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Review article

The Effects of Physical Activity Interventions on Children's Perception: A Systematic Review and Meta-Analysis

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Abstract

Perception is an essential component of children's psychological development, which is foundational to children's ability to understand and adapt to their external environment. Perception is also a crucial tool for understand and navigating one's surroundings, enabling children to identify objects and react appropriately to settings or situations. Substantial evidence indicates that engaging in physical activity is beneficial for the development of children's perceptual abilities, as the two are closely intertwined. Still, more research is necessary to gain a full understanding of the impact of physical activity on children's perception. To further identify and quantify the effects of physical activity on a number of specific perceptions in children. Systematic review and meta-analysis. Searches were performed using five online databases (i.e., PubMed, SPORTDiscus, PsycINFO, Web of Science, and Cochrane Library) for articles published up to and including June 2023 to identify eligible citations. A total of 12 randomized controlled trials, encompassing 1,761 children under the age of 12, were analyzed. Overall, physical activity as an intervention showed a notable effect on the development of children's perceptions. The meta-analysis indicated that participating in physical activity for 30 minutes around, daily, had a greater impact on children's visual perception and executive functioning than on their motor perception, body perception, and global self-worth (SMD = 1.33, 95% CI: 0.75, 1.91, $p < 0.001$). The effects of physical activity on children's perception performance varied by participant characteristics, with physical activity having better effects on body perception and overall self-worth in children who were obese or overweight. Furthermore, physical activity can also enhance executive function and attention in children with developmental coordination disorders. The effects of physical activity on children's perception performance varied according to the intervention time, with different activity durations resulting in different perception performances. Therefore, parents and educators must prioritize an appropriate length of physical activity time for children to ensure their optimal growth and development. Registration and protocol CRD42023441119.

Key words: Physical activity, children, perception performance, meta-analysis.

Introduction

Perception as a psychological ability refers to one's ability to perceive and understand external stimuli, and includes various types of informational input from our environment - through vision, hearing, touch, smell, and taste - as well as the processing, interpretation, and understanding of this sensory information (Kaiser, 2021; Krishna, 2012). It is through our sensory organs that things become reflected in our consciousness. Simply put, perception is the ability to feel and perceive. As an ability to adapt to changing tasks or problems, perception is foundational to higher cognitive functions (Cahen and Tacca, 2013). At the same time, perceptual ability, a core element of children's executive functioning, is also central to children's cognitive control (Vestberg et al., 2017). Children are born with some perceptions that help them obtain external information, react to external things, and form various social relationships, which are the basis of their physical and mental development (Brazelton, 1992). Children's perceptual abilities are in continuous developmental change, however, and need positive stimuli and experiences for their perceptual development. The period from 6 to 12 years of age, often referred to as middle childhood and pre-adolescence, are essential stages in children's growth and development (Collins, 1984a), being a critical period of the development of both motor skills and perceptual abilities (Solum et al., 2020; Qu et al., 2021). Cognitive abilities are also impacted during this stage, affecting the fundamental performance of motor cognitive processes (Demetriou et al., 2022; Magallón et al., 2016). As a fundamental ability for survival and development, it is particularly important to promote children's perception development (Swain et al., 2021). However, the development of children's perceptual abilities can be promoted and enhanced by providing rich sensory experiences, including touch, auditory, and visual stimuli, and diverse stimulating environments through a variety of external means (Thompson and Strosser, 2012). For these reasons, this study aimed to explore the impact of physical activity (PA) on the perception of children aged 6 to 12 years.

PA is an open form of activity with many benefits for children's physical and mental health development, including improved physical health, cognitive function, executive function, and perceptual ability (Bidzan-Bluma and Lipowska, 2018; Wang et al., 2022; Tomporowski et al., 2011; de Greeff et al., 2018). It is generally believed that participation in PA is also positively associated with perceived school performance, and that more days of moderate to vigorous PA would benefit the health and school performance of all children and adolescents. However, the existing literature is diverse, suggesting that further research on these effects is needed to better support the promotion of PA and maximization of educational outcomes. Ng et al. (2020) explored the relationship between PA and perceived school performance on adolescent health behaviors using collaborative, cross-national data from the Health Behav-

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iors of School-Aged Children study, collected from a total of 48 countries and territories in Europe and North America. They found differences in perceived school performance between boys and girls, with girls perceiving their school performance better than boys, but boys participating in more moderate to vigorous PA on a daily basis. Meanwhile, Xue et al. (2019) conducted a meta-analysis examining the effects of chronic exercise interventions on the executive functioning of children and adolescents, finding that regular, ongoing exercise does have a beneficial impact on their executive functioning. Despite its relatively small effect, long-term exercise interventions implemented in physical education courses may be an important aspect of promoting executive function (Xue et al., 2019).

Although the benefits of PA for children have been well-documented in numerous studies, the direct effects of PA on children's perceptions are still unknown, and there are no meta-analyses examining the effects of PA interventions on the perception of children aged 12 years and younger. Thus, it is also unclear how PA promotes children's perception while appropriately increasing PA levels, or which intensity of PA modality is most effective in improving the perception of children 12 years old and younger. Therefore, the meta-analysis of this randomized controlled trial (RCT) aimed to determine the impact of PA on the perception of children in this mid-childhood/pre-adolescence age group to provide a more reliable reference for the use of PA to promote children's perception performance as well as their physical and mental health development.

Methods

Protocol and Registration

The protocols of this systematic review and meta-analysis are registered in the PROSPERO database under the registration number CRD42023441119, which is available online. To ensure a transparent and standardized research process, and to do a comprehensive review, this study was conducted using the latest version of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021), and followed the requirements and steps of these guidelines.

Search strategy

A search strategy for this study was developed based on the topic and study content, and using the MeSH subject terms and entry terms. After identifying the search terms, corresponding searches were conducted in the PubMed, Web of Science, PsyclNFO, SPORTDiscus, and Cochrane Library databases (Appendix A). The time span of the literature search was from the inception of the database to June 28, 2023.

Study inclusion and exclusion criteria

This study followed the PICOS principle of evidence-based medical literature screening criteria, thus the literature included in this meta-analysis met the following criteria:

(1) The article was published in English; (2) The experimental design was a RCT; (3) The study was about the perceived performance outcomes of PA interventions, and the age of participants in the study sample was 6 to 12 years. Special populations were also included, such as children with developmental coordination disorders (DCD), overweight or obese children, and children with cerebral palsy (CP); (4) PA was the main intervention used in the experimental group, and included a sport or any PA element, and no-PA nor any modalities other than PA were used in the control group (CG); (5) The outcome indicators included at least one indicator about perceived performance aspects.

The study was excluded if it did not meet the following criteria:

(1) The study used non-randomized controlled trials and observational trials; (2) The experimental group interventions were not PA; (3) Studies used inconsistent indicators of perceived performance outcomes or contained incomplete data; (4) The published article was a review article, a duplicate publication, a case study or case report, used qualitative designs, or did not reference journal articles. Conference abstracts were also excluded.

Study quality evaluation and data extraction

We evaluated the risk of bias in the included studies using the Cochrane Handbook for Systematic Reviews of Interventions (Version 6.3) criteria, which were assessed independently by two researchers (XC and ZJ). Information extracted from each eligible trial was evaluated according to the six components of the risk of bias scale (i.e., selection bias, performance bias, detection bias, attrition bias, reporting bias, and other bias), and each potential source of bias was designated as high-risk, unclear, or low-risk. Any disagreement between the two researchers was decided by a third author (LH). The extraction of data was also completed independently by the same two researchers (XC and ZJ). According to the developed systematic tools and processes, and by carefully reading the full text of the included studies, the following information was extracted: name of the first author, date of publication, sample size, interventions used in the experimental and control groups, and indicators of perceived performance. The two researchers then cross-checked their results to ensure that the extracted data were consistent with the research topic; any disagreements were discussed and resolved, or they were referred to a third researcher (TT) for judgment.

