapid evolution of technology in the past decade, the review did not include technology-based interventions. Given its requirement for gross motor activity to participate [21], exergaming is one technology-based intervention strategy which has shown promise in the promotion of motor skill development in child rehabilitation settings [23] and in nontypically developing children [24]. Another recent review was conducted examining the effect of PA interventions on motor skill development in early childhood (i.e., those aged 3-5 years), thereby missing the opportunity to examine the effects PA interventions in childhood (i.e., those aged 6-12 years)—a critical developmental period and the last chance to establish PA behaviors before reaching adolescence where nonschool and leisure-time PA levels tend to significantly decline [25, 26].

Based on the preceding literature review, we developed the following research question: based on RCT-based evidence, are traditional and exergaming-based PA interventions effective for improving motor skill development in typically developed children? Therefore, the purpose of our study was to address these gaps in the literature and to systematically evaluate the current RCT-based evidence examining the effects of traditional and exergaming-based PA interventions on healthy children's motor skill development. Findings from this review will help to better inform scholars, physical educators, and other health professionals of the benefits of regular PA participation on children's motor skills and strengthen the development of empirically based PA guidelines for this age group.

2. Materials and Methods

We followed the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) statement for reporting of this review [27].

2.1. Information Sources and Search Strategies. We searched the following electronic databases for relevant literature: Medline, PsycInfo, Web of Science, PubMed, Education Resources Information Center (ERIC), Scopus, and SportDiscus, as well as Google Scholar. All investigators (D.M., W.L., and Z.G.) collaborated and searched literature by applying the following search terms in all possible combinations: ("physical activity" OR "exercise" OR "sports program" OR" "physical education" OR "exergaming" OR "active video game") AND ("motor skill" OR "motor skill competency" OR "motor coordination" OR "motor development" OR "motor function" OR "motor performance" OR "motor abilities" OR "fine motor skills" OR "gross motor skills" OR "locomotor skills" OR "object control skills").

2.2. Eligibility Criteria. We applied the following inclusion criteria with reference to the participants, interventions, comparisons, outcomes, and study design (PICOS) guidelines: (1) study sample consisted of healthy, normal developing children (6-12 years) without motor or mental impairments (e.g., motor disabilities, autism spectrum disorders); (2) the study assessed the effects of a traditional or technology-based PA intervention against a control group; (3) the study employed quantitative fundamental motor skills assessments; and (4) the study employed a RCT. Moreover, we only included empirical, peer-reviewed research published in English between January 2000 and October 2020 and other study designs (e.g., cohort and cross-sectional) were retrieved but excluded from the analysis.

2.3. Data Extraction. Three investigators (D.M., W.L., and Z.G.) independently screened all potential articles by evaluating the titles, and if able to discern study relevance, we evaluated the abstracts. Data extraction was completed by one investigator (W.L.) and checked for accuracy by another (D.M.). We then created list of relevant published articles in a Microsoft Excel spreadsheet. In detail, we extracted the following information: (1) publication year and the country the research was conducted in; (2) details of study methodology (i.e., study design, sample characteristics, study duration, type of PA intervention employed, study outcomes, and instruments used); and (3) key findings regarding the effectiveness (or lack thereof) and potential of PA on children's motor skills. Finally, we cross referenced the bibliographies of selected articles to further identify relevant studies. Noteworthy is the fact that we were not blinded to the authors or journals of the included articles and we made no attempts to contact study authors or correspondents to acquire missing information.

2.4. Risk of Bias within and across Studies. Two investigators (D.M. and W.L.) independently assessed the risk of bias within each included study. Specifically, we rated each study using an 8-item quality assessment tool used in previous

literature reviews of predominantly field-based RCTs [28, 29]. Notably, we used this tool because other tools for assessing bias in RCTs (e.g., Cochrane Risk of Bias 2.0) contain domains which are more applicable to clinical trials (e.g., allocation concealment, blinding of participants, and personnel) whereas this tool uses domains like employment of validity measures and follow-up assessments which we deemed more appropriate for field-based PA interventions. We rated each within-study item as "positive" if the item was present and explicitly described or "negative" if the item was absent or inadequately described. To ensure reliable scoring, two investigators (D.M. and W.L.) independently scored the risk of bias of each study within the quality assessment. If necessary, disagreements were adjudicated by a third reviewer (Z.G.). We calculated final quality scores for each study by summing all "positive" scores. Studies were considered high-quality when they scored above the median score (i.e., 7) following the scoring of all included studies. For the risk of bias across studies, the domains which we agreed may affect the cumulative evidence most were the employment of validity measures and participant retention given the variety of tools available for assessing children's motor skill development and the need for the ability to maintain children's interest in the employed PA interventions to promote long-term PA behaviors and motor skill development, respectively.

3. Results

3.1. Study Selection. Through a search of the databases, we identified a total of 727 potential articles. Following the removal duplicate articles, two investigators (D.M. and W.L.) screened the titles and abstracts of the remaining articles to further identify potentially relevant articles. An additional 3 studies were located through bibliography crosschecks. After thorough assessment of all full-text articles, 25 studies met all of the *a priori* established inclusion criteria and were included in this systematic review (see Figure 1). Reasons for excluding potential articles included ineligible age (i.e., those < 6 and >12 years), special populations (e.g., those with chronic disease), did not include measures of motor skills, and non-English language articles. Noteworthy is that we observed high interrater agreement such that 24 of 25 (96%) of the included articles were agreed upon and obtained between the study investigators.

3.2. Study Characteristics. Characteristics of all included studies are shown in Table 1. Of the 25 RCTs, 7 (28%) studies examined the effects of exergaming-based physical activity interventions on children's motor skills [30–36] and the remaining 18 (72%) assessed the impact of traditional PA interventions on children's motor skills [33, 37–54]. The studies were conducted in different countries: 6 in Australia [30, 33, 45, 46, 50, 53], 3 in the United States [31, 38, 39], 3 in China [37, 44, 51], 3 in the United Kingdom [40, 43, 47], 2 in Canada [35, 36], 2 in Greece [32, 48], 2 in the Netherlands [34, 54], 1 in Ireland [42], 1 in Switzerland [41], 1 in Italy [52], and 1 in Norway [49]. Among these studies, 20 were conducted in the school setting [30–39, 42–49, 53, 54], 1 was conducted in a home-based setting [40], 1 was conducted in a laboratory setting [51], 1 was conducted in a childcare center [41], 1 was conducted in a field-based (sports) setting [52], and 1 was conducted in a community-based setting [50]. Notably, most of the studies were published after 2010, except for 1 study that was published in 2002 [48] and 2 studies that were published in 2008 [43, 53], and 16 (64%) of the studies were published after 2015 [30–33, 37–40, 42, 44–46, 49, 51, 54], indicating that high-quality research examining PA interventions on children's motor skill development is an emerging scientific field of inquiry.

Further, we observed a relatively large variability in sample size (n = 34 to 891) and intervention length (4 weeks to 12 months) across studies. The exposure in most (72%) of the studies was a traditional PA/exercise program or class followed by exergaming-based PA interventions while the control conditions were most often usual care or regular school curriculum (i.e., no PA intervention). Although motor skill development measurement tools varied across studies, they were most often direct observations made by trained research assistants or assessments directly completed by the children. Gross motor skills, locomotor, and object control skills were the most commonly assessed outcomes in the assessment of motor skill performance. In this review, we did not employ a meta-analysis due to the heterogeneity of both exposures and outcomes across the included studies.

3.3. Study Quality and Risk of Bias Assessment. Scores of study quality/risk of bias for all individual studies ranged from 6 to 8 with a median score of 7 (Table 2). An individual study was considered high quality/low risk of bias when it scored above the median score of 7, moderate quality/medium risk of bias if scored at the median score of 7, and low quality/high risk of bias if scored below the median score of 7. In detail, 5 studies (20%) received an overall rating of strong quality/low risk of bias, 7 studies (28%) received an overall rating of moderate quality/medium risk of bias, and 13 studies (52%) received an overall rating of weak quality/-high risk of bias. Noteworthy is the fact that all studies succeeded in retaining at least 78% of the participants. The most common issues with the study quality/risk of bias were lack of power calculations for appropriate sample sizes and a lack of follow-up measurements, respectively. Regarding bias across studies for the 2 primary domains, 25 studies (100%) sufficiently reported on intervention fidelity and retention and as previously mentioned; all studies had high participant retention rates (≥78%). Further, 25 studies (100%) employed valid measures of assessing children's motor skill development, the majority of which used the Test of Gross Motor Development-Second Edition (TGMD-2).

3.4. Measurement Protocols. Various types of instruments were used to measure motor skills. Specifically, the most commonly used instrument in assessing children's motor skills was the TGMD-2, followed by the TGMD-Third Edition and the original TGMD, the Victorian Fundamental Motor Skills Assessment Instrument, the Körperkoordinations für Kinder (KTK) test, the Bruininks-Oseretsky Test

Figure 1: PRISMA flow diagram of studies through the review process.

of Motor Proficiency, Second Edition (BOT-2), the Fundamental Motor Skills Quotient (FMSQ), and the Zurich Neuromotor Assessment (ZNA). Notably, measurement tools used for motor skills varied across studies. Typically, assessments were directly completed by children or through direct observations made by trained research assistants. Although different instruments were used across various studies, validities of these assessments have been proven when being applied to children within the school setting (Table 1).

3.5. The Effectiveness of PA on Motor Skill Development. Overall, of the 25 RCTs examining the effects of PA interventions on children's motor skill development, 20 (80%) reported statistically significant improvements from pre- to postintervention [31, 32, 34–39, 42–53]. More specifically, of the 7 studies examining the effects of exergaming-based PA interventions on children's motor skill development, 5 (71%) observed significant intervention effects and of the remaining 18 studies which employed traditional PA interventions, and 15 (83%) observed significant intervention effects on children's motor skill development. Notably, of the 5 studies which reported no statistically significant changes in children's motor skill development, 2 were long-term interventions (9-12 months) conducted outside of the school setting (1 home-based intervention [40] and 1 child-care center intervention [41]) and the other 3 were short-term interventions [30, 33, 54] (6-14 weeks) performed in the school setting. However, of the 5 studies showing no effects of PA on children's motor skill development, no study reported detrimental effects of increased PA on motor skill development. That is, PA interventions did not adversely affect children's motor skill development.

4. Discussion

The purpose of this review was to synthesize and comprehensively evaluate all published RCTs examining the causal relationship between traditional and exergaming-based PA interventions on the motor skill development of healthy children aged 6-12 years. Twenty-five studies met the inclusion criteria and were included in the final analysis. Overall, findings suggested that increased PA had significant positive effects on children's motor skill development. More studies examined traditional PA interventions compared to exergaming-based PA interventions, but both showed relatively high effectiveness on children's motor skill development. Lastly, no study observed increased PA duration or frequency to have a detrimental effect on the development of children's motor skills.

Table 1: Characteristics of individual studies included in the review.

Study	Sample	Design/setting	Outcome/instrument	Exposure	Dose	Findings
Barnett et al. [30]; Australia	Children aged 4-8 years; $n = 95$	RCT School	Object control skills; perceived object control skills	Intervention children played exergaming (Wii), while control children have no treatment	1 hour per week for 6 weeks	Object control improved overtime, but there was no significant group difference; notably, intervention children found exergaming sessions were more enjoyable
McGann et al. [31]; US	Children aged 5-7 years; $n = 40$	RCT School	Locomotor skills Measured by TGMD-2	Intervention children participated in a purpose-built exergame, while control children participated a commercial exergame	3-minute high intensity gameplay each day, 5 days a week, for 8 weeks	Intervention children showed significant improvement for each locomotor skill (run, hop, skip, and slide), while the control group intervention had significant improvement in only one locomotor skill (the slide)
Chan et al. [37]; China	Primary school children, mean age 8.4 years; $n = 282$	Cluster RCT School	FMS competence, perceptions of physical and movement skill competence, teacher support, and enjoyment FMS was measured by TGMD-3 The athletic competence subscale of the Self-Perception Profile for Children (SPPC–6 items) was used to assess children' subjective evaluation of their athletic ability	Intervention children received an assessment-based teacher-led FMS intervention, while control children remain in their usual PE lessons	A total of 550 minutes, for a period of 13 weeks	Significant intervention effects were found for locomotor skills and perceived teacher support. However, there was a group-by-time effect for perceived physical competence in favour of the control group
Lee et al. [38]; US	Children aged 5-8 years; $n = 36$	RCT School	FMS competence and MVPA FMS was measured by TGMD-2 MVPA was measured by accelerometers	Intervention children participated in FMS-based need supportive afterschool program, while control children participated in a regular unsupervised afterschool program	60 min per session, 3 times per week, for 8 weeks	Intervention children had significant improvement in FMS competence and MVPA compared to control children; there was no gender difference regarding the FMS competence and MVPA
Cohen et al. [39]; US	Primary school children aged 7-10 years; $n = 460$	Cluster RCT School	MVPA, cardiovascular fitness, FMS competence, perceived sport competence MVPA was measured by accelerometer FMS competence was measured by TGMD-2 Perceived sport competence was assessed using the perceived competence sub-scale from Harter's Self-Perception Profile	Intervention children participated in a multicomponent PA and FMS intervention, while control children remained in their usual PE and school program	12 months	Changes in MVPA were associated with changes in object control skills, overall FMSs, and perceived competence Overall FMSs had a significant mediating effect on MVPA. In addition, overall FMSs and locomotor skills had a significant mediating effect on cardiovascular fitness

Table 1: Continued.

Study	Sample	Design/setting	Outcome/instrument	Exposure	Dose	Findings
Laukkanen et al. [40]; UK	Children aged 4-7 years; $n = 91$	RCT Home-based	PA and motor competence PA was measured by accelerometer Motor competence was measured by KTK (Körperkoordinations für Kinder) and throwing and catching a ball (TCB) protocols	Parents in the intervention group families received a tailored counseling to increase children's PA, while control group families did not receive any counseling	One-year intervention	The results showed significant decrease of MVPA in the intervention group when compared to the control group ($p < 0.05$). The TCB showed a nearly significant improvement at six months in the intervention group compared to the controls ($p = 0.051$), but not at 12 months. The intervention group had a steadier development of the KTK when the interaction of season was taken into account
Bonvin et al. [41]; Switzerland	Childcare center children with mean age 3.3 years; $n = 648$	Cluster RCT Childcare center	Motor skills BMI, PA, and quality of life Motor skill measures were adapted from the Zurich Neuromotor Assessment (ZNA) test PA was measured by accelerometer Quality of life of the participating children was assessed using the parent report for children of PedsQL 4.0	The intervention included training of the educators, adaptation of the childcare built environment, parental involvement, and daily physical activity, while the control group had no treatment	9 months	There was no significant improvement in motor skills compared to the control group; notably, not all childcare centers implemented all the intervention components
Vernadakis et al. [32]; Greece	Elementary school children aged 6-7 years; $n = 66$	RCT School	Object control skills The object control skills were measured by TGMD-2	Two intervention groups: (1) exergame-based training program and (2) traditional training program The control group did not receive any treatment	8 weeks; 2 times per week; 30 minutes per session	Significant improvement in object control skills in both intervention groups, but not in the control group. There was no significant difference regarding the improvements between two intervention groups
Costello and Warne [42]; Ireland	3rd and 4th grade school children aged 8-9 years; $n = 100$	RCT School	Motor skills Measured by fundamental motor skill quotient	Intervention children received FMS lessons, while control group children did not receive any treatment	4 weeks; 2 times per week; 30 minutes per session	Intervention children had significant improvements in FMSs, but not in control group
Johnson et al. [33]; Australia	Children aged 6-10 years; $n = 36$	RCT School	Object control skills and competence Object control skills were measured by TGMD-3; perceived object control skill was measured by the Pictorial Scale of Perceived Competence for Young Children	Intervention children received weekly exergaming intervention, while control group children did not receive any treatment	6 weeks; 50 min per week	No significant differences between the control and intervention groups were observed for both outcomes

Table 1: Continued.

Study	Sample	Design/setting	Outcome/instrument	Exposure	Dose	Findings
Foweather et al. [43]; UK	Children aged 8-9 years; $n = 34$	RCT School	FMS Skills were measured by process-oriented measures with video analysis	Intervention children participated in an after-school FMS training program, while control group children remain normal routine	9 weeks; one hour per session; 2 times per week	Significant improvement in static balance, but no significant improvements in other skills
Sit et al. [44]; China	Children aged 6-10 years; $n = 131$	RCT School	FMS proficiency, PA, self-perceived competence FMS was measured by TGMD-2, PA was measured by accelerometer (GT3X+), and self-perceived competence was measured by Physical Self-Descriptive Questionnaire (PSDQ)	The experimental group received a training program focusing on the practice of five specific FMS skills (running, jumping, catching, kicking, and throwing) Control group children received regular PE lessons	8 weeks; 40 minutes per week	FMS training resulted in significantly improved FMS proficiency and increased PA and enjoyment of activity participation in children
Lander et al. [45]; Australia	Year 7 girls aged 11-13 years; $n = 190$	Cluster RCT School	FMS Skills were measured by Victorian FMS assessment instrument	Intervention children received teacher-led FMS-focused training, while control group children remained normal PE	12 weeks; 90 minutes per week	Significant improvements in object control skills and total skill compared to the control group
Lander et al. [46]; Australia	Year 7 girls aged 11-13 years; $n = 200$	Cluster RCT School	FMS Skills were measured by Victorian FMS assessment instrument	Intervention children received teacher-led FMS-focused training; while control group children remained normal PE	12 weeks; 90 minutes per week	Significant improvements in perceived motor skill competence and actual motor skills
Johnstone et al. [47]; UK	Elementary school children; $n = 137$	Cluster RCT School	FMS, PA, inhibition, and math fluency FMS was measured by TGMD-2, PA was measured by accelerometer, inhibition was measured by Flanker Test, and math fluency was measured by One Minute Basic Facts Test	Intervention children received outdoor PA session, while control group had no treatment	10 weeks; one hour per week	Active play sessions were shorter than planned on average by 10 min, and participants spent a mean of 39.4% (14.2) of the session time in MVPA. There was preliminary evidence of a small intervention effect on MVPA ($d = 0.3$), FMS score, inhibition, and math fluency
Karabourniotis et al. [48]; Greece	Children aged 5-7 years; $n = 45$	RCT School	FMS, content areas of PE courses FMS was measured by TGMD, PE content was measured by the Academic Learning Time-Physical Education	Intervention children received a skill-oriented program, while control children received regular school PE	12 weeks	Intervention children had significant FMS improvements compared to the control group
Mombarg et al. [34]; Netherlands	Children aged 7-12 years; $n = 29$	RCT School	Balance skills Measured by M-ABC-2 and the Bruininks-Oseretsky test of motor proficiency (BOT-2)	Intervention children received Wii exergaming, while control children did not receive any treatment	6 weeks; 30 minutes per session; 3 times per week	Intervention children had significant improvements in balance skills compared to the control group

Table 1: Continued.

Study	Sample	Design/setting	Outcome/instrument	Exposure	Dose	Findings
Aadland et al. [49]; Norway	Children aged 10 years; $n = 123$	Cluster RCT School	Executive function FMS was measured by TGMD-2	The intervention constituted three PA elements: PA educational lessons, PA breaks, and PA homework, adding 165 minutes of PA to the mandatory 135 minutes of PA and physical education	7 months	There was no effect of the intervention on executive functions in the intention-to-treat analyses. Per protocol analyses revealed small effects of the intervention on the composite score of executive functions, cognitive flexibility, and motor skills
Cliff et al. [50]; Australia	Children aged 5-9 years; $n = 132$	RCT with 6- and 12-month follow-up Community-based	FMS, perceived athletic competence, PA, screen behaviors FMS was measured by TGMD-2, perceived competence was measured by Self-Perception Profile for Children, PA was measured by accelerometer, and screen behaviors were measured by the Children's Leisure Activities Study Survey	Children were randomly assigned to three groups: (1) a child-centered physical activity skill development program (Activity), (2) a parent-centered dietary modification program (Diet), and (3) a combination of both programs (Activity+Diet)	6 months; 10 2 h weekly group sessions (~90 min of physical activity per session) and weekly "home challenge" activities	The findings indicated that the PA and PA+Diet groups had significant improvements in FMS
Pan et al. [51]; China	Children aged 7-12 years; $n = 60$	RCT Clinic	FMS, executive function FMS was measured by TGMD-2, and executive function was measured by Stroop Color and Word Test and Wisconsin Card Sorting Test	Intervention children received table tennis and physical and cognitive training, while control group did not receive treatment	12 weeks; 70 minutes per week	Training group had significant improvements in both locomotor and object control skills compared to the control group
Piazza et al. [52]; Italy	Female rhythmic gymnasts, aged between 10 to 13 years, $n = 57$	RCT Field-based	Squat jump test, counter movement jump test, hopping test, flexibility of the hip	Participants were randomly assigned to the unspecific resistance training group or specific resistance training group	6 weeks 2 days per week (nonconsecutive days)	The main result was that both unspecific resistance training and specific resistance training protocols positively affected the jumping performance, with an increase of the lower limb explosive strength of 6-7%, with no side effects No significant differences were detected among groups for flexibility, body mass, calf, and thigh circumferences

Table 1: Continued.

Study	Sample	Design/setting	Outcome/instrument	Exposure	Dose	Findings
Salmon et al. [53]; Australia	School children aged 10-11 years; $n = 311$	RCT School	BMI, PA, screen behaviors, PA enjoyment, FMS PA was measured by accelerometers, screening behaviors were assessed by the self-reported screen behaviors questionnaire, and FMS was measured by TGMD	Children were randomized by class to one of the four conditions: a behavioral modification group (BM); a fundamental movement skill group (FMS); a combined BM/FMS group (BM/FMS); and a control (usual curriculum) group	One school year Each of the intervention conditions consisted of 19 lessons (40–50 minutes each)	There was a significant intervention effect from baseline to post intervention on age- and sex-adjusted BMI in the BM/FMS group compared with controls, which was maintained at 6- and 12-month follow-up periods. Compared with controls, FMS group children recorded higher levels and greater enjoyment of PA
Sheehan and Katz [36]; Canada	Children aged 6-10 years; $n = 67$	RCT School	Balance	Intervention children participated in a Wii Fit exergaming program, while control group children participated in traditional PA	6 weeks; 3 days per week	The intervention children had significant improvements in postural stability compared to the control group
Sheehan and Katz [35]; Canada	Fourth grade children; $n = 64$	RCT School	Balance	Intervention children participated in a iDance exergaming program, two control groups were used: (1) a physical education (PE) class geared toward agility, balance, and coordination (ABC) improvement and (2) a typical PE curriculum class	6 weeks; 34 min per day; 4-5 days per week	Exergaming students improved their postural stability significantly over a 6-week period compared to those in the typical PE class
van der Fels et al. [54]; Netherlands	Children aged 7-10 years (grades 3-4); $n = 891$	Cluster RCT School	Gross motor skills were assessed using the Körperkoordinations für Kinder test Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2), was used to include a measure for ball skills	Intervention children participated	Intervention groups received aerobic or cognitively engaging exercise (14 weeks, four lessons per week). Control groups followed their regular physical education program	No main effects of the aerobic intervention and the cognitively engaging intervention on cardiorespiratory fitness and motor skills in primary school children in grades three and four

Table 2: Risk of bias/quality of individual studies included in the review.