Statistical analyses and publication bias

The meta-analysis of perceptual performance data was performed using Review Manage 5.4 software and Stata17.0. As the outcome indicator was a continuous variable, the effect magnitude was represented by standard mean difference (SMD) and 95% confidence interval (CI). The included studies were tested for heterogeneity using the I^2 test, and the homogeneity between the results was expressed as $P > 0.1$ and $I^2 < 50\%$, using a fixed effects model. When $P < 0.1$ and $I^2 > 50\%$, it indicates significant heterogeneity, using a random effects model. When excessive heterogeneity between groups was found, descriptive analysis was performed.

A subgroup analysis of participant characteristics was also conducted, and studies with different participant groups were included in the covariate survey, and a random effects model was used for the meta-analysis. Each different perceived ability performance outcome of the PA versus non-PA intervention was also included in the covariate study, and meta-analysis was performed using a random effects model. To evaluate the extent of potential publication bias in this study, a funnel plot was used. Additionally, to quantify any publication bias, Egger's and Begg's tests were also used, and the specific risk of bias is shown in the Supplementary Material (Appendix B).

Results

Trial selection

We initially identified 1,815 studies, of which 437 were excluded due to duplication. After reading titles and abstracts, 62 studies were identified as potentially relevant, and the full articles were obtained to review the full text of these. The review process resulted in the exclusion of 21 articles as the participants' ages were not within the desired range, 24 items were excluded as they did not report perception-related performance, and five items were excluded as the full text was incomplete. In the end, a total of 12 studies met the inclusion criteria of this study. The detailed screening process and final results are shown in the PRISMA flowchart (Figure 1).

Study descriptions

The characteristics of the studies included in this meta-analysis are shown in Table 1. These RCTs were all published between 2001 and 2022. All children included in the study samples were aged 6 to 12 years, and the mean age of both the CG and intervention group (IG) was less than 12 years. The sample sizes ranged from 10 to 263 for the IG, and from 8 to 249 for the CG. In the included studies, the participants were predominantly obese or overweight children with DCDs, with the percentage of boys outnumbering that of girls. The main types of interventions used in the studies were video gaming and aerobic exercise. The perception performance results were categorized into three major categories: (1) Body perception and global self-worth; (2) Perception of motor and sensory abilities; and (3) Visual perception and executive function.

Risk of bias assessment

According to the results of the Cochrane Collaboration's tool evaluation, nine of the 12 included studies (75%) had a low risk of bias in random sequence generation. Nine studies (75%) had a low risk of bias in allocation concealment. Seven studies (58%) had a low risk of bias for blinding of participants and personnel. Five studies (42%) had a low risk of bias for blinding of outcome assessments. All studies (100%) had a low risk of bias for incomplete outcome data. Ten studies (83%) had a low risk of bias for selective reporting. All other risks of bias were unknown. A high risk of bias was present in 8% of the randomized sequence generation, 8% for allocation concealment, 8% for blinding of participants and personnel, 8% for blinding to outcome assessment. A total of 0% of the studies had incomplete data or selective reporting of outcomes. Details regarding specific risk of bias assessments are shown in Figure 2.

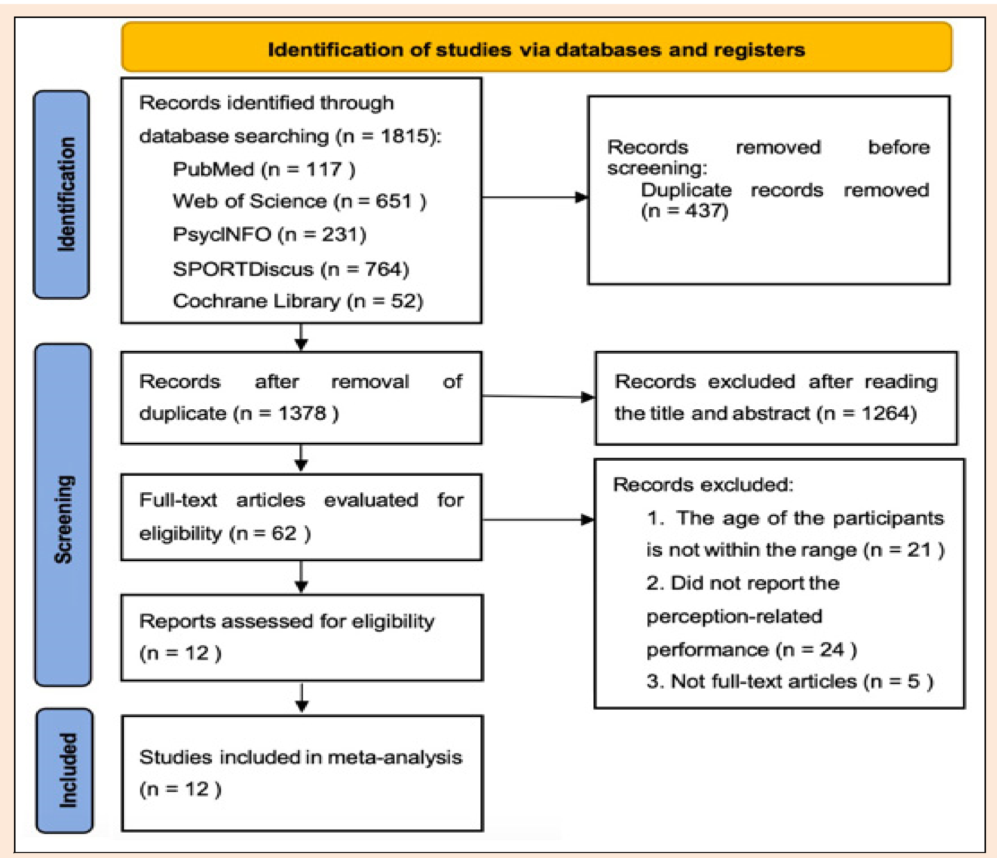

Figure 1. PRISMA flow diagram of the study process.

Table 1. **Summary of details of included studies.**

Study	Country/ Region	Sample size and characteristics		Age, Mean (*SD*)	Intervention content		Time and frequency	Outcomes
		Total; IG/CG	Gender (M/F)	IG/CG	IG	CG		
Petty et al., 2009	United States	207; 139/68 Overweight children	120/87	High dose Black 9.3 (1.0) White 9.6 (1.3)/ Black 9.4 (1.2) White 9.4 (1.1)	High dose (40 min/day, *n* = 70) aerobic exercise program	No exercise	40 min/day, 13±1.6 weeks	Global self-worth
Straker et al., 2015	Australia	21; 11/10 Children with DCD	10/11	10.8 (1.1)/ 11.3 (0.8)	Active video gaming (Sony PlayStation 3 with Move and Eye motion input devices and a Microsoft Xbox360 with Kinect motion input)	Normal activities	20 min most days (minimum four or five days every week), 16 weeks	Perceived motor skills
Christison et al., 2016	United States	80; 59/21 Overweight or obese children	34/46	10.1 (1.3)/ 10.0 (1.2)	Didactic and exergaming PA curriculum	Didactic curriculum only	10 weekly two-hour sessions, followed by four one-hour monthly didactic maintenance classes, six months	Behavioral, physical self-worth, and self-perception
Williams et al., 2019	United States	175; 90/85 Overweight or obese children	68/107	9.6 (0.88)/ 9.7 (0.88)	Aerobic exercise	Sedentary program	40 min/day, eight months	Perceptions of global self-worth
Fong et al., 2012	Hong Kong, China	62; 21/41 Children with DCD	49/13	7.7 (1.3)/ DCD-control group 7.4 (1.2)/ Normal-control group 7.2 (1.0)	Taekwondo training	No training	Taekwondo training session 1 hr/week for 12 consecutive weeks (i.e., three months)	Sensory organization and balance (somatosensory ratio, visual ratio, and vestibular ratio)
Hashemi et al., 2022	Iran	50; 25/25 Children with DCD	50/0	9.43 (2.10)/9.67 (2.39)	Wii Fit training	Usual school program	Three 30 min sessions/week, eight weeks	Visual perception and executive function
Bumin & Kayihan, 2001	Turkey	41; 32/9 Children with cerebral palsy	17/24	First group 7.06 (1.88), second group 7.68 (1.70)/7.00 (1.22)	Sensory-perceptual-motor training	Home program	1.5 hours, three days/week, three months	Sensory -perceptual motor functions
Beckmann et al., 2022	South Africa	481; 257/224 Normal children	247/234	8.80 (2.95)/ 8.08 (1.29)	PA lessons	Placebo	45-min, two times/week, 12 weeks	Executive functions and cognitive performance
Duncan et al., 2009	United Kingdom	68; 33/35 Overweight and obese children	34/34	aged 10 to 11 years	Circuit training-style plyometric exercises	No any Additional extracurricular sports or PA	40 min, two times/week, six weeks	Body image
van den Berg et al., 2019	The Netherlands	512; 263/249	274/238	10.9 (0.7)/ 10.9 (0.7)	Moderate- to vigorous-intensity exercise (aerobic exercise)	Classroom educational lessons	10 min/day, nine weeks	Cognitive performance (i.e., attention and inhibitory performances)
Hammond et al., 2012	United Kingdom	18; 10/8 Children with DCD	14/4	8.53 (1.15)/ 9.53 (1.42)	Wii Fit training	Regular Jump-Ahead program	10 min, three times/week, one month	Perception of motor ability
Mazzoni et al., 2009	Canada	46; 23/23 Children with disability as well as difficulty in motor functioning	37/9	8.7 (1.6)/ 8.1 (1.7)	Indoor wall-climbing	Normal treatment	One 1-hour session/week, six weeks	Perceived athletic competence, self-efficacy, and self-worth

IG = Intervention group, CG = Control group, M = Male, F = Female, DCD = Developmental coordination disorder, SD = Standard deviation.

Outcomes

The effect of PA on body perception and global self-worth

A total of five studies (Petty et al., 2009; Christison et al., 2016; Williams et al., 2019; Duncan et al., 2009; Mazzoni et al., 2009) reported the effects of PA on body perception and global self-worth. The heterogeneity of these studies was high (p = 0.002, $I^2 = 77\%$), and meta-analysis was performed using a random-effects model. Subgroup analyses were conducted based on the inclusion of participant characteristics, and the duration of PA intervention. The results of the subgroup analyses are shown in Figure 3 and Table 2. The noted participant characteristic was that they were "overweight" (SMD = 0.42, 95% CI: -0.04, 0.88), with high heterogeneity (I^2 = 82%, $p < 0.05$). The most commonly-used PA intervention duration was 30 to 60 minutes (SMD = 0.33, 95% CI: -0.24, 0.90), with significance heterogeneity (I^2 = 86%, $p < 0.001$). In the overweight subgroup, PA was shown to have a higher effect on body perception and global self-worth than in the non-exercise group. PA was most effective in promoting body perception and global self-worth in the more than 60 minutes' duration subgroup. Tests of the between-group differences of the subgroups showed no significant differences between the overweight and other subgroups (p = 0.40), and studies regarding duration also showed no significant differences (p = 0.81).

The effect of PA on perception of motor and sensory abilities

Five studies (Straker et al., 2015; Bumin and Kayihan, 2001; Hammond et al., 2012; Mazzoni et al., 2009; Hashemi et al., 2022) reported the impact of PA on children's perception of motor and sensory abilities. Subgroup analyses were conducted based on the noted participant characteristics, and the duration of the PA intervention. The results of the subgroup analyses are shown in Figure 4 and Table 3. The participant characteristic of DCD (SMD = 0.27, 95% CI: -0.58, 1.11) showed with high heterogeneity (I^2 = 71%, $p < 0.05$). The PA intervention duration of 30 to 60 minutes (SMD = 1.60, 95% CI: -2.54, 0.09) also had strong heterogeneity (I^2 =98%, $p < 0.001$). In the subgroup of children with DCD, PA had a greater effect on perception of motor and sensory abilities than it did in the no-physical-activity group. In the 30- to 60-minute subgroup, PA was more effective in promoting perceived movement and sensory abilities than in other groups. Tests of between-subgroup differences showed no significant differences between DCD and the other subgroups (p = 0.73).

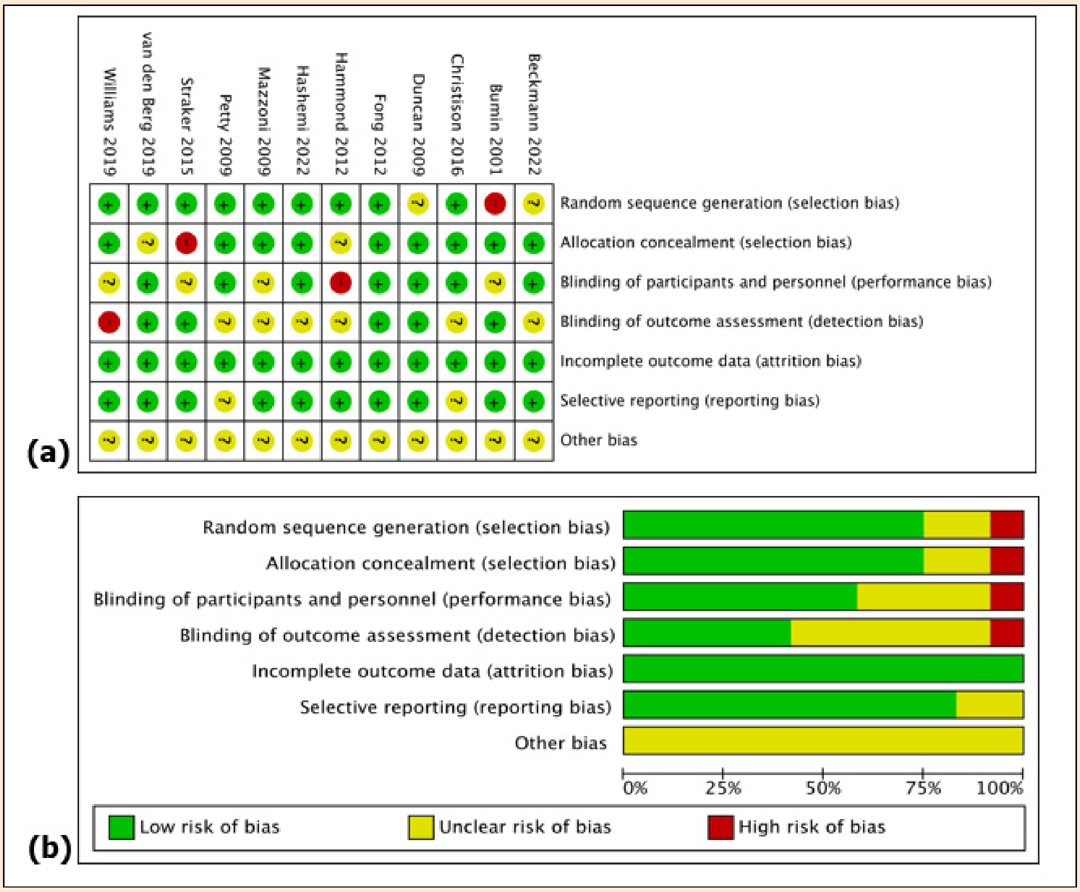

Figure 2. Risk of bias charts: (a) risk of bias graph, (b) risk of bias summary.

Table 2. Subgroup analysis of the effect of physical activity on body perception and global self-worth.

Subgroup	Cut-off	Included literature	Heterogeneity test		SMD(95% CI)	*P*
			I^2 %	*P*		
Sample characteristics	Overweight	4	82.0	.001	0.42(-0.04, 0.88)	0.07
	DCD	0	/	/	/	/
	Others	1	/	/	0.11(-0.47, 0.69)	0.72
Activity duration	< 30 min	0	/	/	/	/
	30 to 60 min	3	86.0	.000	0.33(-0.24, 0.90)	0.26
	> 60 min	2	60.0	.110	0.44(-0.18, 1.05)	0.16

DCD = Developmental coordination disorder, SMD = Standard Mean Difference, CI=Confidence interval.