Articles	Randomization	Control	Pre-post	Retention	Missing data	Power analysis	Validity measure	Follow-up	Score	Effectiveness
Barnett et al. [30]	+	+	+	+	+	+	+	—	7	No
McGann et al. [31]	+	+	+	+	+	—	+	—	6	Yes
Chan et al. [37]	+	+	+	+	+	+	+	+	8	Yes
Lee et al. [38]	+	+	+	+	+	+	+	+	8	Yes
Cohen et al. [39]	+	+	+	+	+	+	+	—	7	Yes
Laukkanen et al. [40]	+	+	+	+	+	—	+	+	7	No
Bonvin et al. [41]	+	+	+	+	+	+	+	+	8	No
Vernadakis [32]	+	+	+	+	+	—	+	—	6	Yes
Costello and Warne [42]	+	+	+	+	+	—	+	—	6	Yes
Johnson et al. [33]	+	+	+	+	+	—	+	—	6	No
Foweather et al. [43]	+	+	+	+	+	+	+	+	7	Yes
Sit et al. [44]	+	+	+	+	+	+	+	+	8	Yes
Lander et al. [45]	+	+	+	+	+	—	+	+	7	Yes
Lander et al. [46]	+	+	+	+	+	—	+	—	6	Yes
Johnstone et al. [47]	+	+	+	+	+	—	+	—	6	Yes
Karabourniotis et al. [48]	+	+	+	+	+	—	+	—	6	Yes
Mombarg et al. [34]	+	+	+	+	+	—	+	—	6	Yes
Aadland et al. [49]	+	+	+	+	+	—	+	+	7	Yes
Cliff et al. [50]	+	+	+	+	+	—	+	—	6	Yes
Pan et al. [51]	+	+	+	+	+	—	+	—	6	Yes
Piazza et al. [52]	+	+	+	+	+	—	+	—	6	Yes
Salmon et al. [53]	+	+	+	+	+	—	+	+	7	Yes
Sheehan and Katz [36]	+	+	+	+	+	—	+	—	6	Yes
Sheehan and Katz [35]	+	+	+	+	+	—	+	—	6	Yes
van der Fels et al. [54]	+	+	+	+	+	+	+	+	8	No

"+" refers to positive (explicitly described and present in details); "—" refers to negative (inadequately described and absent); "Yes" indicates significant positive effect; "No" indicates no significant effect. Median score = 7.

Overall, the majority (80%) of studies observed beneficial effects of PA promotion interventions on children's motor skill development, the majority of which were conducted within a school setting. Of the 5 studies which reported no significant effects, 40% were conducted outside of the school setting (1 home-based intervention [40] and 1 childcare center intervention [41]). Thus, we postulate that PA promotion interventions are more effective at increasing children's motor skill development when conducted in the school setting. Indeed, given the amount of time children spend at school and the structured schedules within these settings, it is well-documented that schools have the greatest influence on children's PA behaviors [55] and school-based PA has been observed as a strong predictor of children's total daily and weekly PA [56] and is positively associated with higher levels of daily moderate-to-vigorous intensity PA [57]. That said, we are not surprised that motor skill development was not significantly enhanced in childcare or home-based settings given there is less PA-related structure and study adherence (PA participation in this case) is less controlled [58]. Indeed, one study reported dropout of intervention participants [40], and the other noted the complexity of conducting PA interventions outside of a study setting and how intervention fidelity suffered as a result [41]. Additionally, these two interventions were long-term (9-12 months) and without structure, and participants likely lost interest in the intervention within the timeframe and PA participation (and motor skill development) likely suffered because of this. Notably, 2 studies which were conducted outside of a school setting observed significant results (1 laboratory-based [51] and 1 sports setting [52])—settings which also have more structure and control of participants' adherence and fidelity outcomes. Indeed, previous research has demonstrated and noted the importance of structure when aiming at promoting children's motor skill development [59–62].

Another possible mediating factor in the relationship between PA and motor skill development in children is PA dose (i.e., the frequency and amount of time devoted to the instruction and practice of motor skills [63]). Indeed, there was distinct homogeneity in intervention length across the included studies which ranged from 4 weeks to 12 months. Specifically, of the 5 studies which did not observe significant intervention effects on children's motor skill development, heterogeneity was also present as intervention length ranged from 6 weeks to 12 months, making it difficult to assess whether PA dose was responsible for the mixed findings. Taken together, previous research has demonstrated inconsistencies with regard to PA dose on children's motor skill

proficiency. For example, similar to the findings of this review, individual studies have demonstrated significant effects on children's motor skills after a 540-minute PA dose [59–61] whereas other studies observed statistically nonsignificant findings after 400- and 3600-minute PA doses [53, 64]. One study [63] directly examined the dose-response relationship between PA dose using the same intervention and young children's motor skill development (tested using the TGMD-2) and divided the participants into 1 of 4 groups based on PA dose: (1) 660 minutes, (2) 720 minutes, (3) 900 minutes, and (4) control. Interestingly, the researchers found that all 3 dosages resulted in significantly greater improvements in motor skill performance compared to control, with no significant differences between PA dosages. However, this study was conducted in preschool-aged children and it remains unclear how PA dose affects motor skill development in children.

To the best of our knowledge, this is the first systematic review to examine the causal relationship of traditional and exergaming-based PA RCT interventions on children's motor skill development. We applied strict inclusion criteria and only included high-quality RCTs among a homogenous sample of healthy children. Additionally, we identified participant retention as a potential major risk of bias across studies and 100% of the included studies sufficiently discussed intervention fidelity and participant retention and all studies were able to retain ≥78% of participants, thereby strengthening the cumulative evidence of this review. However, this review is not without limitations, and accordingly, educators and other health practitioners should interpret the results with caution. First, for logistical reasons, we only included peer-reviewed studies published in English when non-English publications, and therefore further comparative evidence, may have been available on the topic. However, language restriction does not consistently bias the results of narrative or quantitative syntheses [65]. Second, there was noticeable heterogeneity of measurement protocols and assessment tools used to test children's motor skills across studies. Nevertheless, validated testing instruments were used across all studies which minimized a major domain of bias and further strengthened the overall evidence of this review. Third, likewise, there was some heterogeneity in the dose of PA administered across studies such that some were acute interventions and some were long-term interventions and some only intervened 1 day per week whereas others intervened 5 days per week. In addition, individual studies and the review as a whole did not assess possible moderating effects of PA on children's motor skill development. For example, study setting (e.g., home- vs. school-based) or PA intervention type (e.g., exergaming vs. traditional PA) may have moderated the effectiveness of the PA interventions on children's motor skill development. Lastly, 2 major sources of within-study risk of bias were lack of a power analysis and lack of long-term follow-up testing. In detail, we observed over half of the included studies to be of low quality/high risk of bias due to a lack of power analysis to determine appropriate sample sizes and a lack of follow-up observations to track the long-term effectiveness of the employed interventions. Thus, we suggest future RCTs in this field of inquiry to address these gaps in study design to strengthen the quality of available evidence and to better establish the long-term effectiveness of PA promotion interventions on children's motor skill development.

5. Conclusions

Overall, findings suggested a causal relationship between increased PA and improved motor skill development in children, especially when interventions were conducted in a school setting [66]. Although traditional PA intervention strategies have been examined in the literature more than exergaming-based PA intervention strategies, exergaming interventions showed similar effectiveness relative to the number of available trials, and given their enjoyable and innovative nature and ability to leverage children's interest in videogame play, they hold promise for future motor development in this population. These findings have important public health implications as they help to inform educators and other health practitioners that regardless of the employed PA promotion strategy (traditional or exergaming-based PA), simply getting older children to move more can enhance their motor skill development which, in turn, may help establish healthy PA behaviors which track into adulthood [7] and, ultimately, help attenuate the grand challenge of adult overweight and obesity in the U.S. [67].

Therefore, if school funding allows, we recommend teachers and/or physical educators implement exergaming stations within the school to allow students to engage in enjoyable PA before, during, and/or after school to increase PA output and, ultimately, motor sill development. If school funding is not available, other free and creative PA promotion strategies should be used, such as intermittent learning breaks wherein short bouts of PA are integrated throughout the day during class. Likewise, parents should consider implementing exergames in their homes to help encourage PA participation *outside* of the school setting and/or encourage their children to play traditional games that require PA. Nevertheless, our study shows that whether in the school setting or outside of the school setting and whether traditional or technology-based PA, simply getting children to move more and engage in PA is beneficial to improving motor skill development which may lead to greater PA-related self-confidence and healthy PA behaviors that track throughout the lifespan.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Research Article

A Follow-Up Study of Motor Skill Development and Its Determinants in Preschool Children from Middle-Income Family

Huan Wang,[1] **Yanjie Chen**,[2] **Jianing Liu**,[3] **Huanhuan Sun**,[3] **and Weizhen Gao**[1]

[1]*China Institute of Sport Science, 100061, China*
[2]*Beijing Children's Hospital, Capital Medical University, 100045, China*
[3]*Shanghai University of Sport, 200438, China*

Correspondence should be addressed to Huan Wang; wanghuan@ciss.cn

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We tracked the motor skill development of young children aged 3–6 years and investigated the influence of middle-income home environment on the development of motor skill. 268 children were selected from kindergartens in Beijing. The Test of Gross Motor Development (TGMD) tool was used to test the development of locomotor and object-control skills (LS and OS), and a survey of children's behaviour and home environment was conducted. During the follow-up, the LS and OS of children aged 3–6 years continued to grow, with an annual growth rate of 20% and 30%. Five LS indicators and two OS indicators were significantly higher in the 3–4-year group than in the 4–5 and 5–6-year groups ($p < 0.01$). The age-sex trend model showed that girls' locomotor skill developed at a significantly higher rate than that of boys ($\beta = 6.3004$ and 4.6782, $p < 0.001$). Three-year-old boys performed significantly better than girls on object-control motor skill ($p < 0.05$). Factors affecting the rate of children's motor skill development in middle-income families included the frequency of playing with friends ($\beta = 0.133$, $p = 0.032$) and the frequency of bicycling, skateboarding, dancing, running, and jumping ($\beta = 0.041$, $p = 0.042$). Family income, parents' education level, and family activity area did not significantly affect the growth rate of motor skills. For middle-income families, the improvement of material environment at home like more playing spaces and toys did not speed up the motor development, while more opportunities to play with friends and engage in a variety of sports activities could promote children's motor skill development.

1. Introduction

Motor skill development plays an important role in children's health and development and is the foundation for performing physical activities [1–3]. The first six years of childhood are devoted to learning and practicing fundamental motor skills in an exploratory and experiential manner, including locomotor skill, object-control skill, and posture-control skill [4]. These motor skills need to be developed at an appropriate level between the ages of three and six, and different types of movements should have their own developmental patterns [5]. Studies on motor development characteristics at the childhood stage have produced diverse results. Previous study found a gradual decrease in the average annual growth value of motor skills with age in a study of 1,614 Belgian children aged 3–6 years [6]. And a study of 1,046 children found that the average annual growth values of locomotor and object-control skills were highest among 4–5 years in children aged 3–6 years [7]. In these studies, the cross-sectional method was used to collect data of different age groups to reflect the changes of the motor development in the process of growth. However, this method has limitation in a certain level. Children in different generations are influenced by different environments; hence, the cross-section method which connects data of different generations is not sufficiently convincing. To gain a deeper understanding of this issue, it is essential to follow up the research data to provide more powerful data support.

In addition to the following physical growth patterns, the development of motor skills is inevitably related to physical activities (PA) [8] and the home environment [9]. Past research reports were inconsistent regarding the

relationships between PA and the home environment. Some studies have found no association [10, 11], while others have reported weak but positive association [12, 13]. This could be related to the intensity and type of PA engaged in by the study subjects and with whom they exercise. In addition, young children's activity behaviours depend heavily on the home environment. It was argued that in a family with more abundant sports facilities and a larger space where parents were at a higher educational level, children would be more active and their motor skills would develop faster [14, 15]. However, it has been suggested that the influence of home environment on children's motor skill development is affected by the family's socioeconomic status (SES) and that the key factors affecting children's motor development may differ across families with different SES levels and cannot be generalized [16, 17]. Positive factors that promote motor skill development in low-income families may not necessarily play a role in middle- and high-SES families [18–20]. China is in a period of rapid economic development, and an increasing number of families are moving from low-income to middle-income level. As rapid economic development in China, an increasing number of families have been moved from the low-income group to the middle-income group. It is significant to study the motor development of children in middle-income families and to create a better home sporting environment for their healthy development.

Therefore, this study followed-up the motor skill development of preschool children aged 3–6 years, examined the trajectory of motor and object-control development, and explored the influence of the motor environment on motor development in medium-SES families, aiming at providing a basis for future interventions.

2. Methods

2.1. Participants. Random cluster sampling was used to select 353 children in 15 classes at four kindergartens in downtown Beijing, of whom 198 were boys and 155 were girls. Ten children with congenital disorders such as motor disorders, intellectual disabilities, Autism Spectrum Disorder, Attention Deficit Hypersensitivity Disorder, and speech disorders were excluded. After consultation with researchers and teachers, parents signed the informed consent form. During the 1-year study period, 75 children were lost from the study because they transferred to other kindergartens or attended preschool. Finally, 268 children, 126 boys (47.0%) and 142 girls (53%), participated in the study: 63 in the 3–4-year group, 127 in the 4–5-year group, and 78 in the 5–6-year group. The characteristic of the participants can be seen in Table 1. The study was approved by the Ethics Committee of China Institute of Sport Science.

2.2. Research Procedure. The 268 preschool children were divided into a 3–4-year group, a 4–5-year group, and a 5–6-year group. Two specially trained testers administered the Test of Gross Motor Development-3rd Edition (TGMD-3) test to the subjects from June to July 2017. The entire testing process was videotaped in multiple directions with (model) video camera, and the video was rewatched for any question-

Table 1: Height, weight, and BMI of the children at the beginning of the study.

Indicator	Age					
	3-4 yr. (n = 63)		4-5 yr. (n = 127)		5-6 yr. (n = 78)	
	Mean	SD	Mean	SD	Mean	SD
Height (cm)	103.6	5.1	107.4	5.3	113.1	5.1
Weight (kg)	16.9	2.9	18.0	2.5	20.1	3.2
BMI (kg/m^2)	15.7	1.6	15.6	1.3	15.6	1.5

able on-site scoring to ensure the consistency of the test results. Moreover, parents were asked to fill out the Environmental Opportunities Questionnaire based on the situation in the past month. From June to July 2018, the same group of testers administered the TGMD-3 test with the same content.

2.3. Test Methods

2.3.1. Methods of Motor Development Assessment. Children's motor skill competence was assessed using the TGMD-3. This test was developed by Professor Ulrich in the United States and was used to measure the level of basic motor skill development in children aged 3–10 years, which is considered a valid and reliable instrument [21]. It assesses 13 skills: 6 locomotor (run, gallop, hop, leap, horizontal jump, and slide) and 7 object-control skills (overhand throw, underhand throw, catch, dribble, one-hand strike, two-hand strike, and kick). The total scores for locomotor and object-control skills were 46 and 54, respectively. The testers were college students who received special training before the test. During the test, the testers first demonstrated the correct movements once; following that, the children practiced once and then took two formal tests.

In the quality control of the test, every year, the TGMD test was undertaken by the same college students. Before the test, they were trained with the TGMD-3manual, and they watched videos on the website of the University of Michigan. They tested the children on site and standardized the scores.

The test sequences followed the order from locomotor skill to object control skills and from simple movement to complex movement. However, considering the changes in mood and interest of some children, the test process would be adjusted accordingly, such as starting the test from object control skills.

Before each formal test, 10% of participants were selected to carry out a test-retest reliability experiment. Interrater reliability for locomotor subscale and ball skill subscale was good (ICC: 0.89–0.95). Intrarater reliability across all raters was good (ICC: 0.76–0.96).

2.3.2. Questionnaire. The Environmental Opportunities Questionnaire supporting early motor development in the first year of life is used as a research tool to evaluate the home environment of young children. The scale has good reliability and validity [22], and its Cronbach α coefficient used in China is 0.88 [23]. The questionnaire consists of two sections:

Table 2: Key indicators of the Environmental Questionnaire.

Variable category	Indicator	Assignment description
Children behaviour	Weekly frequency of sports activities	Continuous variable, cumulative frequency of multiple physical activities, including bicycling, skateboarding, roller skating, swimming, and playing ball
	Weekly frequency of media activities	Continuous variable, cumulative frequency of multiple media activities, including watching TV, videos, DVDs, and playing video games
	Frequency of use of sports equipment	Continuous variable, cumulative frequency of use of multiple sports equipment, including balls, skates, bicycles, swings, slides, and skipping ropes
	Number of times of playing with friends	More than 5 times per week 3–5 times per week 1–3 times per week Occasionally Never
Home environment	SES	Continuous variable, a higher score indicates a better family SES.
	Parental support for children's sports activities (i) We do a lot of physical exercises with our children (ii) Our family values sports (iii) As parents, we are very interested in our children's sports activities (iv) Our children's sports activities are often a topic of conversation in our family (v) As parents, we support our children's sports activities (e.g., chaperoning and transportation).	Entirely supportive Basically supportive Uncertain Basically unsupportive Entirely unsupportive
	Frequency of parents' physical exercise	More than 5 times per week 3–5 times per week 1–2 times per week No participation

children's activities and parent questionnaire. It was completed by the guardian after signing an informed consent form. The children's activity section includes the children's health status, siblings' age, leisure sports activities and frequency, existing sports equipment and use, sports activities and frequency after school, and people and partners that children come into contact with in their daily life. The parent questionnaire includes general information about parents (family members, marital status, parents' occupation and educational level, daily caregivers and their educational level, household income per capita, and household living area), parents' participation in sports activities in the last six months, toy supply at home, and parents' attitudes and supportive behaviours towards children's sports (Table 2).

To facilitate the SES assessment of the families of young children, the educational level of the main caregiver, household disposable income per capita, and the household living area were evaluated together. The educational level of the caregiver was scored on a scale of 1–4, in the descending order of graduate, undergraduate, postsecondary and secondary schools, and elementary school. The monthly household income per capita was scored on a scale of 1–4 in a descending order: greater than ¥10,000, ¥5,001–¥100,000, and ¥1,000–5,000 and less than ¥1,000. The household living area per capita was scored on a scale of 1–4 in descending order: greater than 50 m^2, 31–50 m^2, and 21–30 m^2 and less than 20 m^2. The cumulative score of the three indicators was used as the SES score for young children's families, with a full score of 12; a higher score indicated a better family SES. Based on the results of the 2005 survey conducted by the National Bureau of Statistics of China, the annual income of urban middle-income families in China (calculated based on the average family size of three) was ¥60,000–¥500,000; i.e., the household living area was usually above 80 m^2. Consequently, SES scores were classified into three grades, with greater than 10 being classified as high-SES families, 6–10 as medium-SES families, and less than 6 as low-SES families.

2.4. Statistical Methods. The SPSS18.0 statistical tool was used for statistical analysis of the data. Descriptive statistics were used to describe the TGMD-3 results and questionnaire information for preschool children. The hierarchical linear modelling (HLM) model was used to fit the data from the two longitudinal tests to a developmental curve from age 3–6 years. Age trends and gender differences in the development of locomotor and object-control skills were calculated in turn. $p < 0.05$ was considered statistically significant.

A general linear model (GLM) was used to analyse the effects of age and gender on basic motor skills using a between-subjects effect test and parameter estimation with gender and age as fixed factors, with the average annual growth value of each item as the dependent variable. Finally,

a multifactor generalized linear regression analysis was conducted with the annual growth rate (%) of the TGMD-3 score as the dependent variable and age, individual activity behaviour, and family support environment as the independent variables, to explore the factors influencing the rate of motor skill development. The independent variables with the highest p values were eliminated one by one using the regression method, and the independent variables were retained according to $\alpha \leq 0.05$, thus building the final model. Statistical significance was set at $p < 0.05$.

3. Results

3.1. Annual Growth Rate of Motor Skills. Table 3 shows that boys and girls in the three age groups improved their locomotor and object-control skills after one year of growth. The average annual growth in locomotor skills was 3.9 points for boys and 6.0 points for girls, while the average annual growth in object-control skills was 5.8 points for boys and 5.6 points for girls. Dividing the TGMD average annual growth value by the baseline value to the average annual growth rate resulted in an annual growth rate of 14.7–22.2% for locomotor skills and 30.6–31.7% for object-control skills.

The one-year motor skill growth of the three age groups was used to fit the motor skill change curves from three to six years old. Taking children's locomotor skills and object-control skills as the dependent variables and age as the independent variable, a trend model of motor skill level and age (HLM model) was constructed to describe the trends in children's locomotor skills and object-control skills with age. The convergence test showed that the models all conformed to the principle of convergence; therefore, the development trend of children in each age group was basically consistent and could be described by a single curve. The slopes of the fixed parts of the locomotor and object-control scores were statistically significant ($p < 0.001$), indicating that both scores changed linearly with age and that the slope of object-control skills was larger than that of locomotor skills. Figure 1 shows the resulting age-specific change curves.

Gender was included in the model to further investigate whether there were gender differences in the age-dependent characteristics of children's locomotor and object-control scores, and the results are shown in Figure 2. Figure 2(a) shows that at the age of 3 years, boys' locomotor skills was slightly higher than that of girls, but there was no statistical difference ($p > 0.05$). However, girls' locomotor skills developed at a significantly higher rate with age than that of boys ($p < 0.001$), with slopes of 6.3004 and 4.6782, respectively. Figure 2(b) shows that at the age of three years, boys' object-control skills was significantly higher than that of girls ($p < 0.05$), but girls' locomotor skills developed at a significantly higher rate with age than that of boys ($p < 0.001$), with slopes of 6.6485 and 6.2663, respectively ($p < 0.001$).

3.2. Influence of Age and Gender on the Growth Rate of Motor Skills. The GLM was used to further examine the effects of age and gender on the results of the 13-item TGMD motor indicators (Table 4). A between-subjects effect test and parameter estimation were conducted using the average annual growth value of each item as the dependent variable, with gender and age group as fixed factors.

Of TGMD's 13 locomotor and object control skills, gender had a significant effect on the growth rate of gallop performance, with girls having significantly higher average annual growth values than boys ($p = 0.01$, $\beta = -1.07$). In the six locomotor skill indicators, age had a significant effect on running, gallop, slide, horizontal jump, and hop. The average annual growth value was significantly higher in the 3–4-year group than in the 4–5-year group and 5–6-year group ($p < 0.01$), with no significant difference between the two groups. The effect of age on the average annual growth value of object-control skills was related to the indicator. The table shows that the skill growth of overhand throw ($\beta = 1.25$, $p = 0.01$) and kick ($\beta = 0.10$, $p = 0.02$) was age related, with the fastest average annual growth in the 3–4-year group. Growth in other ball skills did not differ significantly between age 3, 4, and 5 years ($p > 0.05$) (Table 4).

3.3. Individual Behaviour and Home Environment of the Children. In the first year of the baseline test, the children's individual behaviour and home environment were investigated. The survey showed that there were only significant differences between diverse age groups in the frequency of using sports equipment and that there were no age differences in other behavioural indicators ($p < 0.05$). The SES level of children's families was relatively concentrated in the range of 8.7–8.9 points, which belonged to medium-SES families. In the parents' support for children's physical activities, the highest degree of "entirely supportive" was for "chaperoning and transportation," reaching over 60%. The proportion of parents participating in physical activities more than 3 times a week was about 30% (Table 5).