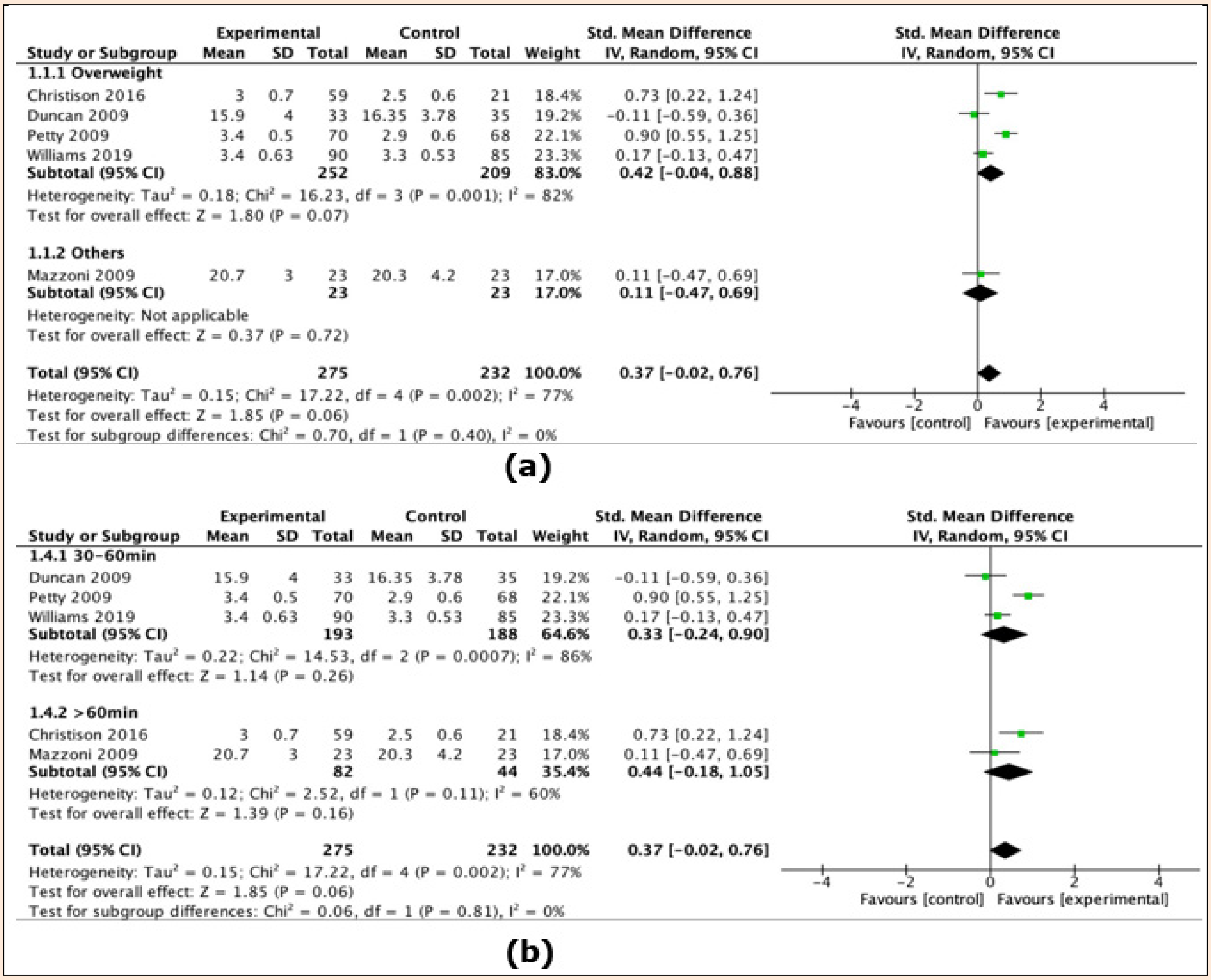

Figure 3. Subgroup analyses: (a) impact of physical activity (PA) on body perception and global self-worth according to participant characteristics; (b) impact of PA on body perception and global self-worth according to intervention duration.

The effect of PA on visual perception and executive function

A total of four studies (Fong et al., 2012; Hashemi et al., 2022; Beckmann et al., 2022; van den Berg et al., 2019) reported the influences of PA on visual perception and executive function. Subgroup analyses were conducted according to participant characteristics, and PA intervention duration. The results of the subgroup analyses are shown in Figure 5 and Table 4. DCD as a participant characteristic (SMD = 1.02, 95% CI: -3.41, 5.46) showed significant heterogeneity (I^2 = 99%, $p < 0.001$). A PA intervention duration of 30 to 60 minutes (SMD = 0.34, 95% CI: -0.30, 0.98) also had large heterogeneity (I^2 = 81%, $p < 0.05$). In the DCD subgroup, PA had a higher effect on visual perception and executive functioning than it did in the non-exercise group. When PA duration was 30 minutes or less, its effect on visual perception and executive function was higher than for the 30- to 60-minute duration group. Between-subgroup tests showed no significant differences between DCD and other subgroups (p = 0.93).

Publication bias

Publication bias was determined using a funnel plot, as shown in the Supplementary Material (Appendix B). However, this analysis approach is subjective to judgment and may be inaccurate. Therefore, this study also used quantitative methods such as Begg and Egger tests to further determine the presence of publication bias. The results all showed *p*-values greater than 0.05, which indicates no significant publication bias in the included literature.

Table 3. Subgroup analysis of the effect of physical activity on perception of motor and sensory abilities.

Subgroup	Cut-off	Included literature	Heterogeneity test		SMD(95% CI)	*P*
			I^2 %	*P*		
Sample characteristics	Overweight	0	/	/	/	/
	DCD	3	71.0	.030	0.27(-0.58, 1.11)	0.540
	Others	2	85.0	.009	0.54(-0.74, 1.81)	0.410
Activity duration	< 30 min	2	0	.480	-0.15(-0.79, 0.48)	0.630
	30 to 60 min	2	98.0	.000	1.60(-2.54, 0.09)	0.220
	> 60 min	1	/	/	1.22(0.43, 2.01)	0.003

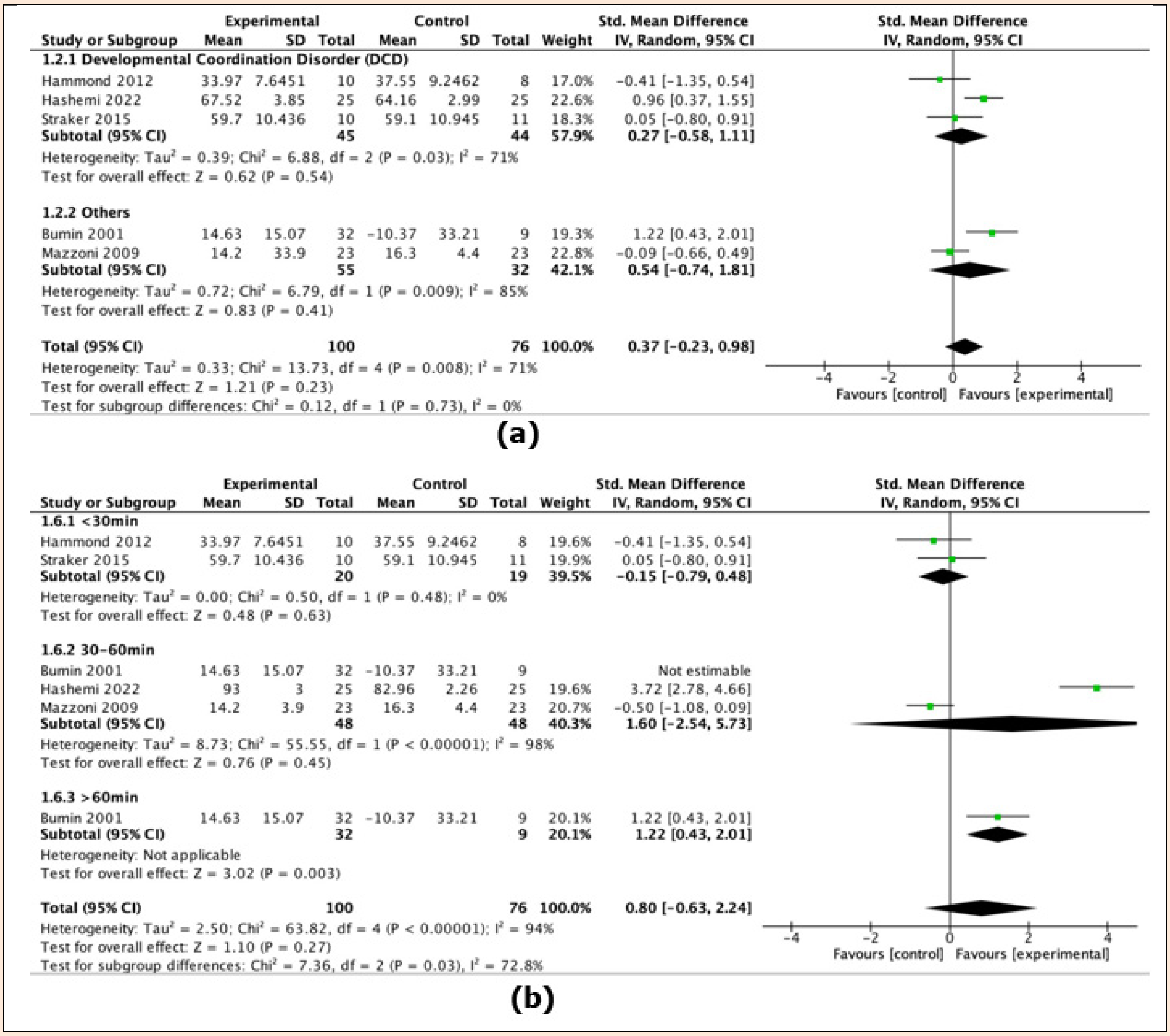

Figure 4. Subgroup analyses: (a) impact of physical activity (PA) on perception of motor and sensory abilities according to participant characteristics; (b) impact of PA on perception of motor and sensory abilities according to intervention duration.

Table 4. Subgroup analysis of the effect of physical activity on visual perception and executive function.

Subgroup	Cut-off	Included literature	Heterogeneity test		SMD(95% CI)	*P*
			I^2 %	*P*		
Sample characteristics	Overweight	0	/	/	/	/
	DCD	2	99.0	0.000	1.02(-3.41, 5.46)	0.650
	Others	2	99.0	0.000	0.81(-0.66, 2.28)	0.160
Activity duration	< 30 min	2	73.0	0.060	1.33(0.75, 1.91)	0.000
	30 to 60 min	2	81.0	0.020	0.34（-0.30, 0.98)	0.290
	> 60 min	0	/	/	/	/

Sensitivity analysis

To further explore the sources of heterogeneity, a sensitivity analysis was performed. Individual studies were excluded sequentially. The results of the analysis are shown in the Supplementary Material (Appendix C). Consistent with the results of the initial analysis, individual studies had little effect on the combined results. This indicates that the evaluation results of this study have good stability.

Discussion

This meta-analysis provides a comprehensive and systematic review of the effects of PA on children's perception performance. A total of 12 studies were included, and the results indicate that PA is more effective in promoting body perception and global self-worth in children who are obese or overweight compared to other children. The findings also show that there is a positive correlation between the participation of children aged 6 to 12 years old in PA and their perception performance in three major aspects in particular: (1) Body perception and global self-worth; (2) Motor and sensory perception; (3) Visual perception and execution function. In the subgroup of sample characteristics, PA has a greater impact on the perception of motor and sensory abilities in children with DCD than those without PA. Among overweight children, PA has a higher impact on body perception and overall self-worth than the non PA group. Therefore, PA can significantly improve and enhance the perceptual performance of special children populations, such as those with DCD and overweight children. In the subgroup of activity durations, different periods generated varied perceptual effects. PA interventions had a stronger effect in the < 30-minute subgroup compared to the 30- to 60-minute group in visual perceptual and executive function. However, in the 30- to 60-minute subgroup, PA was more effective in promoting motor and sensory perception than in the other groups. Meanwhile, PA was most effective in promoting body perception and global self-worth in the group of interventions which exceeded 60 minutes. So, when formulating a schedule and the program for PA, it is necessary to consider the duration of the event and the corresponding perception of development, which can help achieve more optimal results.

The 6- to 12-year age range (mid-childhood/pre-adolescence) is crucial for the development of children's physical fitness and cognitive abilities (Bidzan-Bluma and Lipowska, 2018; Amenya et al., 2021). Psychologically, children are in a transitional stage, going from non-arbitrariness to arbitrariness. During this period, they begin to understand complex concepts, and become better at observing and analyzing things around them, especially in terms of perception (Collins, 1984b). PA plays a different role in the perceptual development of children at various ages, and with different physical developmental characteristics. For children with physical illnesses (e.g., DCD, obese/overweight children), PA improves and develops their appropriate body perception and perceptual-motor abilities (Barros et al., 2022; Zaragas et al., 2023). This is also consistent with the results of this meta-analysis. Motor acquisition relies more on brain maturation, perceptual and cognitive abilities, as well as experience (Blauw-Hospers and Hadders, 2005). For children to participate in PA requires that they have high levels of time, spatial, and motion perception. They need to mobilize multiple perceptions, such as motion perception, vision, and hearing, to participate and collaborate with others, and especially to complete complex spatial movements (e.g., up and down, left and right, front and back, far and near, in and out, high and low). Sets of movements become even more demanding. PA improves children's visual acuity and perception, thus allowing them to form and develop their perceptions, and establishes a basis for their mental development (Burns et al., 2017; Kohl and Cook, 2013).