3.4. Influence of Young Children's Behaviour and Home Environment on the Growth Rate of Motor Skills. In this section, a multifactorial GLM regression analysis was conducted using the annual growth rate (%) of TGMD scores as the dependent variable and children's age, individual activity behaviour, and family support environment as the independent variables, to explore the factors influencing the rate of motor skill development.

Using the regression method, the independent variables with the highest p values were eliminated one by one in sequence, and the independent variables were retained according to the principle of $\alpha \leq 0.05$, thereby building the final model (Table 6). The model suggested that children's age ($\beta = -0.393$, 95% CI: 0.552~-0.234), the weekly frequency of sports activities ($\beta = 0.133$, 95% CI: 0.021~-0.245), and the number times of playing with friends ($\beta = 0.041$, 95% CI: 0.001~-0.081) were associated with the speed of motor skill development. According to the regression coefficients and their significance tests, the annual growth of TGMD score was faster in children at a younger age, with a higher frequency of sports activities, and in a greater number times of playing with friends. Conversely, other behavioural factors such as the frequency of media activities and the frequency of use of sports equipment were

Table 3: TGMD test scores of motor skills.

Test item	Baseline test		Testing after one year		Annual growth value						Annual growth rate (%)	
	Male	Female	Male	Female	Male			Female				
					Average annual growth value	95% CI		Average annual growth value	95% CI		Male	Female
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD		Lower bound	Upper bound		Lower bound	Upper bound		
Run	6.33 ± 1.93	6.19 ± 2.14	7.00 ± 1.56	7.01 ± 1.26	0.67	0.26	1.09	0.82	0.41	1.22	10.70	13.20
Gallop	4.71 ± 2.61	4.26 ± 2.72	4.94 ± 2.74	5.55 ± 2.21	0.22	-0.46	1.09	1.29	0.76	1.82	4.70	30.20
Side	6.04 ± 2.36	5.98 ± 2.57	6.33 ± 2.02	6.86 ± 1.66	0.29	-0.20	0.78	0.88	0.41	1.35	4.90	14.70
Skip	2.51 ± 2.20	3.01 ± 2.21	3.45 ± 2.16	4.07 ± 2.13	0.94	0.44	1.45	1.06	0.63	1.49	37.70	35.40
Horizontal jump	4.29 ± 1.73	4.27 ± 1.93	4.98 ± 1.89	5.30 ± 1.80	0.69	0.23	1.15	1.04	0.63	1.44	16.10	24.30
Hop	3.04 ± 2.19	3.45 ± 2.00	4.17 ± 2.25	4.39 ± 2.20	1.13	0.63	1.64	0.94	0.51	1.38	37.30	27.30
Overhand throw	3.12 ± 2.05	2.89 ± 2.00	4.16 ± 1.86	3.83 ± 1.78	1.04	0.55	1.53	0.94	0.55	1.33	33.30	32.70
Underhand throw	2.40 ± 1.88	2.13 ± 1.55	3.14 ± 1.77	2.85 ± 1.83	0.74	0.34	1.14	0.71	0.38	1.04	30.70	33.30
Catch	2.93 ± 1.57	2.89 ± 1.68	3.40 ± 1.68	3.50 ± 1.86	0.47	0.09	0.85	0.61	0.26	0.95	16.00	20.90
Dribble	1.99 ± 2.13	2.16 ± 2.27	3.46 ± 2.31	3.40 ± 2.21	1.47	0.98	1.96	1.24	0.82	1.66	73.70	57.30
One-hand forehand strike	0.95 ± 1.29	0.83 ± 1.17	1.95 ± 1.86	1.45 ± 1.76	1.00	0.61	1.39	0.62	0.27	0.97	105.00	74.60
Two-hand strike	4.10 ± 2.39	3.51 ± 2.49	3.94 ± 2.62	3.83 ± 2.85	-0.17	-0.72	0.38	0.32	-0.21	0.84	-4.10	9.00
Kick	3.56 ± 1.53	3.50 ± 1.47	4.84 ± 1.91	4.77 ± 1.83	1.29	0.87	1.70	1.27	0.90	1.65	36.20	36.40
Locomotor skills	26.91 ± 9.17	27.15 ± 9.80	30.87 ± 7.78	33.18 ± 6.64	3.96	2.05	5.87	6.03	4.49	7.56	14.70	22.20
Object-control skills	19.06 ± 8.69	17.94 ± 8.56	24.89 ± 9.10	23.63 ± 9.14	5.83	4.01	7.66	5.69	4.31	7.07	30.60	31.70
Overall	45.97 ± 16.34	45.10 ± 16.92	55.76 ± 7.62	56.82 ± 6.89	9.79	6.53	13.06	11.72	9.34	14.09	21.30	26.00

SD, Standard deviation; CI, Confidence interval.

Figure 1: Age characteristics of locomotor and object-control skills.

not associated with the rate of motor skill development. Three family factors (family SES, parental support for sports activities, and parental physical activities level) did not significantly affect the growth rate of motor skills.

Although the model constructed in the last step ($F = 10.505$), was significant, the coefficient of determination and adjusted coefficient of determination were low ($R^2 = 0.175$ and 0.158, respectively). This suggested that there might have been other crucial influencing factors that have not been included in the equation and await exploration in future studies.

Based on the speed of motor skill development, children with annual TGMD change rate ≥ 50% and ≤5% were selected to compare daily activity behaviour and home support environment, and the results are shown in Table 7. The two groups significantly differed in the weekly frequency of sports activities and the number of times of playing with friends ($p < 0.05$). There were differences in home environment scores, with children with fast motor skill development having lower family SES scores than those with slow motor skill development, but they were not statistically significant. The proportion of parents who were "entirely supportive" of children's sports activities was slightly higher in children with fast motor skill development, as well as the proportion of parents exercising more than 3 times a week, but the overall difference was not statistically significant.

4. Discussion

The golden age for motor development is between the ages of three and six years. Understanding the trends and characteristics of motor development is a prerequisite for formulating targeted development strategies. We tracked and analysed the trajectory of the gross motor development of children from urban middle-income families for one year. We identified the characteristics of children's motor development in different motor categories, ages, and genders and compared the effects of different activities and family support environments on children's motor skill development. The results will provide empirical evidence for preschool education workers and parents to guide children to develop motor skills reasonably.

4.1. Development Characteristics of Motor Skills by Age. Our results showed that after one year of natural growth, children aged three to six years developed both locomotor and object-control skills each year. The annual growth score of locomotor skills was higher than that of object-control skills, whereas the annual growth rate of locomotor skills was greater. This was consistent with a previous study which is conducted in Xi'an, China [24]. Children's basic motor development follows the principle of improving from simple movement to complex movement and from low-level skill to high-level skill [25]. From 0 to 3 years old, children's locomotor skills are mainly exercised. Their muscles, bones, and cardiopulmonary function are not fully developed, and the main exercise is crawling, walking, and running. After 3 years old, children's gross motor development has already had a certain foundation. They are no longer satisfied with simple walking, running, and jumping and began to develop coordination and object-control skills while consolidating locomotor skills. By fitting the change curves of locomotor and object-control skills, we found that the growth rate of 3 to 6-year-old children's object-control skills was faster than that of locomotor skills. It indicated that as more complicated skills, the object-control skills might develop slower than the locomotor skills in the initial stage [26], but as the nervous system matures, the development of object-control skills would accelerate and may even exceed that of the locomotor skills. Therefore, after the age of 3, appropriate ball games should be provided to the children for promoting their object-control skills.

4.2. Influence of Gender on Motor Skill Development. This study indicated that there were gender differences in motor skill development in early childhood. Particularly, girls outperformed boys in locomotor skill development in early childhood, which was similar to the results of Legear et al. and Kit et al. [27, 28]. Nevertheless, some studies have not shown gender differences in the acquisition of some locomotor skills [6, 29]. The research showed that there was no significant difference in biological maturity between boys and girls in early childhood, so their motor skill developments were similar [27]. However, in addition to biological maturity, the motor development of boys and girls is also affected by the social and family environment [30, 31]. It has been demonstrated that girls are more cooperative and sharing in instructional interactions and games, watching action performance, and cheering each other on, whereas boys are more self-expressive and competitive [32]. Thus, for locomotor skills that are relatively competitive and less difficult to perform, girls perform better than boys on some movements. In our test of six locomotor skills, girls performed significantly better than boys on gallop. The reason might be that girls would have more opportunities of dancing, so they have better sense of rhythm [6, 7, 33].

Conversely, the development of object-control skills in early childhood was superior for boys over girls, which was similar to most current research results [6, 27, 28]. The reasons are threefold: first, there are gender differences in the strength of boys and girls, and pitching among object-control movements is particularly pronounced as the movement most related to strength [30]. Second, boys master

Figure 2: Gender characteristics of locomotor and object-control skills: (a) locomotor skill; (b) objective-control skill.

object-control skills faster than girls and can approach the mature movement stage earlier, a phenomenon that is particularly evident in technically difficult movements such as pitching [34, 35] and kick [36, 37]. The third reason is related to sociology. As noted earlier, boys place a greater value on individual performance and competition among peers and are more willing to improve their technical skills, leading to more practice in this area than girls and more effective improvement of their object-control skills [30].

4.3. Influence of Age on Motor Skill Development. Our results showed that age had a significant effect on the average annual growth value of locomotor skills for children aged 3–6 years, showing a gradual decrease in the average annual growth value with age. The average annual growth rate of object-control skills was the same. However, basic object-control skills, kick and overhand throw, grew faster at the age of 3–4 than at the age of 4–5 and 5–6. Kick and pitching are common movements used by children in everyday ball play and require some muscle strength and coordination of the limbs. These two ball skills are easier to master than other object-control skills [38]. According to the principle of simple to complex development of basic movements [25], these two motor skills will develop earlier. Therefore, at the age of 3–4, in addition to focusing on locomotor skills, the learning of ball skills can start with kick and overhand throw.

A study found a significant effect of age on both locomotor and object-control skills in a cross-sectional study of 1,614 Belgian 3- to 6-year-old children, and the average annual growth value of locomotor skills decreased with age [6]. In a cross-sectional study of basic motor skill development in 1,046 children aged 3–10 years in Shandong, China, it was suggested that the average annual growth values of both locomotor and object-control skills were highest in children aged 4–5 years, followed by those aged 3–4 years and 5–6 years [7]. In a cross-sectional study of basic motor skill development in 1,200 preschool children aged 3–7 years in Taiwan, it was revealed that age had a significant effect on both locomotor and object-control skills, and the average annual growth values of both locomotor and object-control skills were highest in children aged 4–5 years, followed by those aged 3–4 years and 5–6 years [27]. Their findings were not exactly the same as ours, which may be due to the following:

(1) Varying research design: other studies tended to adopt a cross-sectional design and used different children for the analysis of annual rates of change. In contrast, our study was a longitudinal follow-up study, in which the same subjects were used to calculate the annual growth value and rate. Thus, the data from the follow-up study may be more convincing than those from the cross-sectional study.

(2) Varying ethnicity and geographic location of the study subjects: our subjects were preschoolers in Beijing, China, while other studies have reported on mostly Western children [6, 7, 33, 39]. Whether the developmental characteristics of motor skills in young children are related to ethnicity and geography has not yet been reliably evidenced, and further research is needed.

4.4. Influence of Young Children's Activity Behaviour and Home Environment on Motor Skill Development. After one year of follow-up, our findings revealed that the acquired factors affecting motor skill development were mainly the amount of physical activities and the frequency of playing with friends, while family SES, parental support, and parents' own exercise level did not have a significant effect.

The survey data exhibited that the physical activities that young children frequently participated in were bicycling, skateboarding, roller skating, dabbling, swimming, dancing, patting, kick, running, and jumping. A higher frequency of daily physical activities leads to faster motor skill development. Especially at the age of 3–4 years when motor skills are developing rapidly, it is necessary to participate more frequently in these sports. The literature is inconsistent regarding the relationship between motor skill levels and physical activities: some authors suggest a strong correlation with moderate-intensity activities, while E Kipling Webster argues that TGMD scores in 3–5 years are only related to high-

Table 4: The effects of age and gender on the results of TGMD 13 indicators based on the GLM model.

Test item	Groups	Mean square	F	Sig.	β	95% confidence interval Lower bound	Upper bound	Sig.
Run	Gender = male	1.03	0.19	0.67	-0.12	-0.69	0.45	0.67
	Gender = female				0[a]			
	Age group = 3-4	28.83	5.18	**0.00****	1.21	0.43	2.00	**0.00****
	Age group = 4-5				0.23	-0.44	0.90	0.50
	Age group = 5-6				0[a]			
Gallop	Gender = male	76.37	6.18	**0.01***	-1.07	-1.92	-0.22	**0.01***
	Gender = female				0[a]			
	Age group = 3-4	25.90	2.10	0.13	1.20	0.03	2.38	**0.04***
	Age group = 4-5				0.68	-0.32	1.68	0.18
	Age group = 5-6				0[a]			
Slide	Gender = male	19.17	2.63	0.11	-0.54	-1.19	0.12	0.11
	Gender = female				0[a]			
	Age group = 3-4	77.71	10.67	**0.00****	1.66	0.76	2.56	**0.00****
	Age group = 4-5				-0.20	-0.97	0.57	0.61
	Age group = 5-6				0[a]			
Skip	Gender = male	0.81	0.11	0.74	-0.11	-0.77	0.55	0.74
	Gender = female				0[a]			
	Age group = 3-4	1.15	0.15	0.86	0.09	-0.82	1.00	0.84
	Age group = 4-5				-0.13	-0.91	0.64	0.74
	Age group = 5-6				0[a]			
Horizontal jump	Gender = male	6.82	1.11	0.29	-0.32	-0.92	0.28	0.29
	Gender = female				0[a]			
	Age group = 3-4	21.51	3.50	**0.03***	0.91	0.08	1.74	**0.03***
	Age group = 4-5				-0.06	-0.76	0.65	0.88
	Age group = 5-6				0[a]			
Hop	Gender = male	2.71	0.37	0.55	0.20	-0.46	0.86	0.55
	Gender = female				0[a]			
	Age group = 3-4	21.97	2.97	0.05	1.10	0.19	2.01	0.01*
	Age group = 4-5				0.33	-0.44	1.10	0.40
	Age group = 5-6				0[a]			
Overhand throw	Gender = male	0.57	0.09	0.76	0.09	-0.52	0.70	0.76
	Gender = female				0[a]			
	Age group = 3-4	27.62	4.35	**0.01***	1.25	0.41	2.09	**0.00****
	Age group = 4-5				0.68	-0.04	1.39	0.06
	Age group = 5-6				0[a]			
Underhand throw	Gender = male	0.09	0.02	0.89	0.04	-0.48	0.55	0.89
	Gender = female				0[a]			
	Age group = 3-4	3.53	0.78	0.46	0.38	-0.34	1.09	0.30
	Age group = 4-5				-0.01	-0.62	0.59	0.97
	Age group = 5-6				0[a]			

Table 4: Continued.

Test item	Groups	Mean square	F	Sig.	β	95% confidence interval Lower bound	Upper bound	Sig.
Catch	Gender = male	1.40	0.31	0.58	-0.15	-0.66	0.37	0.58
	Gender = female				0[a]			
	Age group = 3-4	3.55	0.79	0.45	-0.41	-1.12	0.29	0.25
	Age group = 4-5				-0.05	-0.65	0.55	0.86
	Age group = 5-6				0[a]			
Dribble	Gender = male	4.02	0.57	0.45	0.25	-0.40	0.89	0.45
	Gender = female				0[a]			
	Age group = 3-4	11.66	1.65	0.20	0.70	-0.19	1.58	0.13
	Age group = 4-5				0.00	-0.76	0.75	1.00
	Age group = 5-6				0[a]			
One-hand forehand strike	Gender = male	9.68	2.04	0.16	0.38	-0.15	0.91	0.16
	Gender = female				0[a]			
	Age group = 3 ~ 4	3.67	0.77	0.46	-0.46	-1.18	0.27	0.22
	Age group = 4 ~ 5				-0.24	-0.86	0.37	0.44
	Age group = 5 ~ 6				0[a]			
Two-hand strike	Gender = male	14.76	1.48	0.23	-0.47	-1.23	0.29	0.23
	Gender = female				0[a]			
	Age group = 3-4	2.83	0.28	0.75	0.20	-0.85	1.26	0.70
	Age group = 4-5				-0.16	-1.06	0.73	0.72
	Age group = 5-6				0[a]			
Kick	Gender = male	0.16	0.03	0.86	0.05	-0.50	0.60	0.86
	Gender = female				0[a]			
	Age group = 3-4	20.12	3.87	**0.02***	0.10	-0.66	0.86	0.80
	Age group = 4-5				-0.73	-1.38	-0.09	0.03
	Age group = 5-6				0[a]			
Overall locomotor	Gender = male	255.82	2.69	0.10	-1.96	-4.32	0.40	0.10
	Gender = female				0[a]			
	Age group = 3-4	786.35	8.26	**0.00****	6.18	2.92	9.43	**0.00****
	Age group = 4-5				0.85	-1.92	3.62	0.55
	Age group = 5-6				0[a]			
Overall object-control	Gender = male	3.01	0.04	0.85	0.21	-2.03	2.46	0.85
	Gender = female				0[a]			
	Age group = 3-4	112.19	1.29	0.28	1.75	-1.36	4.85	0.27
	Age group = 4-5				-0.55	-3.19	2.09	0.68
	Age group = 5-6				0[a]			
Overall performance	Gender = male	203.31	0.78	0.38	-1.75	-5.64	2.15	0.38
	Gender = female				0[a]			
	Age group = 3-4	1444.07	5.54	**0.00****	7.92	2.54	13.31	**0.00****
	Age group = 4-5				0.30	-4.28	4.88	0.90
	Age group = 5-6				0[a]			

[a]Reference. The bold font is used to highlight significance level at $p < 0.05$. $^{*}p < 0.05$; $^{**}p < 0.01$.

Table 5: The behaviour and home environment of the participants.

Category	Indicator (mean ± SD or %)	3 years	4 years	5 years
Children behaviour	Weekly frequency of sports activities	11.0 ± 2.7	11.0 ± 2.6	12.0 ± 2.7
	Weekly frequency of media activities	14.0 ± 2.8	13.0 ± 3.1	15.0 ± 3.0
	Frequency of use of sports equipment	14.0 ± 2.4	14.0 ± 2.0	18.0 ± 2.5
	Number of playdates with friends	10.0 ± 1.9	10.0 ± 2.3	9.0 ± 2.4
Family SES	Parental educational level Household disposable income per capita household living area	8.7 ± 1.5	8.8 ± 1.9	8.8 ± 1.9
Parental support for children's sports activities (full support ratio %)	As parents, we accompany and transport children to participate in sports.	63.4%	75.5%	66.7%
	We do a lot of physical exercises with our children.	22.5%	17.1%	16.0%
	Our family values sports.	30.1%	36.1%	38.0%
	As parents, we are very interested in our children's sports activities.	37.5%	47.2%	48.1%
	Our children's sports activities are often a topic of conversation in our family.	28.9%	36.8%	25.2%
Proportion of parents' physical exercise level	More than 3 times a week	30.8%	34.6%	28.3%

SD, Standard deviation.

Table 6: Final GLM model and parameter estimation.

Indicator	Mean square	F	Sig.	β	95% confidence interval	
					Lower bound	Upper bound
Constant	11.292	28.040	0.000	2.419	1.516	3.322
Age	9.577	23.781	0.000	-0.393	-0.552	-0.234
Weekly frequency of sports activities	2.095	6.023	0.032	0.133	0.021	0.245
Number times of playing with friends	1.687	4.189	0.042	0.041	0.001	0.081

$R^2 = 0.175$ (adjusted $R^2 = 0.158$).

Table 7: Comparison of activity behaviour and home environment of children with the different speeds of motor skill development.

	Fast motor skill development (annual growth value of TGMD ≥50%)	Slow motor skill development (annual growth value of TGMD ≤5%)	P
Sample size	66	70	
Weekly frequency of sports activities	12.100 ± 2.800	10.600 ± 2.100	0.028
Number times of playing with friends	3.300 ± 1.000	2.100 ± 1.200	0.045
Family SES score	8.290 ± 1.750	8.940 ± 1.790	0.152
Parental support			
Entirely supportive	13.6%	6.7%	
Basically supportive	59.3%	70.7%	0.163
Uncertain	25.4%	20.0%	
Basically unsupportive	1.7%	2.7%	
Average parental exercise level			
More than 3 times a week	20.3%	15.4%	0.231
1-2 times a week	44.9%	49.2%	
Less than once a week	39.7%	28.8%	

intensity physical activities [40] and not to moderate-intensity physical activities. More high-intensity activities result in higher TGMD scores [41]. Nilsen AKO's findings support E Kipling Webster that only high-intensity physical activities (accelerometer counts of 5,000–8,000 cpm) are associated with TGMD [42]. In addition to measuring the amount and intensity of physical activities, some scholars have also studied the relationship between the type of physical activities and motor skills of young children. It is believed that preschool children's participation in targeted sports, such as running, bicycling, skateboarding, and trampolining, is associated with higher TGMD scores [43]. Similar to the results of the present study, when participating in these sports, children's physical activity level is high, and they also develop locomotor-type motor skills and ball control skills in running, jumping, and playing with a ball, laying the foundation for future participation in more complex sports.

This study also found that children growing up to play more and exercise more with their peers had an accelerated rate of development of motor skills. Scholar Deanne Fay compared the effects of individual play environments and multiperson group play environments on children's motor skill development. Repeated measures of within-group statistics showed that children performed better on motor skill assessment in group settings, which was associated with being influenced by competition, motivation, and role modelling when playing with multiple people [44]. Hung and Pang carried out a comparison of the effects of group and individual interventions for young children with motor developmental delays. The results showed that although both approaches improved motor skills, activities with 4–5 children were more popular, compliance was better, and the program was more cost-effective overall [45]. In China, one-child families are the majority; thus, children do not have siblings as companions at home and spend most of their time playing with their parents and grandparents, which lacks the supportive peer effect. Therefore, parents should take their children out of the home more often to play with their neighbours and friends in the playground, to learn motor skills, enrich motor experience, cultivate motor interest, and develop motor skills through an interactive play.

According to Barnett et al.'s study, in addition to the children's own activities, home environmental factors are also associated with motor skill development, and the activity behaviour of 3–6 years depends largely on the home environment and parenting style [46]. However, in the present study, an analysis through the GLM model showed that family support for children's exercise and parents' own exercise level did not affect the speed of motor skill development. The reasons for this were two-fold: first, the influence of family on children's motor skill development in this study was reflected through parental self-evaluation, and the subjectivity of responses could affect the accuracy of the analysis of the influence relationship. In addition, the family SES of the young children in this study was medium; i.e., the household income per capita was between ¥5,000 and ¥10,000, the parents' education level was college or higher, and the material conditions of the families were similar. A lack of comparison with low-income families made it difficult to demonstrate the influence of different household living areas as well as sports equipment supply and use on the motor skill development of young children. Consequently, this study did not produce the same results of other studies on the influence of family SES on the development of motor skills in young children [47]. However, by comparing the behavioural characteristics and home environment of children with fast and slow motor development, this study found clues about the relationship between different middle-income families and children's motor development, although it did not show statistical significance. In middle-income families, the children's motor development was slower under better family conditions (SES score: 8.9). The proportion of parents with a graduate degree in these families reached 23%, their support for children's sports was lower than that in families with faster motor development (SES score 8.2), and the children exercised and played less frequently with their friends. It has been indicated that highly educated Chinese parents attach great importance to their children's early education, especially in reading, mathematics, and art and do not want to occupy a lot of time for their children to play freely with friends [48, 49], which may affect their children's early motor skill development to some extent. Whether these subtle differences between middle-income families are truly environmental factors that influence the rate of motor skill development in young children, however, needs to be further confirmed by more convincing research data.