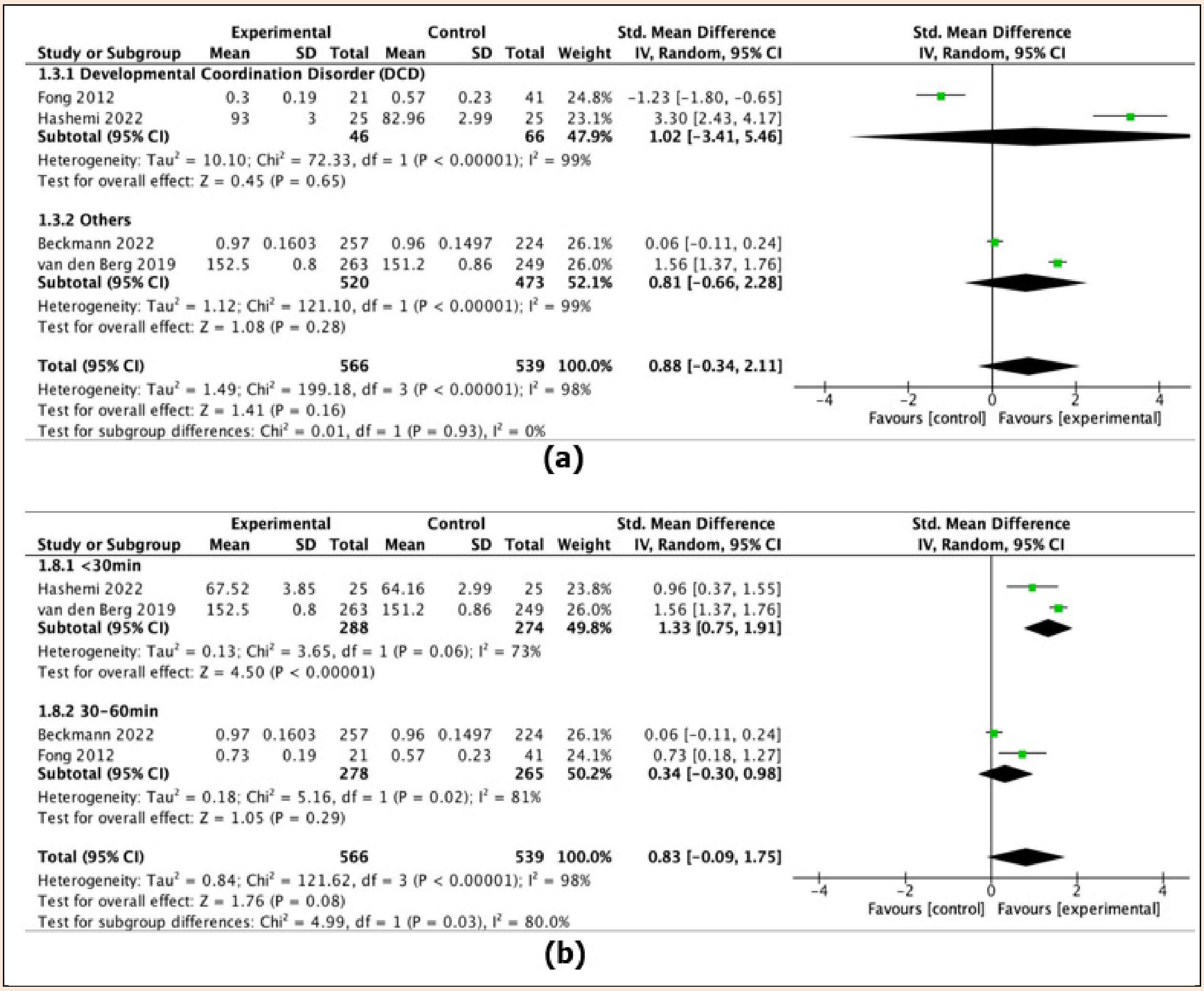

Figure 5. Subgroup analyses: (a) impact of physical activity (PA) on visual perception and executive function according to participant characteristics; (b) impact of PA on visual perception and executive function according to intervention duration.

This meta-analysis explored the impact of PA on the development of perceptual abilities in children aged 6 to 12 years of age, as another critical development stage. Not only does it provide further evidence regarding the perceptual abilities of children in this stage of growth, understanding the relationship between PA and perception will also help in formulating PA plans for these children, particularly in school settings or as family sports activities. The ability to accurately perceive the movements of one's own body, and those of others, is a vital part of participating in PA. Even the simplest, most basic movements (e.g., shaping hands, ankle flexion/extension, turning one's head, etc.), require specific coordinated movements and control of one's body (Wakeling et al., 2011). Through PA, children continuously improve their perceptual abilities, which in return leads to a more comprehensive development of their intelligence. Despite its contributions to our understanding of this relationship, however, the current study does have certain limitations, particularly in regards of gender differences. As most of the literature included in this meta-analysis did not investigate nor discuss gender differences, we were unable to draw any conclusions around the effects of gender on the relationship between children's perception skills and PA in our analysis. Furthermore, most of the studies included in this analysis focused on specific child populations; subsequent research on the effects of PA on perception should look at more general populations of children.

In the process of performing this systematic analysis, we found that many studies have examined the influence of parental perceptions on children's PA participation. These studies have focused on factors such as the parents' level of knowledge, the family's socio-economic status, parental occupations, recognition of PA, and family support (Brockman et al., 2009; Bentley et al., 2012; Xiang et al., 2023; Kroshus et al., 2021; Ha et al., 2019; Mutz and Albrecht, 2017), finding a diverse range of awareness levels among different family environments, all of which have different degrees of influence on children's PA participation or them eventually becoming a professional athlete (Siekańska, 2012; Côté, 1999; Kramers et al., 2022). This meta-analysis shows that perception and PA are interdependent, and that PA can not only help improve children's motor perception and reaction abilities, but also that the encouragement of these perceptions will improve children's level of PA, as well as their and performance. Therefore, a child's environment, which includes the influences of their parents and educators, plays a significant role in shaping their perceptions. It is the responsibility of the physical educator to design PA that supports the optimal growth and development of children by taking into account their age, gender, physical and mental traits, and how best to promote children's perception performance.

Implications

This meta-analysis strengthens our understanding of the effects of PA on the perceptions of children aged 6 to 12 years through a systematic review of the existing literature. Although the benefits of PA have already been discussed or demonstrated in various studies, few meta-analyses have addressed the impact of perception in children at this stage of development. Through our results, however, we obtain a clearer understanding of how PA can promote children's perceptual abilities while improving their PA levels appropriately for their age group. Furthermore, our findings suggest the ideal PA durations to effectively improve the perceptual abilities of children in mid-childhood/early-adolescence. In short, PA does have a positive impact on the body perception and global self-worth of 6- to 12-year-olds, especially among populations of obese or overweight children. Obesity is a common public health problem among both children and adolescents, with numbers increasing due to a wider lack of physical exercise and poorly-structured diets, resulting in a decrease in these children's external perceptions, particularly in terms of their own self-esteem and body image (Sahoo et al., 2015; Gow et al., 2020; Russell-Mayhew et al., 2012; Wang et al., 2009). Perception is also key to interpreting and understanding time, space, and motion. Through various aerobic activities (e.g., learning motor skills, curriculum-driven PA, extracurricular sports or games), obese children are able to exercise their temporal, spatial, and motor perceptions, and improve their perception of their own body and their global self-worth (Morano et al., 2010; Berleze and Valentini, 2022; Williams et al., 2019). Meanwhile, the development of perceptual-motor ability is an essential component of healthy maturation, improving children's abilities to obtain external information, make judgments, and respond to situations or objects accordingly (Stodden et al., 2008). PA helps children learn and develop a variety of motor skills, including running, balance, climbing, and catching things, and the practice and mastery of these skills improves children's physical coordination and perceptual-motor abilities, as well as their ability to perceive and control various parts of their own body (Sutapa et al., 2021; van der Fels et al., 2015; Zeng et al., 2017). This is particularly true for children with DCD, as participating in PA or motor exercise is shown to greatly enhance and promotes their movement and sensory perceptions (Zaragas et al., 2023; Tajari et al., 2022).

Mid-childhood and adolescence are also critical periods for physical development. Regular physical exercise can promote healthy bone growth and positively promote the development of muscles and skeletal systems (Alves and Alves, 2019; Kohl and Cook, 2013). Meanwhile, when children play sports, they must first be able to make thorough observations of the immediate activities taking place, while also observing and taking note of their own posture, movements, and changes in rhythm so that they can not only comprehend the situation, but also imitate, rehearse, or change their own actions. Keen observation and concentration are therefore crucial to the mastery of movement techniques, and PA encourages children to learn to concentrate and react quickly. For example, when participating in action-based video games or somatosensory games (e.g., Wii Sports), children need to be able to distinguish between their left and right hands, as well as directions, to be able to steer their movements correctly and experience the game through bodily participation; this improves their perception-related abilities (e.g., reactions, visual perception, attentional control) while also effectively cultivating their adaptability to the digital world (Green and Bavelier, 2012;

Franceschini et al., 2021; Achtman et al., 2008; Chang and Yen, 2023).

Conclusion

PA is an essential part of the development of children's perceptions, and its effect is particularly pronounced in children with DCD, or who are obese or overweight. By participating in various sports or other activities, children are able to holistically develop their skills of perception, and learn to synthesize multiple aspects of bodily, motor, and visual perceptions. In terms of research content, future studies should also explore the variability of the perceived impact of PA with regard to different genders, age groups, exercise intensities, and types of PA. Finally, regarding the measurement of perception-related indicators, current studies have primarily used scales or subjective questionnaires, which may be subject to biases. Future studies should consider using advanced perceptual sensors to quantitatively detect children's perception performance.

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Key points

- Physical activity has a positive impact on the body perception and global self-worth of children between 6 and 12 years of age, particularly among obese or overweight children.
- A duration of 30 minutes or less had the greatest impact on children's visual perception and executive functioning.
- Parents and educators must fully the physical and psychological characteristics of children holistically when developing optimal physical activity programs.

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Supplementary Materials

Appendix A

A1. PubMed search strategy.

Search	Query	Results
#8	Search: ((((("Perception"[Mesh]) OR (Sensory Processing[Title/Abstract])) OR (Processing, Sensory[Title/Abstract])) AND (("Child"[Mesh]) OR (children[Title/Abstract]))) AND (((((((((((((((((((((((("Exercise"[Mesh]) OR (Exercises[Title/Abstract])) OR (Physical Activity[Title/Abstract])) OR (Activities, Physical[Title/Abstract])) OR (Activity, Physical[Title/Abstract])) OR (Physical Activities[Title/Abstract])) OR (Exercise, Physical[Title/Abstract])) OR (Exercises, Physical[Title/Abstract])) OR (Physical Exercise[Title/Abstract])) OR (Physical Exercises[Title/Abstract])) OR (Acute Exercise[Title/Abstract])) OR (Acute Exercises[Title/Abstract])) OR (Exercise, Acute[Title/Abstract])) OR (Exercises, Acute[Title/Abstract])) OR (Exercise, Isometric[Title/Abstract])) OR (Exercises, Isometric[Title/Abstract])) OR (Isometric Exercises[Title/Abstract])) OR (Isometric Exercise[Title/Abstract])) OR (Exercise, Aerobic[Title/Abstract])) OR (Aerobic Exercise[Title/Abstract])) OR (Aerobic Exercises[Title/Abstract])) OR (Exercises, Aerobic[Title/Abstract])) OR (Exercise Training[Title/Abstract])) OR (Exercise Trainings[Title/Abstract])) OR (Training, Exercise[Title/Abstract])) OR (Trainings, Exercise[Title/Abstract]))) AND (Randomized controlled trial or RCT or random)	117
#7	Search: Randomized controlled trial or RCT or random	1472381
#6	Search: (((((((((((((((((((((((("Exercise"[Mesh]) OR (Exercises[Title/Abstract])) OR (Physical Activity[Title/Abstract])) OR (Activities, Physical[Title/Abstract])) OR (Activity, Physical[Title/Abstract])) OR (Physical Activities[Title/Abstract])) OR (Exercise, Physical[Title/Abstract])) OR (Exercises, Physical[Title/Abstract])) OR (Physical Exercise[Title/Abstract])) OR (Physical Exercises[Title/Abstract])) OR (Acute Exercise[Title/Abstract])) OR (Acute Exercises[Title/Abstract])) OR (Exercise, Acute[Title/Abstract])) OR (Exercises, Acute[Title/Abstract])) OR (Exercise, Isometric[Title/Abstract])) OR (Exercises, Isometric[Title/Abstract])) OR (Isometric Exercises[Title/Abstract])) OR (Isometric Exercise[Title/Abstract])) OR (Exercise, Aerobic[Title/Abstract])) OR (Aerobic Exercise[Title/Abstract])) OR (Aerobic Exercises[Title/Abstract])) OR (Exercises, Aerobic[Title/Abstract])) OR (Exercise Training[Title/Abstract])) OR (Exercise Trainings[Title/Abstract])) OR (Training, Exercise[Title/Abstract])) OR (Trainings, Exercise[Title/Abstract])	425382
#5	Search: "Exercise"[Mesh] Sort by: Most Recent	245822
#4	Search: ("Child"[Mesh]) OR (children[Title/Abstract])	2496065
#3	Search: "Child"[Mesh] Sort by: Most Recent	2148752
#2	Search: (("Perception"[Mesh]) OR (Sensory Processing[Title/Abstract])) OR (Processing, Sensory[Title/Abstract])	483856
#1	Search: "Perception"[Mesh] Sort by: Most Recent	479518

A2. Search strategy for Web of science.

#	Search Query	Database	Results
1	TS=(Exercise OR Exercises OR Physical Activity OR Activities, Physical OR Activity, Physical OR Physical Activities OR Exercise, Physical OR Exercises, Physical OR Physical Exercise OR Physical Exercises OR Acute Exercise OR Acute Exercises OR Exercise, Acute OR Exercises, Acute OR Exercise, Isometric OR Exercises, Isometric OR Isometric Exercises OR Isometric Exercise OR Exercise, Aerobic OR Aerobic Exercise OR Aerobic Exercises OR Exercises, Aerobic OR Exercise Training OR Exercise Trainings OR Training, Exercise OR Trainings, Exercise) and Preprint Citation Index (Exclude – Database)	All Databases	1992299
2	TS=(Child OR Children) and Preprint Citation Index (Exclude – Database)	All Databases	4340935
3	TS=(Perception OR Sensory Processing OR Processing, Sensory) and Preprint Citation Index (Exclude – Database)	All Databases	1508406
4	TS=(Randomized controlled trial OR random OR RCT) and Preprint Citation Index (Exclude – Database)	All Databases	2638454
5	#4 AND #3AND #2 AND #1 and Preprint Citation Index (Exclude – Database)	All Databases	651

A3. Search strategy for PsyclNFO

Name	Query	Database	Action	Results
Search history (PsycINFO)	Abstract: physical activity *OR* Abstract: exercise *OR* Abstract: fitness *OR* Abstract: physical exercise *OR* Abstract: sport *OR* Abstract: Acute Exercise *OR* Abstract: Exercise, Isometric *OR* Abstract: Exercise Training *AND* Abstract: Perception *OR* Abstract: Sensory Processing *OR* Abstract: Processing, Sensory *AND* Abstract: children *OR* Abstract: child *OR* Abstract: kids *AND* Document Type: Journal Article *AND* Age Group: School Age (6-12 yrs)	APA PsycInfo, APA PsycArticles, APA PsycBooks, APA PsycExtra	Edit SearchGet PermalinkSet Email AlertGet RSS FeedDelete permalink	231

A4. Search strategy for SPORTDiscus

#	Query	Limiters/Expanders	Last Run Via	Results
S1	AB (physical activity or exercise or fitness or physical exercise or sport or Acute Exercise or Exercise, Isometric or Exercise Training) AND AB (Perception or Sensory Processing or Processing, Sensory) AND AB (children or child or kids)	Limiters - Language: English; Publication Type: Academic Journal; Document Type: Article Expanders - Also search within the full text of the articles; Apply equivalent subjects Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - SPORTDiscus with Full Text	764

A5. Search strategy for Cochrane Library

ID	Search	Hits
#1	MeSH descriptor: [Perception] this term only	2449
#2	Sensory Processing* or Processing, Sensory*:ti,ab,kw	1414
#3	#1 or #2	3847
#4	MeSH descriptor: [Child] this term only	69224
#5	children*:ti,ab,kw	124632
#6	#4 or #5	148952
#7	MeSH descriptor: [Exercise] this term only	25464
#8	Exercises* or Physical Activity* or Activities, Physical* or Activity, Physical* or Physical Activities* or Exercise, Physical* or Exercises, Physical* or Physical Exercise* or Physical Exercises* or Acute Exercise* or Acute Exercises* or Exercise, Acute* or Exercises, Acute* or Exercise, Isometric* or Exercises, Isometric* or Isometric Exercises* or Isometric Exercise* Exercise, Aerobic* or Aerobic Exercise* or Aerobic Exercises* or Exercises, Aerobic* or Exercise Training* or Exercise Trainings* or Training, Exercise* or Trainings, Exercise*:ti,ab,kw	137023
#9	#7 or #8	142208
#10	#3 and #6 and #9 in Trials	52

Appendix B-Funnel plot

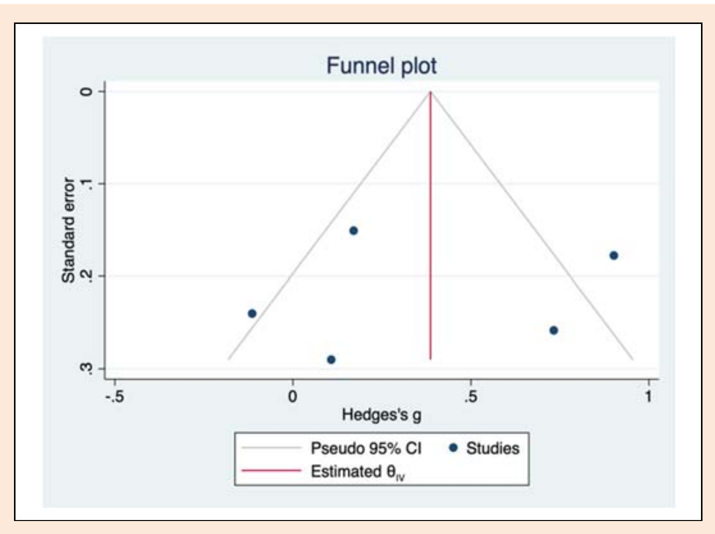

Figure B1. Funnel plot of publication bias risk of body perception and global self-worth (Egger's test: *p*= 0.7113 Begg's test: *p*=1.000).