The following are the strengths and limitations: the first strength of this study lies in its use of a tracking approach to study the developmental characteristics of motor skills in the early years of children aged 3–6 years, and the persuasive power of the data is better than the evidence provided by previous cross-sectional studies. The second strength is that it provides an in-depth analysis of the individual behaviours and home environmental factors that influence children's motor development in China's emerging middle-class families, which provides an empirical basis for preschool education workers and parents to guide children's motor skill development. The first limitation of this study is that the follow-up period is only one year; a longer follow-up period will provide a better understanding of the pattern of motor development in Chinese children. The second limitation is the use of an internationally used questionnaire for the survey of family support environment. Since Chinese family education has its own culture and national conditions, it is necessary to develop a Chinese family survey that includes both objective and subjective environmental factors, thereby fully exploring the appropriate ecological patterns that influence children's motor development.

5. Conclusions

Locomotor and object-control skills continue to grow between the ages of 3 and 6 years, with object-control skills growing faster than locomotor skills. With the age group of 3–4 years having the fastest growth rate, it is recommended to practice more basic movements such as running, jumping, overhand throw, and kick [50]. Boys and girls between the ages of 3 and 6 also have their own gender advantages in

motor skill development, and therefore, priorities can be considered accordingly in their practice activities.

Factors influencing children's motor skill development in Chinese middle-income families include doing sports with friends, bicycling, skateboarding, dancing, bouncing ball, kicking ball, running, jumping, etc.; however, the material sporting conditions offered by families have no influence on children's motor skill development. How families provide effective support for children's motor skill development needs further research and exploration.

Data Availability

The data used to support the findings of this study are available from the corresponding author.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Research Article

Assessment of Validity of Children's Movement Skill Quotient (CMSQ) Based on the Physical Education Classroom Environment

Jindong Chang,[1,2,3,4] **Yan Li**,[1,4] **Hanbing Song**,[1,4] **Liming Yong**,[1,4] **Lin Luo**,[5] **Zhanjia Zhang**,[6] **and Naiqing Song**[2,3]

[1]*School of Physical Education, Institute of Motor Quotient, Southwest University, Chongqing 400715, China*
[2]*School of Mathematics and Statistics, Southwest University, Chongqing 400715, China*
[3]*The Branch of the Collaborative Innovation Center of Assessment toward Basic Education Quality, Southwest University, Chongqing 400715, China*
[4]*Key Laboratory of Physical Fitness Evaluation & Motor function Monitoring, General Administration of Sport of China, Southwest University, Chongqing 400715, China*
[5]*School of Physical Education, Guizhou Normal University, Guiyang 550001, China*
[6]*Department of Physical Education, Peking University, Beijing 100871, China*

Correspondence should be addressed to Jindong Chang; changlai@swu.edu.cn and Naiqing Song; songnq@swu.edu.cn

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The development of movement skills in children is a critical element in promoting physical activity and other positive health trajectories over their lifetime. A reliable and valid assessment tool is essential for evaluating children's movement skills in daily physical education environments. The purpose of this study was to examine the validity of Children's Motor Skills Quotient (CMSQ) used in the classroom setting. Six raters conducted evaluation to participants, and a total of 734 children completed all the test items and were included in the study. Descriptive statistics and Rasch analysis were used in this study. The descriptive statistics were mainly used for calculating the mean, standard deviation, percentage, and internal consistency coefficient. Rasch analysis was used to verify the fitting statistics, project difficulty, and functional differences of the items of the CMSQ. The findings showed that the CMSQ met the assumption of the Rasch model, including the unidimensionality, local independence, person measure, and item difficulty hierarchy. The CMSQ also demonstrated adequate interrater reliability and internal consistency. The differential item functioning (DIF) demonstrated a few items showing different probabilities across sex and age. To maintain the item difficulty hierarchy of the CMSQ, no items were deleted. Overall, the CMSQ seems to have appropriate test items with an appropriate rating scale structure for measuring 6-9-year-old children's movement skills in the physical education classroom environment.

1. Introduction

Numerous studies demonstrate that sufficient participation in physical activity is beneficial for children's fitness and health [1–4]. Still, across the globe, more than 80% of children and adolescents fail to meet the physical activity recommendations of the World Health Organization (WHO) [5]. Some studies indicate that health-related physical fitness is positively correlated with the development of movement/-motor skills in children [6–10]. Research also suggests that developing appropriate levels of motor skills in children may be a critical element in promoting their physical activity and other positive health trajectories over their lifetime [9, 11]. Recent literature emphasizes the importance of competence in movement skills concerning the positive developmental trajectories of children's health [11]. Today, the development of children's motor skills has become of paramount importance in promoting children's health and fitness

[7, 9–11]. Evaluating the development of children's movement/motor skills is also a significant concern in the contemporary motor development field.

In the past decade, assessment has made tremendous achievements in the education system [12]. Large-scale international educational assessment projects such as the Program for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMMS) are widely used in the assessment of reading, mathematics, and science in children and adolescents [13–18]. As part of the education system, movement testing in physical education has also gained extensive attention [19], and various studies of movement testing in physical education have been conducted in recent years [20–26]. However, because of the inconsistent general academic terms and different research purposes, the concepts, operations, and measurements in the research of motor skills overlap and are confusing [9, 23, 27, 28]. The concepts of "motor skill," "movement skill," "motor skill competency," and so on are used interchangeably to express the same meaning, but they form their own systems. Logan et al. reviewed the term "fundamental movement/motor skills" (FMS), and they found that fundamental movement skills (69%) are used more frequently than fundamental motor skills (31%) in the literature [25]. Considering that the term "movement" is more specific and widely used than "motor," the following use of movement skill includes the meaning of motor skill and motor skill competency.

The primary purpose of the movement test in physical education is the identification of students with motor deficiencies or the description/monitoring of motor proficiency levels [29, 30]. The choice of an assessment tool and their reliability and validity is critical in assessing children's motor skills. Cools et al.'s study indicated that the most frequently used assessment tools for children aged 6–9 were the Movement Assessment Battery for Children (MABC) [31], the Test of Gross Motor Development (TGMD-2) [32], the Bruininks–Oseretsky Test of Motor Proficiency (BOTMP) [33], the Körperkoordinationstestfür Kinder (KTK) [34], and the Maastrichtse Motoriek Test (MMT) [35]. The frequency of use can be used as a reference indicator for the choice of children's movement skills assessment tools in the physical education classroom setting.

Satisfying reliability and validity are prerequisites for the selection of children's motor skills assessment tools. Scheuer et al.'s [26] literature review showed that the assessment tools of movement skills with the highest validity scores are the athletic skills track (AST) [36], the BOT-2, the MABC-2, the MAND-2 [37], and the TGMD-2. However, Scheuer et al. also found that the factorial validity of several test instruments has not been established and that more studies are needed to verify their psychometric quality for use in physical education testing in the future [26]. Cools et al. reviewed these different assessment tools and concluded that the concurrent validity of the majority of them was moderate [35], thus showing that they lacked feasibility in a physical education setting. Addressing the controversy over whether the assessments should be process- or product-oriented, Logan et al. supported using a combination of process and product assessment patterns, and choosing an assessment pattern based on the purpose of evaluation [25]. Ward et al. investigated the impact of assessor experience on assessment accuracy and stated that accurate criterion identifications are crucial in conducting motor skills assessment [24]. Therefore, reliability and validity should be satisfied not only for the assessment tool and the interraters but also for the assessment pattern and a physical education settings.

Despite some tools having acceptable reliability and validity and being suitable for the measurement and evaluation of movement skills, most of these tools are composed of several (e.g., the KTK with four items) to dozens (e.g., the MABC with 32 items) of independent movements with no sequential connection among them [31, 35]. Only a few movement skills assessment tools are composed of a continuous sequence of test combinations, such as the AST, the Canadian Agility and Movement Skill Assessment (CAMSA) [38], and the Children's Movement Skill Quotient (CMSQ) [39]. The AST consists of a series of fundamental motor tasks ($n = 10$) that include crawling, hopping, traveling, jumping, throwing and catching, kicking, front rolling, back rolling, walking backwards, climbing, and jumping [35]. It is a feasible screening tool in a physical education setting, as each child can complete each test in less than one minute. Moreover, sports equipment and materials for testing are readily available in every gym. The CAMSA was developed to assess the fundamental, combined, and complex movement skills of children to determine childhood physical literacy. It includes seven items and 14 scoring points, and each test should be completed within 30 seconds; otherwise, the score is recorded as 0 points [38]. The CAMSA test is suitable for children aged 8-12 years old. The CMSQ is first reported orally at the 66th Annual American College of Sports Medicine (ACSM, 2019) and is a sequential combination of movement skills, which includes 14 items (see Figure 1 and Table 1), each of which needs to be evaluated for processes and products, and the completion time is also recorded [39].

To perform tests, equipment and materials are required. The knowledge of the test protocols can be mastered by most teachers in the physical education curriculum, and the test cost should not be too high nor should the test time be too long. Cools et al.'s study showed that for the four typical instruments of independent movement (i.e., the M-ABC, the KTK, the TGMD-2, and the BOT-2), the test cost was in the range of €262–1352, and the assessment time varied from 20 to 60 minutes [35]. As such, considering the assessment time, cost, and level of the assessors, it was appropriate to develop the CMSQ as an assessment tool of the movement skills in the physical education classroom setting.

Product-based measures are the most common approach to assessing movement skills [40], and the Rasch model has been increasingly applied to determine the validity of motor test tools [41]. To the best of our knowledge, the CMSQ is the first children's movement skills assessment tool with a skill track in a physical education setting that measures process-based (i.e., skill level) and product-based (i.e., skill completion) scores, as well as completion time. The skill components, the completion time, and the weight of the skill score were determined by 19 international experts through

Figure 1: The flow figure of the CMSQ.

the three-round experts Delphi's progress [39]. Although the CMSQ reported its face validity, the sample size (only 58 subjects) and statistical methods limited the validity of the CMSQ. The purpose of this study was to examine the validity of the CMSQ using Rasch analysis to evaluate the fit of the CMSQ items, to test for potential item bias, to check the dimensionality and rating scales, to determine the item difficulty, and to establish the interrater reliability.

2. Materials and Methods

2.1. Materials. The CMSQ is a part of the assessment of the Chinese Children Motor Quotient (CCMQ) developed by Chang et al. [39]. The CMSQ is a set of continuous, closed-loop, and combined motor skill test tools that were recommended and selected by 19 international experts. The CMSQ consists of 14 items in three types, including locomotor (e.g., running, hopping, and crawling), object control (e.g., catching, throwing, and kicking), and stability status (e.g., roll and balance) skills [39]. Its scoring system includes three sections: (1) process-oriented evaluation, (2) product-oriented evaluation, and (3) time evaluation. The present study explored the second part of the production-oriented evaluation, and Table 1 shows an explanation of the movement skills and rating standards. The product-oriented evaluation recorded a score of 0 points or 1 point. The children who participated in the test successfully were given 1 point for that skill; otherwise, the score was recorded as 0 points. The process-oriented evaluation record was 0, 1, and 2 points. The time was converted to 0-42 points in the corresponding order. The test flow is shown in Figure 1, and the details of the measurement process are introduced in Section 2.3.

2.2. Participants. This study was approved by the Ethics Committee of the Institute of Motor Quotient, Southwest University (IRB No: SWUIMQ20180312) and followed the guidelines of the International Declaration of Helsinki. All children were required to be healthy and free from congenital physical defects (e.g., physical disability). All participants with approval from their parents or guardians and who completed all the tests were included in this study. The participants included valid convenience samples of 734 children aged 6-9 (369 males and 365 females) from four cities (i.e., Beibei in Chongqing, Xuzhou in Jiangsu Province, Kunming in Yunnan Province, and Suining in Sichuan Province) in China. All participants were enrolled in public schools; one urban school and one rural school were selected from each city. The population of students in the candidate elementary schools was not less than 600. Participants were classified into four age groups: 6, 7, 8, and 9 years from grades 1 to 3. Twenty-five children were randomly selected from each age group to participate in the test. The demographic information of the participants is shown in Table 2.

2.3. Measures

2.3.1. Rater Assessment. The tests in this project were carried out jointly by six raters. The raters were trained in the strict

Table 1: The skill description and rating standard of Children's Movement Skill Quotient (CMSQ).

Item	Name	Skill description	Rating standard (product)
CS01	Hoop jumping	Two-footed jump into a single hoop, the alternate jumps into a circle with each foot	No stepping on or missing circles
CS02	Sliding	Hands and feet in the same direction, sliding sideways, with hands touching the cone	The hand should not miss and the foot should not touch the cone
CS03	Catching and throwing	The tester throws the ball to the subject, the subject then catches the ball with both hands and underhand throws it to the target	Throw the ball to the target area
CS04	Hurdle jumping	Jump over three hurdles (height = 30 cm) without alternating feet	No stepping on or touching the bar and no changing feet
CS05	Crawling	Crawl forward, alternately with arms and legs, close to the ground through three 60-cm-high hurdles	Crawl on hands and feet and no touching the fence
CS06	Rope jumping	With feet together, swing the rope into place and jump 10–15 times	Continuous rope skipping without interruption
CS07	One-foot jumping	Jump with one foot over all of the hula hoops in turn	No stepping on or missing circles
CS08	Agility running	Move sideways to the left, placing feet alternately in and out of the agility ladder grid while moving forward	No stepping on the line and no missing the grid
CS09	Overhand throwing	After taking a ball, turn the lead arm and throw the softball at the target from above the shoulder	Hit the target area
CS10	Bouncing	Use a racket to bounce a table tennis 5–10 times	The ball should be bounced uninterrupted
CS11	Front rolling	Roll forward by crouching, bowing head, narrowing chest, tucking in stomach, and rolling over	Roll straightforward
CS12	Dribbling	Dribble a ball in place 10 times with one hand	This should be uninterrupted
CS13	Longitudinal rolling	With hands above the head, bringing the hands, feet, and torso, and then the hands, feet, and body inline, carry out a controlled body rollover 1.5 m with no change in posture	Straight-line rolling, and the slope should not exceed 15 degrees
CS14	Kicking	Running, supporting, swinging, kicking	Score a goal

Note: for each item, all the actions that met the rating standard were scored as 1, while any that did not were scored as 0.

professional evaluation of the CMSQ for two weeks. In the process of training, we provided instructions and demonstrations of the CMSQ testing procedures and rating criteria, as well as specific skill analysis combined with videos, on-site presentations of action passwords and organizations, and practical operational guidance. Following the training, each rater was required to evaluate the CMSQ for twelve children (the number of evaluations during the training period was not included in the final validity analysis), including on-site evaluations for two children and video evaluations for 10 children. The consistency of the CMSQ scores was more than 0.8, which was considered acceptable. Finally, only the appraisers who passed the consistency check performed the tests.

2.3.2. Measurement Procedure. The assessments were performed in a 15 × 15 meter square outdoor or indoor environment based on the specific site conditions of each school. In accordance with the CMSQ manual guidelines, the raters appraised the materials and tools in the CMSQ task for 6-9-year-old children. After setting up the test site, five nonselected children were invited to conduct a simulation test (only once). Each school was a test unit, and each test unit conducted a simulation test. The five invited kids were tested one by one before the formal test in each school. The primary purpose of these testing included three aspects: (1) to examine whether the site met the test standards, (2) to examine whether the cooperation between raters was consistent, and (3) to calibrate the consistency between raters. The participants were divided into groups of five children. Before the formal test, each group of children was given 10 minutes of video learning of the test content, and an evaluator was responsible for explaining the requirements of the CMSQ. After entering the test site, each child practiced once and then carried out the test. Each child was tested twice, taking the best score as the outcome.

In the trial, the six raters were divided into two groups. Rater A was responsible for organizing (i.e., video learning and management of the test site), rater B for guiding (i.e., issuing action passwords) and timing, and rater C for rating. Rater A needed to explain the test content to the children and to ensure they stayed quiet on the test site. Rater B was mainly responsible for guiding the children to conduct the action, issuing the action password, throwing and picking up the ball, and so on. This test did not check the children's memory. Therefore, rater B needed to issue a password directly, accurately, and in a timely manner in the test. Rater C was required to concentrate on each movement of the child and to judge it accurately according to the CMSQ standard guidelines. For each test group, the division of labor was

Table 2: Demographic characteristics ($N = 734$).

Characteristics	Mean (SD)	N (%)
Age		
6 years old		196 (26.7)
7 years old		189 (25.7)
8 years old		174 (23.7)
9 years old		175 (23.8)
Gender		
Male		369 (50.3)
Female		365 (49.7)
Height		
6 years old	119.1 (4.2)	
7 years old	126.1 (3.6)	
8 years old	131.2 (4.5)	
9 years old	137.1 (5.6)	
Weight		
6 years old	22.2 (3.6)	
7 years old	25.9 (3.9)	
8 years old	28.6 (4.8)	
9 years old	32.7 (5.6)	
Sources		
Beibei, Chongqing		192 (26.2)
Xuzhou, Jiangsu		187 (25.5)
Kunming, Yunnan		171 (23.3)
Suining, Sichuan		184 (25.1)

Note: SD: standard deviation.

rotated to ensure the accuracy of the raters' judgment. Each group of tests typically took about 45 minutes. Twenty groups were tested in each school, which took five days to complete. The test duration was six weeks, from May 6 to June 15, 2019. To ensure the relative consistency of the test results, we considered weather factors to determine the test arrangements. All tests were conducted in good weather conditions, with indoor or outdoor temperatures between 20 and 30°C.

2.4. Statistical Analysis. Descriptive statistics were performed for participants' characteristics, such as gender (N, %), age (mean ± standard deviation (SD)), height (mean ± SD), weight (mean ± SD), and sample sources (N, %). The intraclass correlation coefficient (ICC) was used to examine the interrater reliability, and values greater than 0.80 were considered satisfactory [42]. The internal consistency was analyzed using Cronbach's alpha, and the values of more than 0.70 were acceptable [43]. SPSS19.0 software (SPSS Inc., Chicago, USA) was used to perform the above statistical analysis.

Rasch analysis was performed to verify the internal validity and the level of difficulty of the items in the CMSQ using the Winsteps software, version 4.5.4 (Oregon, USA). The unidimensionality was examined using principal component analysis (PCA) of the Rasch residuals. Once the product-based measures of the CMSQ showed a unidimensionality measurement structure, an item-level analysis was used to perform the Rasch analysis, including rating scale analysis, item fit statistics, person response validity, item difficulty, and differential item functioning (DIF) [44].

2.4.1. Unidimensionality. The core assumption of the Rasch model is to verify the single dominant measurement constructs in test items. A PCA of the Rasch residuals was used to examine the unidimensional constructs of the product-based measures of the CMSQ items [45, 46]. The unidimensionality assumption for the PCA of the Rasch residuals was satisfied by the following criteria: (1) the variance was explained for more than at least 40% by the measurement dimension [47, 48], (2) the variance explained by the first construct was less than 10%, and (3) the eigenvalue of the first construct was less than 2.0 [49].

2.4.2. Rating Scale Analysis. The rating scale model (RSM) was used to measure the rating scale structure. The RSM was selected to calculate the parameters based on the two response options of the product-based measures of the CMSQ [50]. The following criteria verified the fit of the rating scale to the Rasch model. First, at least 10 observations were made in each response category. Subsequently, the outfit mean squares (MnSq) for rating scale categories were less than 2.0, and monotonically advanced average measures could be observed in the rating scale categories [51]. If most of these criteria were not met, the rating categories were reorganized (i.e., some categories were collapsed) [52].

2.4.3. Item Fit Statistics. Fit statistics were performed to monitor the compatibility of the raw item data with the expectations of the Rasch model. Two types of fit statistics showed that the infit statistic (weighted information) was the most sensitive to ratings on the item difficulty close to the children's ability, whereas the outfit statistic (unweighted information) was more affected by the scores of the off-target items. The infit and outfit MnSq and standardized z values (Zstd) were used to test the fit of the Rasch model [53]. The fit criteria of MnSq values were more than 0.7 and less than 1.3, and the ZSTD values were within −2.0 and 2.0 [54].

2.4.4. Item Difficulty. In the motor test, the item difficulty refers to the rate at which children demonstrated motor skills correctly: the higher the skill difficulty, the lower the correct execution rate, demonstrating the test's suitability. In the Rasch model, item difficulties and personal ability were located on the same linear continuum (logits), and an item–person map presented the matching between test items and person measures. In the process of analysis, it was examined whether the order of item difficulty levels estimated by the Rasch model was consistent with the logical progression from the simplest to the most difficult [55]. The ceiling/floor effects and possible gaps (i.e., a certain ability level was low or no items existed) were examined, as well as whether the ceiling and floor impact criteria exceeded 5% of the sample in the maximum and minimum person measures [56].

2.4.5. Differential Item Functioning. DIF was used to estimate the Rasch-based item difficulty parameters [54, 57]. The Rasch–Welch t-test was used to verify the magnitude of

DIF [58]. On the map, the individuals were identified with DIF by gender (male vs. female) and age type (6 years old vs. 7 years old, 7 years old vs. 8 years old, and 8 years old vs. 9 years old) [59]. The effect size of DIF was calculated using the following criteria: (1) a moderate-to-large DIF (more than 0.64 logits, indicating a difference in the comparison groups) and (2) a slight-to-moderate DIF (more than 0.43). An alpha value of 0.05 with a two-sided Rasch–Welch t-test was used to determine the significance of DIF [58].

3. Results

3.1. Interrater Reliability and Internal Consistency. The ICC of the product-based measures of the CMSQ was 0.96 (95% confidence interval (CI) = 0.94-0.98), indicating that the interrater reliability was high. Meanwhile, the internal consistency (Cronbach's alpha = 0.80) of the14 items of the CMSQ was acceptable.

3.2. Unidimensionality. The PCA of the Rasch residuals displayed that 42.7% of the variance was explained by the Rasch model, and the eigenvalue of the first construct was 1.5 (6.2%), while that of the second was 1.3 (5.4%). Next, Rasch analysis of the CMSQ was conducted based on the results of the factor analysis. The residual correlation matrix of a single dominant factor showed that there was no violation of the local independence assumption in the test items ($r = 0.021 - 0.372$).

3.3. Rating Scale Analysis. The rating scale analysis results showed that the 14 items of the CMSQ had good fit. All items' MnSq values (outfit MnSq = 0.74-1.15) were between the standard values in the range of 0.7-1.3. Thus, no rating scale reorganization was made.

3.4. Item Fit. Table 3 shows the item fit results of the Rasch model. The items with infit MnSq values ranged from 0.90 to 1.19, while the outfit MnSq values were from 0.74 to 1.15. In the MnSq values, there were no overfitted or misfitted items, while the infit Zstd values of Item CS05 (3.53) and Item CS14 (2.94) were greater than 2.0. The outfit Zstd value of Item CS08 was less than -2. In terms of Zstd values, Items CS05, CS08, and CS14 did not meet the requirements of the criteria set. However, the Winsteps guidelines state that the infit and outfit values must be in the range of 0.5-1.5; the values of Zstd are for reference only [58]. Therefore, the overall fit statistics of the product-based measures of the CMSQ illustrated a good fit.

3.5. Item Difficulty. Figure 2 displays a person–item map of the personal abilities (logits measures) and item difficulties (distributions) for the 14 items of the CMSQ. On the map, more represents high personal ability, and less represents low personal ability. Rare represents high item difficulty and freq (frequent) represents low item difficulty. The most difficult items were Item CS03 (catching and throwing; 2.58 logits), Item CS09 (overhand throwing; 1.97 logits), and Item CS10 (bouncing; 1.95 logits), and the easiest items were Item CS01 (−3.47 logits) and Item CS02 (−2.59 logits). The mean of the personal abilities and item difficulties was located within 0.5 logits (person = 0.25 logits; item = 0 logits). The means logit measures of the participants in the CMSQ were found to be without significant deviation (item = 0.11 logits). Furthermore, no floor (2.9%) or ceiling (1.8%) effects were found in the person measure of the CMSQ.

Table 3: Item fit statistics and item difficulty results.

Items	Measures (logits)	Model SE	Infit MnSq	Infit Zstd	Outfit MnSq	Outfit Zstd
CS03	2.58	0.12	0.92	−1.17	0.78	−1.22
CS09	1.97	0.10	0.97	−0.61	0.96	−0.20
CS10	1.95	0.10	0.90	−1.83	0.74	−1.72
CS14	1.55	0.10	1.17	3.53	1.13	1.02
CS07	0.36	0.09	0.94	−1.57	0.93	−0.89
CS13	0.18	0.09	0.94	−1.55	1.00	−0.01
CS05	0.15	0.09	1.11	2.94	1.15	1.79
CS04	−0.07	0.09	1.06	1.56	1.11	1.29
CS08	−0.21	0.09	0.92	−1.95	0.83	−2.14
CS06	−0.52	0.09	1.07	1.63	0.96	−0.36
CS12	−0.88	0.10	0.93	−1.36	0.88	−1.14
CS11	−1.00	0.10	0.97	−0.55	0.91	−0.73
CS02	−2.59	0.14	1.05	0.53	0.80	−0.83
CS01	−3.47	0.18	1.19	1.41	1.12	0.46

Note: MnSq: outfit mean squares; Zstd: standardized z values; SE: standard errors of the measures.

In addition, the Rasch analysis revealed that the person reliability coefficient was 0.80 and the separation index was 1.97, while the item reliability coefficient was 1.00 and the separation index was 15.02. The study results indicate that the person and item measures can be reliably estimated at levels higher than 0.80 and 0.9, respectively [48].

3.6. Differential Item Functioning. DIF analysis found that four items fell outside of the criteria across sex and age (see Table 4). Item CS02 had a moderate DIF across sex (DIF contrast = −0.62, $p = 0.04$); Item CS01 (DIF contrast = −1.12, $p = 0.01$) and Item CS10 (DIF contrast = −0.83, $p = 0.01$) had a significant DIF by age (6 years old vs. 7 years old); and Item CS01 (DIF contrast = 1.15, $p = 0.03$) and Item CS12 (DIF contrast = −0.57, $p = 0.04$) also had a significant DIF by age (7 years old vs. 8 years old) (see Table 5). The DIF results indicate that children carrying out the movements associated with these items experienced different levels of difficulty depending on their sex and age.

4. Discussion

The primary purpose of this study was to examine the validity of the CMSQ using Rasch analysis. The study findings indicated that the product-based measures of the CMSQ seemed to indicate appropriate test items with an appropriate rating scale structure for measuring 6-9-year-old children.

As we expected, the CMSQ demonstrated adequate interrater reliability and internal consistency. The reliabilities between the raters obtained high values. However, the

Figure 2: Person–item map for the CMSQ. Each (#) in the person column represents four people, while each (.) represents 1-3 people. More: high personal ability; less: low personal ability; rare: high item difficulty; less: low item difficulty; +M: item mean; M: person mean; S: 1SD from the mean; T: 2SD from the mean.

reliability analysis between the raters included only 12 subjects, which is much less than the minimum requirement of 50 [60]. The product-based measures of the CMSQ met the assumption of the Rasch model, including unidimensionality and local independence. The rating scale of the CMSQ displayed a good fit. The MnSq value of the infit and outfit was within a standard range, and there were no overfitted or misfitted items. However, the three items in the infit and

Table 4: Differential item functioning across sex and age.

Item	Sex (male= Ref. vs. female)					Age (6 years old = Ref. vs. 7 years old)				
	DIF Contrast	Joint SE	Rasch–Welch t	df	Prob.	DIF Contrast	Joint SE	Rasch–Welch t	df	Prob.
CS01	−0.13	0.37	−0.36	692	0.72	−1.12	0.45	−2.50	345	0.01[b]
CS02	−0.62	0.29	−2.11	672	0.04[b]	−0.13	0.38	−0.34	359	0.73
CS03	0.00	0.23	0.00	697	1.00	0.31	0.36	0.86	354	0.39
CS04	0.00	0.18	0.00	697	1.00	−0.28	0.25	−1.12	359	0.26
CS05	−0.28	0.18	−1.55	697	0.12	0.18	0.25	0.72	359	0.47
CS06	0.13	0.19	0.70	697	0.48	0.03	0.26	0.11	359	0.91
CS07	0.18	0.18	1.01	697	0.31	0.21	0.25	0.87	359	0.39
CS08	0.12	0.18	0.64	697	0.52	−0.05	0.25	−0.20	359	0.84
CS09	0.21	0.21	1.02	695	0.31	0.02	0.30	0.08	359	0.94
CS10	−0.25	0.20	−1.23	697	0.22	−0.83	0.30	−2.81	354	0.01[b]
CS11	−0.34	0.20	−1.71	695	0.09	−0.10	0.27	−0.38	359	0.70
CS12	0.00	0.20	0.00	697	1.00	0.33	0.27	1.23	359	0.22
CS13	0.17	0.18	0.94	697	0.35	0.22	0.25	0.90	359	0.37
CS14	0.25	0.19	1.29	696	0.20	0.38	0.27	1.41	357	0.16

Note: DIF: differential item functioning; t: t-statistic; df: degrees of freedom; [b]$p < 0.05$; SE: standard errors of the measures.

Table 5: Differential item functioning across age groups (7 years vs. 8 years; 8 years vs. 9 years).

Item	Age (7 years old= Ref. vs. 8 years old)					Age (8 years old= Ref. vs. 9 years old)				
	DIF Contrast	Joint SE	Rasch-Welch t	df	Prob.	DIF Contrast	Joint SE	Rasch-Welch t	df	Prob.
CS01	1.15	0.51	2.24	295	0.03[b]	0.13	0.69	0.19	317	0.85
CS02	−0.25	0.39	−0.64	348	0.52	0.22	0.44	0.50	322	0.62
CS03	−0.04	0.34	−0.13	348	0.90	0.41	0.32	1.31	325	0.19
CS04	−0.05	0.25	−0.20	347	0.84	−0.09	0.26	−0.36	335	0.72
CS05	0.38	0.25	1.52	346	0.13	−0.26	0.26	−0.98	335	0.33
CS06	0.12	0.26	0.46	345	0.64	−0.21	0.28	−0.76	334	0.45
CS07	0.08	0.25	0.34	347	0.74	−0.13	0.26	−0.51	335	0.61
CS08	−0.02	0.25	−0.08	347	0.94	0.02	0.27	0.08	334	0.94
CS09	0.06	0.29	0.22	348	0.83	−0.18	0.28	−0.62	335	0.53
CS10	0.38	0.30	1.26	348	0.21	−0.17	0.29	−0.61	335	0.54
CS11	−0.05	0.27	−0.16	346	0.87	0.21	0.30	0.68	329	0.50
CS12	−0.57	0.27	−2.08	348	0.04[b]	0.49	0.29	1.67	325	0.10
CS13	−0.11	0.25	−0.46	347	0.65	0.49	0.26	1.85	333	0.07
CS14	−0.41	0.27	−1.56	345	0.12	−0.47	0.28	−1.69	335	0.09

Note: DIF: differential item functioning; t: t-statistic; df: degrees of freedom; [b]$p < 0.05$; SE: standard errors of the measures.

outfit Zstd values exceeded standard values. An explanation given in the Winsteps manual is that if the MnSq value is in the standard range of 0.5-1.5, a Zstd value exceeding the limit can be ignored [40]. In this study, the MnSq values were between 0.74 and 1.19, and the overall item fit statistics were satisfactory.

The items of the CMSQ demonstrated a logical item difficulty hierarchy. In the person–item map, Item CS03 (catching and throwing; 2.58 logits), Item CS09 (overhand throwing; 1.97 logits), and Item CS14 (kicking; 1.95 logits) were the most difficult items, whereas Item CS01 (hoop jumping; −3.47 logits) and Item CS02 (sliding; −2.59 logits) were the easiest items. These results indicate that complex hand and foot movement skills were the most difficult tasks for 6-9-year-old children. Furthermore, we found that there were two groups of items with a similar difficulty level, namely, Item CS09 (overhand throwing; 1.97 logits) and Item CS14 (kicking; 1.95 logits), as well as Item CS13 (longitudinal roll; 0.18 logits) and Item CS05 (crawling; 0.15 logits). Other research proposes that similar difficulty levels of test items may not provide more calibration information for evaluating movement skills [44]. The best solution was to delete some of the items of the same difficulty levels. Determining whether to delete items has often been used as the internal consistency coefficient: If the internal consistency coefficient is too high (i.e., Cronbach's alpha was greater than 0.98), item

redundancies are suggested [44] and it is considered necessary to delete some items. In this study, the internal consistency coefficient of the CMSQ was only 0.80; thus, we did not delete any items.

The items of the CMSQ demonstrated a good match with the person measure. The person reliability and person separation index values for the CMSQ were acceptable. No floor or ceiling effects were found in the person–item map, indicating that the items of the product-based measures of the CMSQ were able to distinguish children with high and low movement skills. The research by Wand et al. showed that the tools of the performance-based (process) assessment had a high level of prediction compared to self-reported measures [61]. In contrast with the process-based measures, during which children's performance outcomes were assessed (i.e., distance, speed, and accuracy) [40], the test results were normative data based on standards (i.e., success = 1 and failure = 0). In other words, in the product-based, process-based, and self-reported measures, the product-based measures had the highest precision, while the self-reported measures had the lowest. Furthermore, a good match between item difficulty and personal ability might reduce measurement errors in the process of person measures [44, 54]. When the distance between the mean of person measures and the mean of item difficulty is less than 0.5 logits, it is considered a good measurement. Indeed, the distance between the mean of person measures and item difficulties was 0.25 logits in this study.

The DIF results demonstrated only one item (i.e., CS02) showing a moderate DIF across sex, while three items displayed significant DIF across age (6 years old vs. 7 years old and 7 years old vs. 8 years old). A significant DIF was not found across age for 8 years old vs. 9 years old. Considering that there were sex differences in the development of children's motor skills, the DIF item across sex was not eliminated from the CMSQ in this study. Comparing the DIF items across ages, we found that Item CS01 had the lowest item difficulty level, and that Item CS10 and Item CS12 had the highest difficulty level. To maintain the difficulty level of the CMSQ test, these three items were not deleted.

The current study had three limitations. First, interrater reliability needed to be further explored, with at least 50 subjects being evaluated by each rater. Second, it was not sufficient that the validity of the CMSQ was assessed only by product-based measures. A comparative follow-up study of process-based measures should be conducted to determine whether the DIF items should be retained or deleted. Third, this study lacked a standard validity test for calibration. The CAMSA or AST should be used as a calibration tool in further studies to further verify the validity of the CMSQ.

5. Conclusions

The CMSQ demonstrated good validity indicators, including dimensionality, fit statistics, DIF, and item difficulty hierarchy. Although a few items did not fully satisfy the fitting, most of the indicators met the Rasch model verification standards. Thus, the product-based measures of the CMSQ were preliminarily proven to be valid. The CMSQ might be a feasible alternative motor test to assess the movement skills of children aged 6–9. In the future, the outcomes of process-based measures should be included to verify the reliability and validity of the CMSQ.

Data Availability

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

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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Supplementary Materials

Table S1: the data of CMSQ (product). Video S1: the test video of the CMSQ. Video S2: rater assessment video of the CMSQ. *(Supplementary Materials)*

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Review Article

High-Intensity Interval Training versus Moderate-Intensity Continuous Training on Health Outcomes for Children and Adolescents: A Meta-analysis of Randomized Controlled Trials

Jun Yin, Zhixiong Zhou, and Tianwen Lan

Institute for Sport Performance and Health Promotion, Capital University of Physical Education and Sports, Beijing, China

Correspondence should be addressed to Zhixiong Zhou; zhouzhixiong@cupes.edu.cn

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Low cardiorespiratory fitness (CRF) is considered as an established risk factor for cardiovascular and metabolic disorders. However, the effectiveness of high-intensity interval training (HIIT) versus moderate-intensity continuous training (MICT) in children and adolescents remained uncertain. Electronic databases of the PubMed, EmBase, and the Cochrane library were searched for randomized controlled trials (RCTs) investigated the role of HIIT versus MICT for children and adolescents throughout December 2019. Sixteen RCTs involving a total of 543 children were selected for final meta-analysis. HIIT versus MICT showed high peak VO_2 (weighted mean differences (WMD): 2.68; 95% confidence intervals (CIs): 1.81 to 3.55; $P < 0.001$), and no evidence of heterogeneity and publication bias was detected. However, there were no significant differences detected between HIIT and MICT on the levels of peak heart rate (HR_{max}), fat mass, free fat mass, weight, body mass index, waist circumference, systolic blood pressure, diastolic blood pressure, glycemia, insulinemia, total cholesterol, high density lipoprotein, low density lipoprotein, triglycerides, HOMA-IR, HbA1c, and leptinemia. The findings of this study revealed that HIIT versus MICT showed a significant improvement in peak VO_2 in children and adolescents. Further large-scale RCTs should be conducted to compare the long-term effects of HIIT versus MICT in children and adolescents.

1. Introduction

Cardiorespiratory fitness (CRF) is an objective reproducible physiological response that is affected by physical activity habits, genetics, and disease status [1]. Low CRF in subjects is identified as a risk factor of cardiovascular morbidity and mortality [2]. Currently, the gold standard for CRF included maximal oxygen uptake, which is measured directly or indirectly by maximal graded cardiorespiratory test [3–5]. According to a study, high CRF during childhood and adolescence showed association with reduced risk of subsequent cardiovascular disease [6]. A study involving 25.4 million children and adolescents from 27 countries with CRF showed declination by 3.6% per decade [5]. Regular physical activity could improve CRF [7] and whether different types of physical activity yields differential effects on CRF and other cardiovascular risk factors in children and adolescents remains controversial.

Although the high-intensity interval training (HIIT) was completed within a shorter time, it increased aerobic fitness and mental health in children [8–10]. Children in schools require effective exercise programs to improve their physical fitness and spend shorter time to exercise in schools [11]. Recently, several studies have already compared the effects of HIIT versus moderate-intensity continuous training (MICT) on the outcomes of body mass index (BMI), hypertension, endothelial function, prediabetes, and type 2 diabetes in adults [12–15]. Moreover, the CRF, fat loss, and cardiometabolic health between HIIT and MICT in children and adolescents were compared, and various role of HIIT and MICT could explain by mitochondrial adaptations to short-term training [16, 17]. Numerous studies have already been conducted to compare the effects of HIIT versus MICT in children and adolescents, which can enter into pooled analysis to reevaluate the effectiveness of HIIT versus MICT. Therefore, the current systematic review and meta-analysis

was conducted on randomized controlled trials (RCTs) that compared the effects of HIIT versus MICT on the health outcomes of children and adolescents.

2. Materials and Methods

2.1. Data Sources, Search Strategy, and Selection Criteria. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) Statement was applied to guide the reporting of this systematic review [18]. Studies designed as RCT that compared the effects of HIIT versus MICT in children and adolescents were considered eligible in our study, and there is no restriction to publication language and status. The core search terms of (high intensity interval OR high-intensity interval OR high intensity intermittent OR high-intensity intermittent OR sprint interval OR HIIT OR HIIE) AND (children [MeSH] OR ∗adolescent [MeSH] OR boy OR girl OR youth [MeSH] OR kids OR student∗) AND (randomized controlled trials) were employed to search for potential trials from the PubMed, EmBase, and Cochrane Library electronic databases throughout December 2019. The reference lists from the retrieved studies were also reviewed manually to identify for studies that met the inclusion criteria.

Two authors independently conducted the literature search and study selection processes, and any disagreements were settled by group discussion until a consensus was reached. The details regarding the inclusion criteria are as follows: (1) participants: the mean age of children or adolescents <18.0 years; (2) intervention: HIIT; (3) control: MICT; (4) outcomes: peak oxygen uptake (VO_2), HR_{max}, fat mass, free fat mass, weight, BMI, WC, systolic blood pressure (SBP), diastolic blood pressure (DBP), glycemia, insulinemia, total cholesterol (TC), high density lipoprotein (HDL), low density lipoprotein (LDL), triglycerides (TG), HOMA-IR, HbA1c, and leptinemia; and (5) study design: RCT. Study with observational design was excluded owing to confounding variables or bias.

2.2. Data Collection and Quality Assessment. The data abstraction and quality evaluation from the retrieved studies were conducted by 2 authors independently, and any conflicts were resolved by group discussion. The data collected included the first author's surname, publication year, country, sample size, mean age, percentage male, intervention, control, follow-up duration, and reported outcomes. The Jadad scale was used to assess the quality of included trials, which is based on the following 5 subscales: randomization, concealment of treatment allocation, blinding, completeness of follow-up, and use of intention-to-treat analysis [19]. In this study, the trials that scored 4 or 5 were considered as high quality.

2.3. Statistical Analysis. The effects of HIIT versus MICT on health outcomes in children and adolescents were included as continuous data, and the weighted mean differences (WMDs) with 95% confidence intervals (CIs) were calculated before data pooling. The random-effects models were used to calculate the pooled effect estimates owing to it considering the underlying varies across included studies [20, 21]. The heterogeneity across included trials were assessed using I^2 and Q statistics, and significant heterogeneity was defined as $I^2 > 50.0\%$ or $P < 0.10$ [22, 23]. The stability of pooled conclusions was then assessed by a sensitivity analysis [24]. Subgroup analyses of investigated outcomes were conducted based on the mean age of subjects, and the differences between subgroups were assessed by interaction P test [25]. Publication biases for investigated outcomes were assessed by using the funnel plots, Egger, and Begg tests [26, 27]. The inspection levels for pooled results are two-sided, and $P < 0.05$ was considered as statistically significant difference between HIIT and MICT. The data in this meta-analysis was analyzed by using the STATA software (version 12.0; Stata Corporation, College Station, TX, USA).

3. Results

3.1. Literature Search. A total of 1,846 articles were identified by initial electronic search, and 1,055 articles of these were excluded owing to duplications. Next, 730 articles were further excluded because of irrelevant topics. Full-text evaluations were done for the remaining 61 studies, and 45 studies were excluded because of the following reasons: no appropriate control ($n = 33$), no desirable outcomes ($n = 6$), and no RCT design ($n = 6$). After this, a total of 16 RCTs were considered eligible and included in the final meta-analysis [28–43]. No new eligible trial was identified by manual searching of the reference lists of retrieved studies (Figure 1). The baseline characteristics of the included trials are summarized in Table 1.

3.2. Study Characteristics. A total of 543 children were included in the trials that are published from 2005 to 2019. The follow-up duration ranged from 3.0 to 24.0 weeks, and 13-94 children were included in each individual trial. Thirteen RCTs were conducted in Western countries or Africa, and the remaining 3 were conducted in Asia. The mean age of children and adolescents included in the trials ranged from 8.2 to 17.4 years, and 4 trials included only boys. The Jadad scale was used to assess the study quality, in which 5 trials had a score of 4, 7 trials scored 3, 3 trials scored 2, and the remaining 1 trial scored 1.

3.3. Peak VO_2. The data regarding the effect of HIIT versus MICT on peak VO_2 were available in 10 trials. The peak VO_2 was significantly higher in the HIIT group (WMD: 2.68; 95% CI: 1.81 to 3.55; $P < 0.001$; Figure 2), and no heterogeneity was detected across the included trials ($I^2 = 0.0\%$; $P = 0.460$). The conclusion was robust and unchanged by sequential exclusion of each individual trial (Supplemental 1 and Supplemental 3). Subgroup analysis showed significant differences between HIIT and MICT in peak VO_2 in children ≥ 12.0 years (Table 2). No significant publication bias for peak VO_2 was detected (P value for Egger: 0.339; P value for Begg: 0.213; Supplemental 2).

3.4. Peak Heart Rate. The data regarding the effect of HIIT versus MICT on HR_{max} were available in 7 trials. No significant difference between HIIT and MICT for HR_{max} was

Figure 1: Flow diagram of literature search and trial selection process.

detected (WMD: 0.35; 95% CI: -3.90 to 4.60; $P = 0.872$; Figure 3), and significant heterogeneity was detected among the included trials ($I^2 = 83.7\%$; $P < 0.001$). Sensitivity analysis found a stable conclusion and was unaltered by sequential exclusion of individual trial (Supplemental 1 and Supplemental 3). Subgroup analysis suggested that HIIT was associated with lower HR_{max} if the mean age of children was <12.0 years (Table 2). No significant publication bias was observed for HR_{max} (P value for Egger: 0.596; P value for Begg: 1.000; Supplemental 2).

3.5. Fat Mass. The data regarding the effect of HIIT versus MICT on fat mass were available from 11 trials. There were no significant differences between HIIT and MICT for fat mass (WMD: -0.15; 95% CI: -1.85 to 1.55; $P = 0.863$; Figure 4), and similarly, no potential significant heterogeneity across the included trials was observed ($I^2 = 48.7\%$; $P = 0.034$). The conclusion was robust and unaltered by sequential exclusion of individual trials (Supplemental 1 and Supplemental 3). The results of subgroup analyses were consistent with the overall analysis (Table 2). Although the Begg test indicated no significant publication bias, the Egger test showed potentially significant publication bias for fat mass (P value for Egger: 0.019; P value for Begg: 0.350; Supplemental 2). The conclusion was changed when the trim and fill method was used to adjust potential publication bias (Supplemental 2).

3.6. Free Fat Mass. The data regarding the effect of HIIT versus MICT on free fat mass were available in 4 trials. HIIT showed no significant effect on free fat mass when compared with MICT (WMD: 0.38; 95% CI: -2.32 to 3.09; $P = 0.781$; Figure 5), and no evidence of heterogeneity was observed ($I^2 = 0.0\%$; $P = 0.920$). The conclusion remained robust after reviewing the results of sensitivity analysis (Supplemental 1 and Supplemental 3). The conclusions of subgroup analyses were consistent with that of overall analysis (Table 2). There was no significant publication bias for free fat mass (P value for Egger: 0.345; P value for Begg: 0.308; Supplemental 2).

3.7. Weight. The data regarding the effect of HIIT versus MICT on weight were available from 11 trials, and no significant differences between HIIT and MICT for weight were observed (WMD: -0.46; 95% CI: -2.29 to 1.37; $P = 0.623$; Figure 6). Moreover, unimportant heterogeneity was detected for weight ($I^2 = 13.5\%$; $P = 0.312$). Sensitivity analysis revealed robust conclusion and showed nonsignificant difference by sequentially excluding each trial (Supplemental 1 and Supplemental 3). Subgroup analyses suggested that the conclusions were consistent with the overall analysis in all subsets (Table 2). No significant publication bias for weight was detected (P value for Egger: 0.600; P value for Begg: 0.631; Supplemental 2).