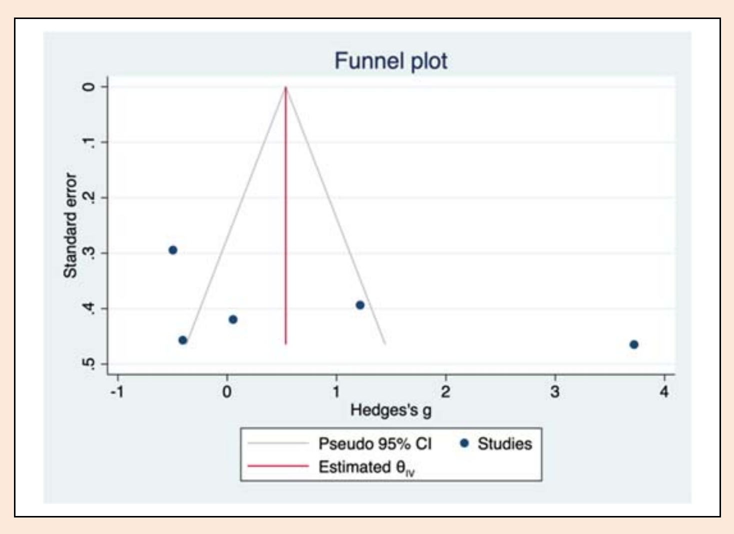

Figure B2. **Funnel plot of publication bias risk of perception of motor ability and sensory (Egger's test: *p*= 0.3161, Begg's test: *p*= 0.4624).**

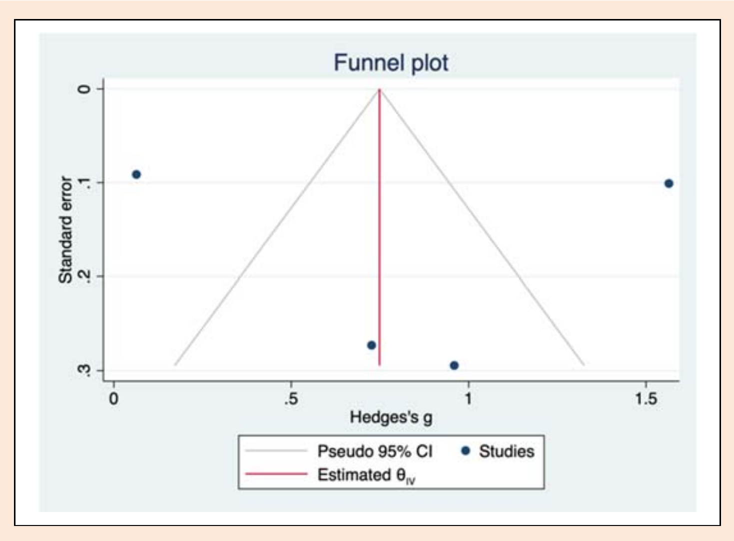

Figure B3. **Funnel plot of publication bias risk of visual perception and executive function (Egger's test: *p*=0.9180 Begg's test: *p*= 0.7341).**

Appendix C-Sensitivity analysis

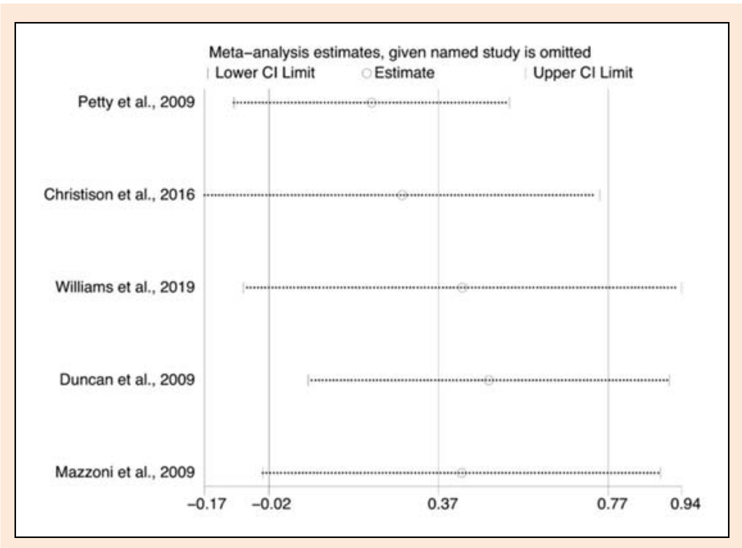

Figure C1. **Sensitivity analysis of body perception and global self-worth.**

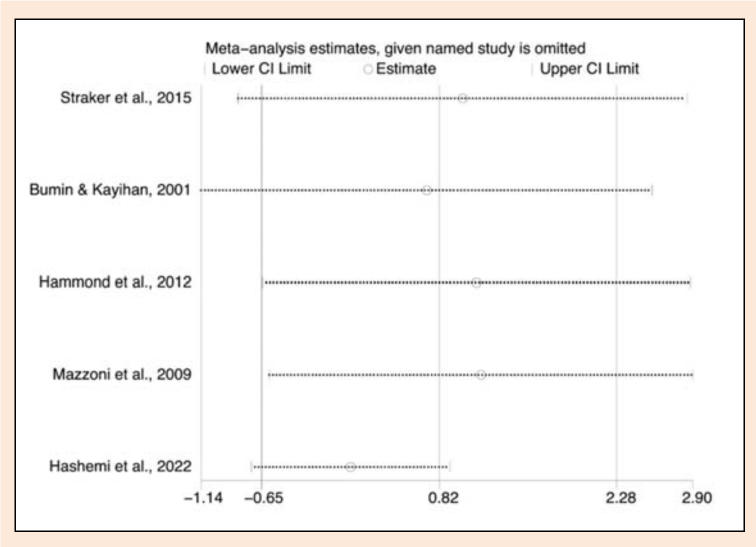

Figure C2. Sensitivity analysis of perception of motor ability and sensory.

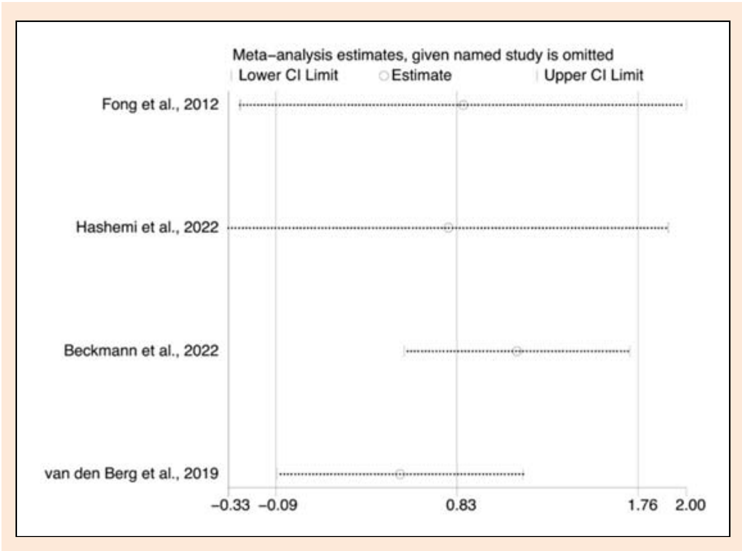

Figure C3. Sensitivity analysis of visual perception and executive function.