3.8. Body Mass Index. The data regarding the effect of HIIT versus MICT on BMI were available from 13 trials. The pooled results suggested that HIIT demonstrated no significant effect on BMI when compared with MICT (WMD: -0.01; 95% CI: -0.62 to 0.60; $P = 0.978$; Figure 7), and unimportant heterogeneity was detected ($I^2 = 19.9\%$; $P = 0.237$). Sensitivity analysis suggested that the conclusion remained unchanged by sequential exclusion of each trial (Supplemental 1 and Supplemental 3). Moreover, the results of subgroup analyses were consistent with that of the overall analysis in all subsets (Table 2). No significant publication bias was observed for BMI (P value for Egger: 0.775; P value for Begg: 0.743; Supplemental 2).

3.9. Waist Circumference. The data regarding the effect of HIIT versus MICT on WC were available in 6 trials. There was no significant difference between HIIT and MICT on WC (WMD: -1.47; 95% CI: -4.67 to 1.73; $P = 0.369$; Figure 8), and significant heterogeneity was seen for WC ($I^2 = 63.4\%$; $P = 0.018$). The conclusion remains stable and unaltered by sequentially excluding each trial (Supplemental 1 and Supplemental 3). No significant difference was observed between HIIT and MICT in subgroup analysis (Table 2). There was no significant publication bias detected for WC (P value for Egger: 0.443; P value for Begg: 1.000; Supplemental 2).

3.10. Systolic Blood Pressure. The data regarding the effect of HIIT versus MICT on SBP were available in 7 trials. The results revealed that HIIT has no significant effect on SBP when compared with MICT (WMD: -1.36; 95% CI: -3.99 to 1.27; $P = 0.311$; Figure 9), and significant heterogeneity was detected ($I^2 = 65.1\%$; $P = 0.005$). The results of sensitivity analysis suggested that the conclusion was robust and unaltered by sequentially excluding individual trial (Supplemental 1 and Supplemental 3). The results of subgroup analyses showed no significant differences between HIIT and MICT on SBP in all subsets (Table 2). No significant publication bias was observed for SBP (P value for Egger: 0.266; P value for Begg: 1.000; Supplemental 2).

Table 1: The baseline characteristics of included studies.

Study	Country	Sample size	Mean age (years)	Percentage male (%)	Intervention	Control	Follow-up	JADAD scale
McManus 2005 [28]	China	20	10.4	100.0	Seven maximal speed sprints for 30 s should be completed during a 20-minute session, with a load set at the power elicited at peak VO_2. Between each sprint, an active unloaded rest bout of 2 minutes 45 s cycling was allowed	20-minute sessions of continuous cycling period with a heart rate between 160 and 170 beats per minute. This is equated to a mean intensity of 75-85% peak VO_2 or 85% HR_{max}, as established in the pretraining peak VO_2 test	8 weeks	2
Corte de Araujo 2012 [29]	Brazil	30	10.6	30.0	Repeated 60-second efforts (covered distance per bout: 118 ± 14.5 m) at 100% of the peak velocity (determined by the maximal graded cardiorespiratory test), interspersed by a 3 min active recovery period at 50% of the peak velocity	30-minute continuous endurance exercise at 80% of the peak HR	12 weeks	3
Koubaa 2013 [30]	Tunisia	29	12.9	100.0	Run for 2 min interspersed with recovery periods of one minute. The exercise intensity was 80% of the vVO_2 max increased by 5% every four weeks	Continuously at 60% of vVO_2 max (first 4 weeks), 65% of vVO_2 max (second 4 weeks), and 70% of vVO_2 max (3rd 4 weeks)	12 weeks	1
Boer 2014 [31]	Belgium	32	17.4	65.6	Warm-up (stretching of the large muscle groups and cardiovascular exercises at 30% of peak watt for five minutes), a sprint interval block (10 minutes), continuous aerobic exercise (10 minutes), another sprint interval block (10 minutes), and cooling down (stretching of the large muscle groups and cardiovascular exercises at 30% of peak watt for 5 minutes)	Warming up (stretching of the large muscle groups and cardiovascular exercises at 30% of peak watt for five minutes), cycling (10 minutes), walking/running (10 minutes), stepping (10 minutes), and cooling down (stretching of the large muscle groups and cardiovascular exercises at 30% of peak watt for five minutes)	15 weeks	2
Farah 2014 [32]	Brazil	19	15.0	52.6	Personalized aerobic training on a treadmill, three times a week under the supervision of an exercise physiologist at an intensity that corresponds to the ventilatory threshold I	Personalized aerobic training on a treadmill three times a week under the supervision of an exercise physiologist at a speed of 20% below the ventilatory threshold I	24 weeks	3
Starkoff 2014 [33]	USA	27	14.7	37.0	10, two-minute cycling bouts at 90-95% of age as predicted by HR_{max}, with one minute of active recovery at 55% of age predicted by HR_{max} between each interval for a total of 30 minutes	Cycle at any speed and workload as long as they stayed within the specified target HR range. Following the warm-up, cycling was continuously done for 30 minutes at 65-70% of age predicted HR_{max}	6 weeks	3
Murphy 2015 [34]	USA	13	14.0	23.1	A 10-minute warm-up, followed by 30 minutes of 10 cycles of vigorous exercise at 80 to 90% HR_{max}, 2 minutes of active recovery at 60% HR_{max}, and 10 minutes of cooldown	50 minutes of supervised aerobic exercise with a regimen consisting of a 10-minute warm-up, 30 minutes of relatively continuous aerobic exercise at 65% of estimated	4 weeks	2

Table 1: Continued.

Study	Country	Sample size	Mean age (years)	Percentage male (%)	Intervention	Control	Follow-up	JADAD scale
						exercise capacity, and a 10-minute cooldown period		
Lee 2015 [35]	Korea	20	15.3	NA	Supervised high-intensity interval exercise (30 s sprint, 30 s recovery) continuously throughout the session, which burns 400 kcal	Supervised exercise on a treadmill six times weekly for 12 weeks at ≤40% HR reserve (6 days/week)	12 weeks	3
Kargarfard 2016 [36]	Iran	40	12.3	NA	50-60 min of continuous running starting at a work rate corresponding to 60-70% of HR reserve in the first week and then progressively increasing to 80-90% heart rate reserve throughout the intervention period	50-60 minutes of continuous running on a treadmill beginning in the first week at a work rate of 60-70% of HR reserve and then progressively increasing to 80-95% HR reserve throughout the intervention period	8 weeks	4
Martínez 2016 [37]	Spain	94	8.2	55.3	2 sessions of 40-minute duration per week. Each session involved 20 minutes of high-intensity intermittent exercises (around 10-20 s) and 20 minutes of sports activities	2 sessions of 40-minute duration per week. Each session involved 20 minutes of high-intensity intermittent exercises (around 10-20 s) and 20 minutes of sports activities	12 weeks	3
Lazzer 2017 [38]	Italy	30	16.5	100.0	6 repeated 40 s efforts of high-intensity walking at a heart rate that corresponds to 100% of VO_2 max and then were intermixed with 5 min of walking at low intensity corresponding to 40% of VO_2 max	Exercising at a HR that corresponds to 40% or 70% of VO_2 max	3 weeks	4
Dias 2018 [39]	Australia	65	12.2	66.0	Three times each week for 12 weeks and all participants received between four and six, 20-30 min nutrition consultations with a dietitian for over 12-week period	Three times each week for 12 weeks and all participants received between four and six, 20-30 min nutrition consultations with a dietitian for over 12-week period	12 weeks	4
van Biljon 2018 [40]	South Africa	58	11.1	44.8	10 intervals of 1-minute sprinting set at >80% of their predicted HR_{max}	33 minutes of continuous brisk walking at an intensity level set at 65%-70% of their predicted HR_{max}	5 weeks	3
Morrissey 2018 [41]	France	29	15.0	27.6	(4 to 6) * (2 min to 2 min 30 s) periods at 90-95% of HR_{max} interspersed by 1 min 30 s periods at 55% of HR_{max}	40 min at 60% of HR_{max} progressing to 60 min at 65-70% of HR_{max}	12 weeks	3
Cvetković 2018 [42]	Serbia	21	11.0-13.0	100.0	Three sets of high-intensity interval run separated by 3 minutes of passive rest, 10-minute warm-up protocol followed by high-intensity interval runs and ended with a 10-minute cooldown (warm-up protocol and cooldown were the same as the football training group)	A 10-minute low intensity warm-up followed by 4* 8-minute periods of play interspersed with 2 minutes of passive rest and ending with a 10-minute cooldown	12 weeks	4
Nugent 2019 [43]	UK	16	15.8	37.5	1 hour (2.8 km) per session, each session was divided into a	2 hours (5.6 km) per session, trained as normal, which	7 weeks	4

Table 1: Continued.

Study	Country	Sample size	Mean age (years)	Percentage male (%)	Intervention	Control	Follow-up	JADAD scale
					warm-up, main, and cooldown sessions	primarily involved zone 1 training across		

Figure 2: Effect of high-intensity interval training versus moderate-intensity continuous training on peak VO_2.

3.11. Diastolic Blood Pressure. The data regarding the effect of HIIT versus MICT on DBP were available in 7 trials. There was no significant difference detected between HIIT and MICT for DBP (WMD: 0.57; 95% CI: -0.55 to 1.69; $P = 0.321$; Figure 10), and no evidence of heterogeneity was seen ($I^2 = 0.0\%$; $P = 0.681$). The conclusion was robust and unaffected by sequential exclusion of individual trial (Supplemental 1 and Supplemental 3) and was stratified by the mean age (Table 2). No significant publication bias for DBP was observed (P value for Egger: 0.165; P value for Begg: 0.174; Supplemental 2).

3.12. Glycemia. The data regarding the effect of HIIT versus MICT on glycemia were available in 4 trials. No significant difference between the groups for glycemia was observed (WMD: -2.14; 95% CI: -7.62 to 3.35; $P = 0.445$; Figure 11), and potentially significant heterogeneity was detected ($I^2 = 64.3\%$; $P = 0.038$). The results of sensitivity analysis (Supplemental 1 and Supplemental 3) and subgroup analysis were consistent with that of the overall analysis (Table 2). No significant publication bias for glycemia was observed (P value for Egger: 0.879; P value for Begg: 0.734; Supplemental 2).

3.13. Insulinemia. The data regarding the effect of HIIT versus MICT on insulinemia were available in 6 trials. The results showed no significant effect of HIIT on insulinemia when compared with MICT (WMD: -1.72; 95% CI: -4.13 to 0.69; $P = 0.163$; Figure 12), and no significant heterogeneity across the included trials was observed ($I^2 = 24.5\%$; $P = 0.250$). The results of sensitivity analysis (Supplemental 1 and Supplemental 3) and subgroup analysis were consistent with that of the overall analysis (Table 2). There was no significant publication bias for insulinemia (P value for Egger: 0.359; P value for Begg: 0.707; Supplemental 2).

3.14. Total Cholesterol. The data regarding the effect of HIIT versus MICT on TC were available in 5 trials. There was no significant difference between HIIT and MICT for TC (WMD: -6.22; 95% CI: -12.87 to 0.42; $P = 0.066$; Figure 13), and no evidence of heterogeneity across included trials ($I^2 = 0.0\%$; $P = 0.584$). The results of sensitivity analysis (Supplemental 1 and Supplemental 3) and subgroup analysis were consistent with that of the overall analysis (Table 2). No significant publication bias was seen for TC (P value for Egger: 0.894; P value for Begg: 1.000; Supplemental 2).

3.15. High Density Lipoprotein. The data regarding the effect of HIIT versus MICT on HDL were available in 4 trials. HIIT showed no association with HDL when compared with MICT (WMD: 0.73; 95% CI: -4.49 to 5.94; $P = 0.785$; Figure 14), but significant heterogeneity was observed ($I^2 = 72.5\%$; $P = 0.012$). The results of sensitivity analysis indicated that HIIT might be associated with low HDL (Supplemental 1 and Supplemental 3). Moreover, subgroup analysis found no significant difference between groups on HDL in all subsets (Table 2). There was no significant publication

Table 2: Subgroup analyses of investigated outcomes based on age (≥ 12.0 years and < 12.0 years).

Outcomes	Subgroup	Number of studies	WMD and 95% CI	*P* value	I^2 (%)	*P* value between subgroups
Peak VO_2	≥ 12.0 years	7	2.81 (1.75 to 3.86)	< 0.001	0.0	0.685
	< 12.0 years	3	2.65 (-0.17 to 5.48)	0.066	55.9	
Peak heart rate	≥ 12.0 years	5	2.46 (-3.11 to 8.02)	0.387	87.8	0.046
	< 12.0 years	2	-4.36 (-8.12 to -0.61)	0.023	0.0	
Fat mass	≥ 12.0 years	9	-0.30 (-2.31 to 1.71)	0.771	55.1	0.258
	< 12.0 years	2	0.64 (-2.23 to 3.51)	0.660	0.0	
Free fat mass	≥ 12.0 years	3	0.54 (-2.68 to 3.76)	0.741	0.0	0.858
	< 12.0 years	1	0.00 (-4.98 to 4.98)	1.000	—	
Weight	≥ 12.0 years	9	-0.59 (-2.73 to 1.55)	0.591	20.8	0.736
	< 12.0 years	2	0.58 (-4.92 to 6.08)	0.836	19.0	
BMI	≥ 12.0 years	10	-0.05 (-0.85 to 0.75)	0.899	35.7	0.705
	< 12.0 years	3	0.15 (-0.93 to 1.24)	0.780	0.0	
Waist circumference	≥ 12.0 years	3	-2.44 (-6.82 to 1.94)	0.274	39.7	0.345
	< 12.0 years	3	-0.71 (-5.86 to 4.44)	0.786	78.9	
SBP	≥ 12.0 years	5	-1.32 (-4.50 to 1.87)	0.419	74.0	0.609
	< 12.0 years	2	-1.41 (-5.82 to 2.99)	0.529	0.0	
DBP	≥ 12.0 years	5	0.81 (-0.45 to 2.07)	0.208	0.0	0.410
	< 12.0 years	2	-0.35 (-2.80 to 2.11)	0.782	0.0	
Glycemia	≥ 12.0 years	3	-3.64 (-12.38 to 5.11)	0.415	70.6	0.204
	< 12.0 years	1	1.00 (-3.67 to 5.67)	0.674	—	
Insulinemia	≥ 12.0 years	4	-1.52 (-5.36 to 2.32)	0.437	50.6	0.805
	< 12.0 years	2	-2.13 (-6.08 to 1.83)	0.292	0.0	
TC	≥ 12.0 years	4	-6.88 (-13.83 to 0.06)	0.052	0.0	0.519
	< 12.0 years	1	1.00 (-21.95 to 23.95)	0.932	—	
HDL	≥ 12.0 years	3	1.24 (-5.89 to 8.38)	0.733	81.1	0.586
	< 12.0 years	1	0.00 (-6.60 to 6.60)	1.000	—	
LDL	≥ 12.0 years	3	-4.32 (-13.82 to 5.19)	0.373	51.2	0.578
	< 12.0 years	1	4.00 (-14.83 to 22.83)	0.677	—	
TG	≥ 12.0 years	4	-5.70 (-13.93 to 2.52)	0.174	0.0	0.804
	< 12.0 years	1	-9.00 (-33.76 to 15.76)	0.476	—	
HOMA index	≥ 12.0 years	4	-0.33 (-0.67 to 0.02)	0.062	0.0	0.663
	< 12.0 years	1	0.00 (-1.43 to 1.43)	1.000	—	
HbA1c	≥ 12.0 years	2	0.18 (0.02 to 0.34)	0.028	0.0	0.067
	< 12.0 years	1	0.00 (-0.11 to 0.11)	1.000	—	
Leptinemia	≥ 12.0 years	2	-3.51 (-14.57 to 7.55)	0.534	88.8	0.116
	< 12.0 years	1	7.00 (-4.10 to 18.10)	0.216	—	

bias for HDL (*P* value for Egger: 0.162; *P* value for Begg: 0.089; Supplemental 2).

3.16. Low Density Lipoprotein. The data regarding the effect of HIIT versus MICT on LDL were available in 4 trials. There was no significant difference between HIIT and MICT for LDL (WMD: -2.58; 95% CI: -9.87 to 4.70; $P = 0.487$; Figure 15), and moderate heterogeneity was detected across the included trials ($I^2 = 32.0\%$; $P = 0.221$). The results of sensitivity analysis (Supplemental 1 and Supplemental 3) and subgroup analysis were consistent with those of the overall analysis (Table 2). No significant publication bias was detected for LDL (*P* value for Egger: 0.552; *P* value for Begg: 0.734; Supplemental 2).

3.17. Triglyceride. The data regarding the effect of HIIT versus MICT on TG were available from 5 trials. The results showed no significant differences between HIIT and MICT for TG was detected (WMD: -6.03; 95% CI: -13.83 to 1.77; $P = 0.130$; Figure 16), and no evidence of heterogeneity among the included trials ($I^2 = 0.0\%$; $P = 0.900$). The results of sensitivity analysis (Supplemental 1 and Supplemental 3) and subgroup analysis were consistent with that of the overall analysis (Table 2). There was no significant publication bias

Figure 3: Effect of high-intensity interval training versus moderate-intensity continuous training on peak heart rate.

Figure 4: Effect of high-intensity interval training versus moderate-intensity continuous training on fat mass.

Figure 5: Effect of high-intensity interval training versus moderate-intensity continuous training on free fat mass.

Figure 6: Effect of high-intensity interval training versus moderate-intensity continuous training on weight.

Figure 7: Effect of high-intensity interval training versus moderate-intensity continuous training on body mass index.

for TG (P value for Egger: 0.127; P value for Begg: 0.221; Supplemental 2).

3.18. HOMA-IR. The data regarding the effect of HIIT versus MICT on HOMA-IR were available in 5 trials. The results showed no significant effect of HIIT on HOMA-IR as compared with MICT (WMD: -0.31; 95% CI: -0.64 to 0.02; $P = 0.070$; Figure 17), and no evidence of heterogeneity was seen ($I^2 = 0.0\%$; $P = 0.771$). The results of sensitivity analysis (Supplemental 1 and Supplemental 3) and subgroup analysis were consistent with that of the overall analysis (Table 2). No significant publication bias for HOMA-IR was seen (P value for Egger: 0.682; P value for Begg: 1.000; Supplemental 2).

3.19. HbA1c. The data regarding the effect of HIIT versus MICT on HbA1c were available in 3 trials. The results showed no significant differences between HIIT and MICT (WMD: 0.08; 95% CI: -0.06 to 0.22; $P = 0.279$; Figure 18). Moreover, moderate heterogeneity for HbA1c was detected across the included trials ($I^2 = 40.5\%$; $P = 0.186$). Sensitivity analysis indicated that HIIT might increase HbA1c when compared with MICT (Supplemental 1 and Supplemental 3). Subgroup analysis suggested that HIIT significantly increased HbA1c when the mean age of children was ≥12.0 years (WMD: 0.18; 95% CI: 0.02 to 0.34; $P = 0.028$; Table 2). There was no significant publication bias detected for HbA1c (P value for Egger: 0.625; P value for Begg: 1.000; Supplemental 2).

3.20. Leptinemia. The data regarding the effect of HIIT versus MICT on leptinemia were available in 3 trials. There was no significant difference between HIIT and MICT for leptinemia

Figure 8: Effect of high-intensity interval training versus moderate-intensity continuous training on waist circumference.

Figure 9: Effect of high-intensity interval training versus moderate-intensity continuous training on systolic blood pressure.

(WMD: -0.77; 95% CI: -9.89 to 8.34; $P = 0.868$; Figure 19), and significant heterogeneity was detected among the included trials ($I^2 = 82.5\%$; $P = 0.003$). The results of sensitivity analysis (Supplemental 1 and Supplemental 3) and subgroup analysis were consistent with that of the overall analysis (Table 2). No significant publication bias was detected for leptinemia (P value for Egger: 0.888; P value for Begg: 1.000; Supplemental 2).

4. Discussion

This systematic review and meta-analysis was included RCTs that compared the effectiveness of HIIT and MICT on the health outcomes of children and adolescents. The findings of this meta-analysis found that HIIT could significantly improve peak VO_2 when compared with MICT, and HIIT showed association with lower HDL and high HbA1c levels. Our results found that children in the HIIT group had high peak VO_2 and HbA1c than those in the MICT group when the mean age of children was ≥12.0 years, and the HR_{max} in children in the HIIT group was significantly lower than those in the MICT group if the mean age of children was <12.0 years. However, no significant differences were observed between HIIT and MICT on HR_{max}, fat mass, free fat mass, weight, BMI, WC, SBP, DBP, glycemia, insulinemia, TC, HDL, LDL, TG, HOMA-IR, HbA1c, and leptinemia.

Several systematic reviews and meta-analyses have investigated the effectiveness of HIIT. The meta-analysis conducted by Bacon et al. including 334 subjects aged <45.0 years from 37 studies revealed the association of HIIT with high peak VO_2 [44]. A meta-analysis conducted by Costigan et al. suggested that HIIT was regarded as a feasible and time-efficient approach to improve CRF and body composition in adolescents [45]. Milanović et al. conducted in his meta-analysis included 723 healthy adults aged 18-45 years and revealed that both HIIT and endurance training showed significant improvement in peak VO_2, and HIIT provided a greater improvement in peak VO_2 than those who

Figure 10: Effect of high-intensity interval training versus moderate-intensity continuous training on diastolic blood pressure.

Figure 11: Effect of high-intensity interval training versus moderate-intensity continuous training on glycemia.

underwent endurance training [46]. A meta-analysis conducted by García-Hermoso et al. included 9 studies and suggested that HIIT is considered as an effective and time-efficient approach to improve blood pressure and aerobic capacity levels than other forms of training in overweight and obese adolescents [47]. Maillard et al. conducted a meta-analysis by including 39 studies and found that HIIT could reduce fat-mass deposits in normal weight and overweight/obese adults [12]. Thivel et al. reported that HIIT significantly improved the maximal oxygen uptake and reduced body mass, body fat, SBP, DBP, and HOMA-IR in overweight and obese children and adolescents [48]. A meta-analysis conducted by Depiazzi et al. found that aquatic HIIT significantly improved the aerobic performance and lower limb strength in a nonathletic population [49]. A meta-analysis conducted by Cao et al. found that HIIT versus MICT showed significant improvement in CRF in children and adolescents [16]. However, the comprehensive health outcomes between HIIT and MICT in children and adolescents were not reported in prior studies. Therefore, the current meta-analysis was conducted to compare the effectiveness of HIIT with MICT in children and adolescents.

The current study revealed that HIIT significantly improved the peak VO_2 than MICT, and the significant difference between the groups was mainly observed if the mean age of children was ≥12.0 years. Although the pooled results were consistent with those in the previous meta-analysis study, irrespective for adults or children [16, 46], they applied standard mean difference as an effect estimate, and no stratification was done by the mean age of the subjects. The potential mechanism for this could be that HIIT versus MICT displayed a greater increase in mitochondrial content, including citrate synthase maximal activity, type II fiber activation, adenosine monophosphate activated protein kinase activity, and mass-specific oxygen flux [50, 51]. Also, HIIT played an important role on central adaptation, including

Figure 12: Effect of high-intensity interval training versus moderate-intensity continuous training on insulinemia.

Figure 13: Effect of high-intensity interval training versus moderate-intensity continuous training on total cholesterol.

Figure 14: Effect of high-intensity interval training versus moderate-intensity continuous training on high density lipoprotein.

Figure 15: Effect of high-intensity interval training versus moderate-intensity continuous training on low density lipoprotein.

Figure 16: Effect of high-intensity interval training versus moderate-intensity continuous training on triglycerides.

Figure 17: Effect of high-intensity interval training versus moderate-intensity continuous training on HOMA-IR.

Figure 18: Effect of high-intensity interval training versus moderate-intensity continuous training on HbA1c.

Figure 19: Effect of high-intensity interval training versus moderate-intensity continuous training on leptinemia.

maximal stroke volume, cardiac output, and blood volume [52–54]. Finally, the improvement of peak VO_2 in the HIIT group was more evident in children aged 12.0 years or more, which could be explained by the intensity and regularity of training.

In this study, no significant differences between HIIT and MICT for HR_{max}, fat mass, free fat mass, weight, BMI, WC, SBP, DBP, glycemia, insulinemia, TC, HDL, LDL, TG, HOMA-IR, HbA1c, and leptinemia were observed, which was not consistent with that of the previous findings. However, the results of HDL and HbA1c between the groups were not robust. The potential reason for this could be that smaller number of included trials reported these parameters, and the power was not enough to obtain a stable result between the HIIT and the MICT groups. Moreover, HbA1c was increased in the HIIT group if the mean age of children was ≥12.0 years. This result showed correlation with high energy intake after training in older children. Interestingly, HIIT showed association with low HR_{max} than MICT if the children were < 12.0 years age. However, this result was based on 2 included trials, and so large-scale RCT should be conducted to verify the result.

There are several strengths in this study that should be highlighted: (1) this study provided the comprehensive health results between HIIT and MICT in children and adolescents; (2) the analysis of this study was based on RCTs, which included high evidence level results; (3) the analysis was based on inclusion of large number of trials, and the results were robust than any individual trial, and (4) stratified analyses for investigated outcomes according to the mean age of subjects were also conducted. Although above strengths, the limitations of this study should be acknowledged: (1) a smaller number of children were included in individual study, and the deviation was large that could affect the robustness of pooled conclusions; (2) various training types and intensities were included, which could affect the net effects between HIIT and MICT; (3) the status of subjects varied, and the place of training showed significant correlation with health outcomes; (4) several outcomes stratified by the mean age were restricted owing to only 1 study included; (5) whether the effectiveness between HIIT and

MICT are differing based on weight status and sexual maturation were not conducted owing to mostly studies did not reported data stratified by weight status and sexual maturation; (6) the data abstracted was based on pooled results in each trial, restricting us in conducting a more detailed analysis; and (7) this analysis was based on published RCTs, and so publication bias was considered inevitable.

5. Conclusions

In summary, a high peak VO_2 in the HIIT group was observed than in the MICT group in children and adolescents. Sensitivity analyses suggested that the levels of HDL and HbA1c might differ between the HIIT and the MICT groups. Finally, the effects of HIIT versus MICT on peak VO_2, HR_{max}, and HbA1c might differ based on the mean age of the subjects. The long-term effects of HIIT versus MICT in children and adolescents require assessment in further large-scale RCTs.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Authors' Contributions

Jun Yin and Zhixiong Zhou contributed equally to this work.

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Supplementary Materials

Supplemental 1 Figure S1: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on peak VO_2. Figure S2: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on peak heart rate. Figure S3: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on fat mass. Figure S4: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on free fat mass. Figure S5: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on weight. Figure S6: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on body mass index. Figure S7: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on waist circumference. Figure S8: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on systolic blood pressure. Figure S9: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on diastolic blood pressure. Figure S10: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on glycemia. Figure S11: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on insulinemia. Figure S12: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on total cholesterol. Figure S13: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on high density lipoprotein. Figure S14: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on low density lipoprotein. Figure S15: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on triglycerides. Figure S16: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on HOMA-IR. Figure S17: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on HbA1c. Figure S18: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on leptinemia. Supplemental 2 Figure S1: funnel plot of high-intensity interval training versus moderate-intensity continuous training on peak oxygen uptake (VO_2). Figure S2: funnel plot of high-intensity interval training versus moderate-intensity continuous training on peak heart rate. Figure S3: funnel plot of high-intensity interval training versus moderate-intensity continuous training on fat mass. Figure S4: results of Trim and fill method for high-intensity interval training versus moderate-intensity continuous training on fat mass. Figure S5: funnel plot of high-intensity interval training versus moderate-intensity continuous training on free fat mass. Figure S6: funnel plot of high-intensity interval training versus moderate-intensity continuous training on weight. Figure S7: funnel plot of high-intensity interval training versus moderate-intensity continuous training on body mass index. Figure S8: Funnel plot of high-intensity interval training versus moderate-intensity continuous training on waist circumference. Figure S9: funnel plot of high-intensity interval training versus moderate-intensity continuous training on systolic blood pressure. Figure S10: funnel plot of high-intensity interval training versus moderate-intensity continuous training on diastolic blood pressure. Figure S11: funnel plot of high-intensity interval training versus moderate-intensity continuous training on glycemia. Figure S12: funnel plot of high-intensity interval training versus moderate-intensity continuous training on insulinemia. Figure S13: funnel plot of high-intensity interval training versus moderate-intensity continuous training on total cholesterol. Figure S14: funnel plot of high-intensity interval training versus moderate-intensity continuous training on high density lipoprotein. Figure S15: funnel plot of high-intensity interval training versus moderate-intensity continuous training on low density lipoprotein. Figure S16: funnel plot of high-intensity interval training versus moderate-intensity continuous training on triglycerides. Figure S17: funnel plot of high-intensity interval training versus moderate-intensity continuous training on HOMA-IR. Figure S18: funnel plot of high-intensity interval training versus moderate-intensity continuous training on HbA1c. Figure S19: funnel plot of high-intensity interval training versus moderate-intensity continuous training on leptinemia. Supplemental 3 Table S1:

sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on peak VO_2. Table S2: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on peak heart rate. Table S3: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on fat mass. Table S4: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on free fat mass. Table S5: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on weight. Table S6: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on body mass index. Table S7: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on waist circumference. Table S8: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on systolic blood pressure. Table S9: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on diastolic blood pressure. Table S10: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on glycemia. Table S11: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on insulinemia. Table S12: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on total cholesterol. Table S13: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on high density lipoprotein. Table S14: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on low density lipoprotein. Table S15: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on triglycerides. Table S16: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on HOMA-IR. Table S17: sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on HbA1c. Table S18: Sensitivity analysis of high-intensity interval training versus moderate-intensity continuous training on leptinemia *(Supplementary Materials)*

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Research Article

The Impact of 12-Week Jaques-Dalcroze Eurhythmics Programme on the Dynamic Agility in Single-Dual-Task Conditions in Older Women: A Randomized Controlled Trial

Jan Adamczyk,[1] **Roman Celka**,[1] **Rafał Stemplewski**,[2] **Kinga Ceynowa**,[3] **Paulina Kamińska**,[4] **and Janusz Maciaszek**[2]

[1]*Department of Dance and Gymnastics, Faculty of Sport Sciences, Poznań University of Physical Education, 61-871 Poznań, Poland*
[2]*Department of Physical Activity Sciences and Health Promotion, Faculty of Sport Sciences, Poznań University of Physical Education, 61-871 Poznań, Poland*
[3]*Faculty of Compositions, Conducting, Theory of Music and Eurhythmics, Academy of Music in Poznań, 61-808 Poznań, Poland*
[4]*Graduate School for Sports Sciences, Poznań University of Physical Education, 61-871 Poznań, Poland*

Correspondence should be addressed to Jan Adamczyk; adamczyk@awf.poznan.pl

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Background. Progressive degenerative changes in the body of elderly people lead to a decrease in physical and mental fitness. Seniors have a problem with performing tasks that involve both physical and mental health at the same time. The risk of falls increases, the consequences of which in old age may be particularly dangerous. It was decided to investigate the impact of performing exercises involving both physical and mental spheres on the dynamic agility in older women. *Methods*. 73 women (69.9 ± 3.2) were divided into two groups: intervention (IG, $n = 34$) and control (CG, $n = 39$). Individuals with IG participated in the Jaques-Dalcroze Eurhythmics exercise programme for 12 weeks, twice a week for 45 minutes each. Dynamic agility was determined by the Timed Up and Go test, which was conducted both in single-task (TUG_ST) and dual-task (TUG_DT) conditions, where the participant was simultaneously counting down from 60 every 3. The percentage difference between the results of both tests (dual-task cost, DTC) was also determined. Both groups had two measurement sessions: one week before the start of the exercise programme and one week after the end of exercise programme. *Results*. After 12 weeks of exercise, IG participants obtained significantly better results in TUG_DT ($p < 0.001$) and DTC ($p = 0.003$) tests. During this time, CG participants had significantly worse results in TUG_DT ($p < 0.001$) and DTC ($p < 0.001$) tests. In the TUG_ST test, neither IG nor CG achieved a significant change in the result. In each test, a significant interaction between the group assignment and the measurement session was observed: TUG_ST: $F = 11.523$, $\eta^2_p = 0.139$, $p = 0.001$; TUG_DT: $F = 60.227$, $\eta^2_p = 0.458$, $p < 0.001$; DTC: $F = 32.382$, $\eta^2_p = 0.313$, $p < 0.001$. *Conclusion*. JDE exercises with a frequency of twice a week, for about 12 weeks, have a significant impact on the improvement of the dynamic agility control in women over 65 years of age.

1. Introduction

With age, a number of degenerative changes occur in the body of seniors. Among the most common is muscle mass loss combined with an increase in body fat [1] and osteoarthritis, which affects more than 50% of the population over 65 years of age [2]. Most cognitive functions, such as memory, logical reasoning, spatial imagination, and the speed of thought processes, are decreasing [3]. There is also a deterioration in the sensory functions, including vision responsible for maintaining body equilibrium [4]. Additionally, in old age, delirium, frailty, dizziness, and fainting are often observed—all of these disorders combine to form a geriatric syndrome and lead to a decrease in functional fitness, i.e., the ability to perform basic daily activities on their own and without rapid and excessive fatigue [5, 6]. Reduced functional efficiency translates into a deterioration in walking performance and body balance; it also increases the risk

of falls [4, 7], which are particularly dangerous for seniors—mortality from falls increases [8, 9].

Gait is a complex biomechanical process that requires continuous brain control [10]. The influence of degenerative changes in the musculoskeletal system on the reduction of gait parameters is beyond doubt. However, studies on the influence of changes in cognitive functions are still in progress. There is a close correlation between gait parameters and dementia development—impaired gait function is an indicator of dementia development in the next 4 years [11]. Cognitive therapies have a positive effect on gait parameters and thus reduce the risk of falls [12].

Knowing that gait parameters and fall risk are influenced by both biomechanical and cognitive processes, it seems reasonable to model the therapy in terms of multitasking (dual-task, DT), where the exercising person simultaneously involves both processes. It has been shown that the difference in the quality of single-task (ST) performance compared to DT is significantly related to cognitive functions [13] and the risk of falls in elderly people [14, 15]. Positive effects of multitasking training involving motor and cognitive functions have been demonstrated in both healthy individuals [16, 17] and those with osteoporosis [18] and Parkinson's disease [19]. At the same time, some studies indicate a lack of improvement in both the physical and cognitive spheres under the influence of DT training [20].

There is a lack of uniform exercise programmes in DT conditions, which, apart from being effective, would be simultaneously available, cheap, and above all safe and attractive for older participants. There is also a lack of standardized guidelines for specific types of additional tasks during DT tests [21]. Such standardization and intensification of DT experiments may bring benefits in the form of a better understanding of the impact of their results on the risk of falling in the elderly [22]. [23] concluded in their systematic review that dynamic exercises (in motion) bring better results than in static conditions (resistance and flexibility), while the simultaneous performance of exercises involving the physical and mental spheres brings better results than performing them separately.

Jaques-Dalcroze Eurhythmics (JDE) is one of still little studied forms of exercises involving both spheres at the same time. To the best of our knowledge, four papers have been published so far describing the impact of JDE on motor skills in older people. Since the results of these studies present JDE as a prospectively effective therapy to improve functional performance in older people, but they are inconclusive at the same time, the authors of this paper decided to study the impact of JDE performance over a 12-week period, twice a week, on the dynamic agility of women over 65 years of age, including multitasking.

2. Methods

2.1. Participants. The selection of participants was conducted on the basis of advertisements in the local press and on the Internet and covered the area of Poznań agglomeration (Poznań metropolitan area, Greater Poland Voivodeship, West Poland). Qualification criteria included women aged 65+ community-dwelling. Candidates had no contraindications to participate in physical activities and agreed to participate in the experiment. The participants whose results were analysed obtained at least 8 points in the Abbreviated Mental Test Score (AMTS) [24]. Individuals taking medication that disrupts natural control of body equilibrium, using orthopaedic equipment, people with Parkinson's or Alzheimer's disease, people with significant visual and/or auditory perception impairment, and people who undertake or have undertaken regular organized physical activity in the last three years were not qualified for the programme.

As shown in Figure 1, 93 individuals have registered and 82 have qualified for the programme. In the course of randomization carried out using the STATISTICA 10 computer programme (Dell Inc. Tulsa OK., USA), the participants were divided into two equal groups: intervention group (IG) and control group (CG). The final statistical analysis included 73 women (mean ± standard deviation): age 69.9 ± 3.2 years, including 34 with IG (69.7 ± 3.2) and 39 with CG (70.0 ± 3.3). None of the participants had previously experienced JDE, even in theory.

2.2. Protocol. The women with IG participated in the physical activity programme, while the CG participants were recommended not to change anything in their existing lifestyle, and in particular not to undertake new, systematized forms of physical activity. The degree of dynamic agility in each participant was assessed twice. The first measurement session (baseline) took place during the week preceding the beginning of exercise and the second one (12-week follow-up) during the week following the end of exercise. The experimenters who made measurements were not aware if participants belonged to the experimental or control group.

The research project was positively assessed by the Bioethics Committee at the Karol Marcinkowski Medical University in Poznań (Resolution 1046/15).

2.3. Exercise Programme. Activities were held twice a week for a period of 12 weeks for 45 minutes. Each training session included exercises in the field of rhythmic using the Jaques-Dalcroze Eurhythmics method with piano accompaniment and music played electronically. The activities were conducted by a JDE specialist.

The JDE exercises consisted mainly of recreating the musical course with the use of body movements. Their main idea was to simultaneously engage the motor and cognitive function. Among the exercises conducted were among others movement exercises of rhythmic themes, double and triple speed of movements, double and triple slowing down, rhythmic transformation of themes, and polyrhythms. Apart from rhythmic exercises, inhibition and stimulation of movement, exercises reflecting dynamic, agogic, and articulatory courses in music, improvisation of movements, and exercises shaping independence of movements and their coordination were performed.

2.4. Measurements. The Timed Up and Go (TUG) test, described by [25], was used to assess dynamic agility. Each participant received a verbal instruction followed by a show

Figure 1: Flowchart for enrollment, randomization, and follow-up of study participants.

and one training round. The participants then proceeded to the proper tests: first in single-task (TUG_ST) and then in dual-task (TUG_DT) conditions, where the participant counted down loudly from 60 every 3. No explicit instruction for prioritization of either task was given.

The outcome measures consist of TUG_ST, TUG_DT, and the difference between them (dual-task cost, DCT), expressed as a percentage according to the equation: DTC (%) = ((TUG_DT (sec) − TUG_ST (sec))/TUG_ST (sec)) × 100.

2.5. Statistical Analysis. All the data were screened and revised regarding missing, skewed, and outlier information. The results of descriptive statistics were presented as averages along with the standard deviation (mean ± SD). The results of TUG tests were shown as averages and confidence intervals of 95%. Intergroup differences were determined using the Mann-Whitney U test (with correction for continuity). A repeated two-factor analysis of variance (ANOVA) was carried out. In the case of significant main effects or interactions, Tukey's post hoc test was conducted. The statistical significance level was set at 5%. All calculations were conducted with STATISTICA 10 (Dell Inc. Tulsa, OK).

3. Results

Table 1 details the results for the two groups in the two periods. The direction of changes in the results obtained by IG and CG before and after the intervention is presented in Figure 2. Significant interaction effects between the group assignment and the measurement session were shown for all measurements (TUG_ST: $F = 11.523$, $\eta^2_p = 0.139$, $p = 0.001$; TUG_DT: $F = 60.227$, $\eta^2_p = 0.458$, $p < 0.001$; DTC: $F = 32.382$, $\eta^2_p = 0.313$, $p < 0.001$). The results of the post hoc test show significant differences in the TUG_DT test between the first and second measurement for IG ($p < 0.001$) and CG ($p < 0.001$). Also in the case of DTC, the significant difference between the first and second measurement for IG ($p = 0.003$) and CG ($p < 0.001$) was found. In the TUG_ST test, post hoc analysis did not show any significant differences (significance of follow-up changes in relation to baseline for IG: $p = 0.058$). No significant main effects were observed.

4. Discussion

The influence of JDE exercises on the dynamic agility in seniors was investigated. In each of the three tests (TUG_ST, TUG_DT, and DTC), a significant interaction effect between the assignment to the group and the measurement session was observed: the participation in proposed exercise programme significantly improved the dynamic agility ($p < 0.001$). In CG participants, the results deteriorated—this can be explained by the fact that in older people, especially those with sedentary lifestyles, the ability to control body equilibrium decreases with age

Table 1: Descriptive data (means and 95% confidence interval (CI)) of the time, in seconds, to perform the Timed Up and Go test without (TUG_ST) and with (TUG_DT) dual-task and the dual-task cost (DTC), in percent, at the baseline and at the 12-week follow-up in both the intervention group and the control group. Significance of differences between groups shown as p-value.

		Baseline		12-week follow-up	
TUG_ST	Intervention	6.98 (6.63-7.33)	$p = 0.951$	6.71 (6.38-7.04)	$p = 0.039$
	Control	6.94 (6.64-7.23)		7.15 (6.84-7.46)	
TUG_DT	Intervention	8.14 (7.57-8.71)	$p = 0.102$	7.40 (6.90-7.91)	$p = 0.001$
	Control	7.45 (7.14-7.76)		8.17 (7.79-8.54)	
DTC	Intervention	16.14 (12.33-19.96)	$p = 0.001$	10.21 (5.86-14.55)	$p = 0.011$
	Control	7.76 (5.14-10.39)		14.43 (11.45-17.40)	

Figure 2: Pre- and postintervention dynamic agility results for Timed Up and Go test in single-task conditions (TUG_ST), Timed Up and Go test in dual-task conditions (TUG_DT), and dual-task cost (DTC).

[26], similarly to the cognitive functions of the brain [27]. Under ST conditions, none of the groups showed any significant changes between the first and second measurements, while under DT conditions such a difference occurred. It can be assumed that cognitive functions, to a greater extent than physical functions, determine the deterioration of results in DT conditions in CG.

In the aforementioned study [28], people practicing the JDE method for 9 weeks once a week significantly increased their walking speed both in ST and in DT, but in contrast

to our results, the DTC index did not change. The improvement of DTC results in our participants may be due to a 3-week longer duration of the programme, its higher intensity, or both. All these possibilities are partly confirmed by World Health Organization data on physical activity of older people at an increased risk of falling, which recommend 3 or more times a week exercise. It seems that the principle "the more the better" works here—even up to 6 times a week for 45 minutes each session of moderate-intensity training is recommended [29]. Therefore, in an easy way, by increasing the frequency of dedicated training programmes, it is possible to improve the effectiveness of proposed therapies.

In the case of the TUG_ST variable, our CG participants did not see any significant improvement in the outcome of their participation in the JDE programme, although at $p = 0.058$, it is possible to refer to a trend. In another study [30], older people improved their performance by about 5% ($p = 0.02$) thanks to their participation in the 6-month JDE test in the TUG_ST test. The difference in results may be due to the difference in the duration of programme—ours was half as long. An additional reason may be a significant difference in the average age of respondents, which translates into significantly different average results obtained in the TUG test. In Trobetti et al., the average age was 75 years and the average TUG_ST test result was 10.25 seconds. In our study, it was, respectively, 70 years and 6.7 seconds.

The aim of this paper was to confirm and enrich the knowledge on the positive influence of the JDE method on the functional efficiency of seniors. Undoubtedly, the strengths of this study are the use of a random controlled trial protocol (RTC), a large research group, and a statistically significant interaction of IG variables with CG in each investigated trait in a relatively short period of time.

The studies carried out are subject to limitations. Above all, it is not possible to determine the changes that occurred in the nervous structures of participants, as no imaging diagnostics of the brain was carried out. Such data could show exactly what is behind the positive changes in IG and negative changes in CG—the proportions between the physical and cognitive spheres could be determined. Furthermore, there were some difficulties with interpreting results, caused by significant differences between results of IG and CG regarding DTC at the baseline, despite properly carried out randomization. Perhaps, increasing the number of participants would level that difference. Additionally, in subsequent studies, it would be advisable to create additional control groups: (1) performing only physical exercises and (2) performing only cognitive exercises. Then, it will be possible to compare and determine more precisely the mechanisms of impact of the JDE method on the dynamic agility of the body.

To sum up, this is the first randomized controlled trial showing a significant effect of JDE exercises, which take place twice a week for 12 weeks and improve dynamic agility control in women over 65 years of age. At the same time, it is worth emphasizing that JDE exercises are attractive for participants, which seem to be a good prognosis for planning and testing effective physical activity programmes for seniors.

Data Availability

The datasets analysed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare no conflict of interest.

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Research Article

Comparison of Functional Movement Screen, Star Excursion Balance Test, and Physical Fitness in Junior Athletes with Different Sports Injury Risk

Wen-Dien Chang,[1] **Li-Wei Chou**,[2,3,4] **Nai-Jen Chang**,[5] **and Shuya Chen**[3]

[1]*Department of Sport Performance, National Taiwan University of Sport, Taichung, Taiwan*
[2]*Department of Physical Medicine and Rehabilitation, China Medical University Hospital, Taichung, Taiwan*
[3]*Department of Physical Therapy and Graduate Institute of Rehabilitation Science, China Medical University, Taichung, Taiwan*
[4]*Department of Rehabilitation, Asia University Hospital, Taichung, Taiwan*
[5]*Department of Sports Medicine, Kaohsiung Medical University, Kaohsiung, Taiwan*

Correspondence should be addressed to Shuya Chen; sychen@mail.cmu.edu.tw

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Objectives. The aim of this study was to assess the relationships between functional movement screen (FMS), star excursion balance test (SEBT), agility *T* test, and vertical jump test scores and sports injury risk in junior athletes. We compared these assessments and the differences between groups with high and low risks of sports injury. *Subjects and Methods*. Eleven volleyball, 12 basketball, and 9 handball athletes were recruited. All participants followed the routine training in school sports teams. Weekly training schedules followed a similar pattern. The 32 junior athletes (age = 16.06 ± 0.21 years; height = 167.28 ± 6.32 cm; and body mass = 68.45 ± 9.67 kg) were assessed using the FMS, SEBT, agility *T* test, and vertical jump test in random order. The correlations of composite and individual item scores of these assessments were analyzed, and the differences between groups with high and low risks of sports injury were compared. *Results*. All participants completed the study protocol. No significant differences were observed between FMS, SEBT, agility *T* test, and vertical jump test scores in groups with high and low risks of sports injuries. Fair and moderate-to-good correlations were observed for anterior reach maximum of SEBT and deep squat ($r = 0.47$, $P = 0.02$) as well as inline lunge ($r = 0.53$, $P = 0.01$) of FMS. The hurdle step of FMS also exhibited moderate-to-good ($r = 0.52$, $P = 0.01$) and fair ($r = 0.42$, $P = 0.04$) correlations with posterior medial and posterior lateral reach maximum of SEBT, respectively. A fair correlation was observed between posterior lateral reach maximum of SEBT and rotary stability of FMS ($r = -0.23$, $P = 0.03$). Fair and moderate-to-good correlations were identified for agility *T* test and maximum anterior reach in the SEBT ($r = -0.42$, $P = 0.04$) and trunk stability push-up in the FMS, respectively ($r = -0.57$ and $P = 0.006$). *Conclusions*. Junior athletes with a high risk of sports injury did not exhibit differences in terms of FMS, SEBT, and physical fitness test scores. Deep squat, hurdle step, inline lunge, and rotary stability scores in the FMS were correlated with the item scores in the SEBT, which may be due to the use of similar movement patterns. Scores for anterior reach maximum in the SEBT and trunk stability push-up in the FMS were correlated with agility *T* test scores, suggesting a similar task requirement of trunk stability and dynamic weight shifting ability.

1. Introduction

Owing to the growing numbers of sports injuries, the American Academy of Pediatrics has highlighted the potential risks of sports specialization and high-intensity training in young athletes [1]. Young athletes chosen in talent programs often have the opportunity to participate in various exercises and multiple competition levels [2]. Such early motor specialization was associated with an increased risk of acute and substantial injuries and an increased risk of injuries from overuse in the top 10% of athletes in a self-assessment group [3]. Because sports specialization and intensive training in

junior athletes may affect musculoskeletal conditions, predicting sports injuries in this age group is imperative.

Functional movement and sports performance tests are used to assess an athlete's conditions and prevent sport-related injuries [4]. These tests could also be used as clinical tests to predict the risk of sports injury, because poor physical fitness, improper movement pattern, and insufficient sensorimotor control are vital factors in sports injuries [4, 5]. Clinical screening tests, such as the functional movement screen (FMS), star excursion balance test (SEBT), and agility and muscle power tests, are commonly used to assess sports performance and injury prevention [6]. The FMS is designed to identify motion deficits and body asymmetry and can assess general musculoskeletal conditions to predict injury risk [7]. This test can predict injuries with high specificity and exhibits moderate interrater reliability [8]. The SEBT assessed dynamic balance and physical performance [7]. It identifies the risk of sport-related injuries of the lower extremities and exhibits high interrater reliability [9]. The agility and muscle power tests are used to evaluate sports performance. Caswell et al. investigated the association between sports injury and physical performance in American youth football teams [10]. They concluded that a complex relationship exists between the agility and muscle power of an athlete in terms of their movements and rates of injury occurrence [10]. These four clinical screening tests could help identify the risk of injury and contribute to the formulation of a successful sports injury prevention strategy.

To the best of our knowledge, FMS and SEBT are functional assessment tools with some specific relevance [11]. However, information regarding a potential relationship between these assessments and physical fitness tests (i.e., agility and muscle power) is still insufficient. Additionally, the FMS and SEBT are used to predict the risk of sports injury occurrence. Currently, no research is available on the differences in FMS, SEBT, and physical fitness test results (i.e., agility and muscle power) between groups with high and low risks of sports injury. We hypothesized that correlations exist among these functional assessment tools and different sports injury risks. Therefore, the aim of this study was to investigate the relationships between FMS, SEBT, and physical fitness test results (i.e., agility and muscle power tests) and examine differences in these assessments in groups with high and low risks of sports injury.

2. Methods

2.1. Study Design. This observational study was conducted in accordance with current national and international laws and regulations governing the use of human subjects (Declaration of Helsinki II). It was approved by the Institutional Review Board of AT Hospital. Participants were informed of study procedures prior to their participation.

2.2. Participants. In this study, participants were junior athletes recruited from school sports teams. Inclusion criteria were as follows: being currently engaged in full sport participation, having a sport training history of more than 3 years, and being able to complete the study process. Exclusion criteria included suffering from acute sports injures and losing time for sport participation. The demographic and anthropometric characteristics of participants were recorded. All participants followed the routine training in school sports teams. Weekly training schedules were similar in the terms. The sessions contained fitness training for two half days per week and sport skill training for three half days per week. Both trainings were alternated in a week. The study procedure started after the academic year, and the assessments were performed before the start of sports competition season. Following the precedence of a study by Smith et al. [12], the sample size was estimated at a minimum of 19 participants. Eleven volleyball, 12 basketball, and 9 handball junior athletes were recruited. A total of 32 junior athletes (age = 16.06 ± 0.21 years; height = 167.28 ± 6.32 cm; body mass = 68.45 ± 9.67 kg) completed the study procedure.

2.3. Procedures. The four assessments (i.e., the FMS, SEBT, and agility and muscle power tests) were conducted in a randomized order. A dynamic stretching exercise as a warm-up was performed prior to the assessments. Both a 30-second break between testing movements and a 10-minute break between each assessment were employed. The participants performed each assessment three times, and all assessments were conducted by a physical therapist.

2.4. Assessments

2.4.1. Functional Movement Screen. The FMS™ (https://www.FunctionalMovement.com, Danville, VA, USA) involves seven components: deep squat, hurdle step, inline lunge, shoulder mobility, active straight-leg raise, trunk stability push-up, and rotary stability. The score for each item ranges from 0 to 3, with 0 indicating pain, 1 indicating a noncompleted skill performance, 2 indicating a skill performance with compensation, and 3 indicating a skill performance without compensation. The maximum score for the FMS is 21, and a total score lower than or equal to 14 points on the FMS indicates a greater possibility of sustaining a sports injury [13]. The FMS has exhibited excellent interrater reliability (0.97) for examining adolescents [14].

2.4.2. Star Excursion Balance Test. The SEBT is a balance test in which participants are asked to perform a single-leg standing test. In this study, the Y Balance Test™ (https://www.FunctionalMovement.com, Danville, VA, USA) was used to assess balance in three directions. Participants reached in the anterior, posteromedial, and posterolateral directions as far as possible, and the maximum distance was recorded in each direction. Three trials were performed, and each participant's limb length, measured from the anterior superior iliac spine to the medial malleolus, was recorded. The maximum distance of each direction was then divided by the participant's limb length. A difference in the anterior distance between both lower extremities greater than 4 cm indicates a high risk of sustaining a lower extremity injury [15]. In high school athletes, the SEBT exhibits good-to-excellent test-retest reliability (interrater reliability = 0.89-0.93) for these three directions [16].

2.4.3. Agility T Test. The agility T test is a running test in which four cones are arranged in a T shape. In this study, three cones were placed 4.57 m apart in a straight line. The starting cone was placed 9.14 m away, perpendicularly extending to the middle cone. Participants were asked to accelerate to touch each cone base and run forwards, laterally, and backwards between the cones as fast as possible. An electronic timing system (T-Test Agility Timing Systems, You-Shang Technical Corp., Taiwan) was used to record times in the test. This test has good test-retest reliability (intraclass correlation coefficient = 0.94) for assessing agility in running performance [17].

2.4.4. Vertical Jump. A vertical jump test was used to assess the muscle power of participants' lower extremities. Participants were asked to touch a provided vane. They started in a standing position and then flexed their knees and hips to jump immediately. Vertical jumping height was calculated using Vertec vertical jump meter (Sports Imports Incorporated, Columbus, OH, USA). The test-retest trial has good reliability (ICC = 0.97) [18].

2.4.5. Injury Risk Determination. FMS and SEBT scores have been used to predict sports injury risk in some studies [13, 15]. The sports injury risk cutoff points were 14 for total FMS score and a difference in the anterior distance of 4 cm in the SEBT, respectively. Total score of FMS > 14 or anterior distance difference distance of SEBT < 4 cm of SEBT was interpreted as low risk of sports injury. Oppositely, total FMS scores ≤ 14 or anterior distance difference of SEBT ≥ 4 cm was interpreted as indicating the group with a high risk of sports injury. Values from FMS, SEBT, agility T test, and vertical jump tests were compared in groups with high and low risks of sports injury.

2.5. Statistical Analysis. All data were analyzed using SPSS software (version 21; SPSS Inc., Chicago, IL., USA). Participant demographics (age, height, body mass, and sport) were calculated and reported as the mean ± standard deviation. Spearman correlation was used to assess the relationship among the FMS, SEBT, agility T test, and vertical jump test. The relationship between individual items of each assessment was analyzed. Correlation coefficients were established as low ($r < 0.25$), fair ($0.25 \leq r < 0.50$), moderate-to-good ($0.50 \leq r < 0.75$), and good-to-excellent ($r \geq 0.75$). The Shapiro–Wilk test was used to perform normality analysis, and the result indicated a nonnormal distribution. Therefore, a nonparametric approach was used for analyzing the data. The Mann–Whitney U test was used to compare differences in the FMS, SEBT, agility T test, and vertical jump test between groups with high and low risks of sports injury. A two-tailed test was used, and the α level was 0.05.

3. Results

The scores of FMS, SEBT, agility T test, and vertical jump for all participants are shown in Table 1. As shown in Table 2, no significant differences were observed in the FMS, SEBT, agility T test, and vertical jump between high risk of injury group (total score of FMS ≤ 14, $n = 20$; anterior distance difference of SEBT ≥ 4 cm, $n = 18$) and low risk group (total score of FMS > 14, $n = 12$; anterior distance difference of SEBT < 4 cm, $n = 14$; $P > 0.05$).

Table 1: Outcomes of FMS, SEBT, agility T test, and power in all participants.

Items	Value ($n = 32$)
FMS	
Deep squat	1.68 ± 0.78
Hurdle step	2.32 ± 0.48
Inline lunge	1.45 ± 0.74
Shoulder mobility	1.64 ± 1.00
Active straight-leg raise	1.86 ± 0.35
Trunk stability push-up	2.32 ± 1.09
Rotary stability	1.50 ± 0.80
Total score	12.18 ± 2.02
SEBT	
Anterior reach maximum (cm)	78.15 ± 7.26
Posterior medial reach maximum (cm)	89.32 ± 8.39
Posterior lateral reach maximum (cm)	90.57 ± 6.94
Composite score (%)	85.98 ± 6.20
Agility T test (sec)	12.59 ± 1.33
Vertical jump (cm)	45.68 ± 7.77

Table 3 shows a significant positive correlation between the anterior reach maximum of the SEBT and the deep squat and inline lunge of the FMS; the correlation was fair ($r = 0.47$, $P = 0.02$) and moderate-to-good ($r = 0.53$, $P = 0.01$, Figure 1), respectively. Moreover, the posterior medial and posterior lateral reach maximums of the SEBT also indicated a significant positive correlation with the hurdle step of the FMS; this correlation was moderate-to-good ($r = 0.52$, $P = 0.01$) and fair ($r = 0.42$, $P = 0.04$, Figure 1), respectively. A significant negative correlation was revealed between the posterior lateral reach maximum of the SEBT and the rotary stability of the FMS ($r = -0.23$, $P = 0.03$, Figure 2).

The agility T test demonstrated a significant moderate-to-good negative correlation with the FMS trunk stability push-up; this correlation was $r = -0.57$ and $P = 0.006$ (Table 4). Moreover, the agility T test also indicated a significant fair negative correlation with the anterior reach maximum of the SEBT ($r = -0.42$, $P = 0.04$, Table 5). No significant correlations were observed between the vertical jump and FMS or SEBT components ($P > 0.05$).

4. Discussion

This study was designed to determine the relationship between FMS, SEBT, agility T test, and vertical jump test results and compared the differences between groups with high and low risks of sports injuries. The current results from this study found that partial items in the SEBT and FMS, particularly trunk stability and dynamic weight shifting abilities, exhibited significant correlations. Agility T test had

Table 2: Scores for the FMS, SEBT, agility T test, and power by high and low risks of sports injury.

	FMS ≤ 14 (n = 20)	FMS > 14 (n = 12)	Difference ≥ 4 (n = 18)	Difference < 4 (n = 14)
FMS				
Deep squat	1.60 ± 0.75	2.50 ± 0.70	1.77 ± 0.92	1.56 ± 0.52
Hurdle step	1.70 ± 0.47	2.01 ± 0.51	1.69 ± 0.48	1.78 ± 0.44
Inline lunge	1.40 ± 0.75	2.02 ± 0.61	1.38 ± 0.76	1.56 ± 0.72
Shoulder mobility	1.60 ± 1.05	2.08 ± 0.42	1.85 ± 1.06	1.33 ± 0.86
Active straight-leg raise	1.85 ± 0.36	2.09 ± 0.55	1.85 ± 0.37	1.89 ± 0.33
Trunk stability push-up	2.25 ± 1.11	2.76 ± 0.31	2.31 ± 1.10	2.33 ± 1.11
Rotary stability	1.45 ± 0.82	2.08 ± 0.09	1.54 ± 0.87	1.44 ± 0.72
Total score	11.85 ± 1.78	15.50 ± 0.70	12.38 ± 2.21	11.89 ± 1.76
SEBT				
Anterior reach maximum (cm)	78.22 ± 7.49	77.44 ± 6.18	78.29 ± 5.93	77.93 ± 9.23
Posterior medial reach maximum (cm)	89.29 ± 8.80	89.54 ± 2.09	90.39 ± 5.05	87.76 ± 9.73
Posterior lateral reach maximum (cm)	90.73 ± 7.24	88.83 ± 2.93	91.43 ± 4.35	89.30 ± 9.22
Composite score (%)	86.02 ± 6.48	85.48 ± 2.39	86.61 ± 1.36	85.05 ± 8.40
Agility T test (sec)	12.65 ± 1.34	12.00 ± 1.41	12.77 ± 9.15	12.33 ± 1.32
Vertical jump (cm)	45.50 ± 8.01	47.50 ± 6.36	45.15 ± 7.53	46.44 ± 5.63

*$P < 0.05$; FMS: functional movement screen; SEBT: star excursion balance test.

Table 3: Correlations between items of FMS and SEBT.

FMS	SEBT		
	Anterior reach maximum	Posterior medial reach maximum	Posterior lateral reach maximum
Deep squat	0.47*	0.14	-0.015
Hurdle step	0.16	0.52*	0.42*
Inline lunge	0.53*	0.26	0.38
Shoulder mobility	-0.28	-0.19	-0.10
Active straight-leg raise	-0.28	-0.18	-0.16
Trunk stability push-up	0.25	0.19	0.06
Rotary stability	0.25	0.11	-0.23*

*$P < 0.05$; SEBT: star excursion balance test.

significantly negative correlations with trunk stability push-up in FMS and anterior reach maximum in SEBT. However, there were no significant differences in FMS, SEBT, agility T test, and vertical jump between high and low risks of sports injuries.

Harshbarger et al. assessed the relationship between the FMS and SEBT scores in intercollegiate athletics [19]. SEBT results had a negligible relationship with FMS results. Nevertheless, correlations were discovered between rotary stability score in the FMS and anterior reach maximum ($r = 0.41$, $P < 0.05$) and posterior medial reach maximum scores in the SEBT ($r = 0.31$, $P < 0.05$) [19]. Harshbarger et al. suggested that both assessments required core muscle stability to maintain postural stability during the performance of extremity movements [19]. A study by Lockie et al. explored the relationship between the FMS and modified-SEBT results of collegiate athletes [11]. Scores for trunk stability push-up in the FMS had a fair correlation with those for posteromedial reach maximum ($r = 0.37$, $P < 0.05$) with the right stance leg and anteromedial reach maximum with the right ($r = -0.33$, $P < 0.05$) and left ($r = -0.32$, $P < 0.05$) stance legs of the SEBT. A fair correlation was revealed between scores for the inline lunge of the FMS and posteromedial reach maximum ($r = 0.46$, $P < 0.05$) with the right stance leg [11]. The outcomes expressed FMS and SEBT challenged the dynamic stability of athletes but did not further explore reasons of their relationship. The aforementioned results differed from the results of this study, as posteromedial and posterolateral excursions of the SEBT exhibited significant positive correlation with the hurdle step movement in our study findings. We suggested that the participant reduces the center of pressure to one leg for the contralateral leg crossover step during the hurdle step exercise. This movement pattern is similar to the posteromedial and posterolateral reach test in the SEBT. Another noteworthy finding in our study is that the rotary stability scores in FMS had a

Figure 1: Significant correlations of anterior reach maximum in the SEBT with (a) deep squat and (b) inline lunge in the FMS. A significant correlation of hurdle step in the FMS with (c) posterior medial and (d) posterior lateral reach maximum in the SEBT.

Figure 2: A significant correlation of posterior lateral reach maximum in the SEBT with rotary stability in the FMS.

Table 4: Correlations between items of FMS and scores of the agility T test and vertical jump.

FMS	Agility T test	Vertical jump
Deep squat	-0.17	0.12
Hurdle step	-0.14	0.06
Inline lunge	-0.10	0.06
Shoulder mobility	0.25	-0.33
Active straight-leg raise	-0.01	-0.03
Trunk stability push-up	-0.57*	0.39
Rotary stability	-0.19	0.35

*$P < 0.05$; FMS: functional movement screen.

significantly negative relationship with that for posterolateral reach in the SEBT. In FMS, rotary stability refers to a trunk rotation movement, whereas posterolateral reach in the SEBT is an antirotation movement of core muscles. The negative relationship between these two movements was due to the use of reverse movement patterns.

Table 5: Correlations between items of SEBT and scores of the agility T test and vertical jump.

SEBT	Agility T test	Vertical jump
Anterior reach maximum	-0.42*	0.11
Posterior medial reach maximum	-0.14	-0.13
Posterior lateral reach maximum	0.02	-0.17
Composite score	-0.08	-0.14

*$P < 0.05$; SEBT: star excursion balance test.

The agility T test and vertical jump test are common athletic performance tests. Andersen et al. noted a significant correlation between muscle strength in the lower extremities of collegiate soccer players and agility ($r = -0.67$, $P < 0.05$) and vertical jump ($r = 0.54$, $P < 0.05$) [20]. Maggioni et al. indicated that jump performance was a potential factor to increase sprint ability [21]. Moreover, an increase of sprint ability could improve jump performance. Both abilities influenced each other and could be predictors of sport performance [22]. The agility T test and vertical jump scores of participants with a high risk of sports injury (FMS score ≤ 14; SEBT score difference < 4 cm) were not significantly different from those with low risk injury in this study. We conjectured that junior athletes had a sufficient level of sport fitness, suggesting that agility and muscle power were not factors related to injury. However, only agility T test scores exhibited significant correlations with scores for trunk stability push-up in the FMS ($r = -0.57$, $P < 0.05$) and anterior reach maximum in the SEBT ($r = -0.42$, $P < 0.05$), respectively. No relationships were observed between vertical

jump, FMS, and SEBT scores. Better core muscle stability and dynamic balance control of anterior distance reflected to perform the task of agility *T* test. Armstrong and Greig postulated that in-line lunge in the FMS was a highlighted predictor of *T* test performance, resulting in a significant correlation with the performance of netball and rugby players [6]. They indicated that the relationships between the FMS, SEBT, and agility performance are sport-specific. This may also explain differences in the results of our study.

FMS scores less than or equal to 14 were associated with increased injury risk, although the sensitivity was low [23]. The risk of sports injury was 2.04 times higher among those with FMS scores less than or equal to 14. Even, injury risk was 4.2 times greater to combine with poor physical fitness [24]. Kiesel et al. obtained that FMS scores were obtained before the start of the season for 46 football players, and FMS ≤ 14 was found to positively predict serious injury (specificity = 0.91; sensitivity = 0.54). The odds of sustaining a serious injury were 11.7 times higher in those with FMS ≤ 14 compared with those with FMS > 14 [25]. Chorba et al. revealed that 69% of athletes scoring 14 or lower sustained an injury, with a sensitivity and specificity of 0.58 and 0.74 for all study participants. A significant correlation was identified between low-scoring athletes and injury ($r = 0.76$, $P = 0.02$) [26]. In the current study, 62.50% of junior athletes ($n = 20$) with an FMS score ≤ 14 had a higher risk of sports injury. The result of this study was higher than that reported by Smith et al., who revealed that 33% of high school male athletes had a high risk of sports injury (FMS score ≤ 14) [12]. Geographical and ethnic differences may be factors behind the differences in these different results. When junior athletes with high (FMS score ≤ 14) or low (FMS score > 14) risk of sports injury were compared, no significant differences were observed in SEBT, agility *T* test, and vertical jump. FMS is a functional movement test and used to identify deficits of exercise movement. FMS score is also predictive of sports injury and is able to assess musculoskeletal conditions. This study found that although participants with an FMS score of <14 had a high risk of sports injury, no differences were found among dynamic balance, agility, and vertical jump scores. The outcomes indicated that FMS cannot identify these intrinsic physical factors.

Gonell et al. demonstrated that a difference in the anterior distance between both lower extremities greater than 4 cm on the SEBT resulted in individuals being 2.5 times more likely to suffer sport injuries, such as an ankle sprain [27]. This finding related to poor dynamic balance could identify basketball players who are more susceptible to ankle injury. Moreover, high school girls with a lower normalized composite reach distance in the SEBT were 6.5 times more likely to sustain a sports injury in the lower extremities [15]. Grassi et al. indicated that the SEBT requires muscle strength of the lower extremities, coordination, and agility. This may increase the test's sensitivity and ability to predict sports injuries [28]. The SEBT could help basketball players to identify deficits in these areas and to improve their performance using a neuromuscular training program [29]. Assessing the neuromuscular characteristics and sports injury of the lower extremity in basketball players receiving neuromuscular training is useful [30, 31]. In the current study, 56.25% of junior athletes ($n = 18$) with an SEBT score difference of ≥ 4 cm had a high risk of sports injury. The findings indicated no significant differences among FMS, agility *T* test, and vertical jump test scores in groups with high (SEBT score difference ≥ 4 cm) and low (SEBT score difference < 4 cm) risks of sports injuries. The SEBT is a dynamic balance test and designed to identify physical performance. It is also used for predicting sports injury risks [32]. Similar to the FMS, however, these results indicated that the SEBT cannot identify functional movement, agility, or muscle power.

This study has some limitations. First, this study did not track the occurrence of sports injuries, and it was impossible to determine the correlation between sports injury events and these variables (i.e., FMS, SEBT, agility *T* test, and vertical jump test scores). Second, a comparison between variables across different age groups was not performed. We suggest that future studies target different races, geographic regions, and age groups to explore the relationship between FMS, SEBT, and physical fitness and to provide reference indicators for sports injury prevention.

5. Conclusion

Overall, junior athletes with an FMS score of ≤ 14 or an SEBT score difference of ≥ 4 cm have a higher risk of sports injury. However, the results did not reveal differences in FMS, SEBT, and physical fitness to compare with low and high risks of sports injury. Correlations between FMS and SEBT showed that the deep squat, hurdle step, inline lunge, and rotary stability exercises in the FMS had fair and moderate-to-good correlations with SEBT components, suggesting similar movement patterns were required to complete both tests. Anterior reach maximum of the SEBT and the trunk stability push-up of the FMS demonstrated fair and moderate-to-good correlations with the agility *T* test, respectively. These relationships may be due to similar task requirements of trunk stability and dynamic weight shifting abilities. We also suggest that exercises involving trunk stability and dynamic weight shifting ability could cover in training sessions. They could influence the functional performance, balance, and agility ability of junior athletes.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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