Title

Acute and chronic effect of physical activity on cognition and behaviour in young people with ADHD: A systematic review

Abstract

Background: Young people with attention deficit hyperactivity disorder (ADHD) often have learning and behavioral control difficulties.

Aim: The aim of this review is analyse the acute and chronic effect of physical activity (PA) on the cognition and behaviour of children and adolescents with ADHD.

Methods: Studies were identified in five databases (PubMed, SPORTDiscus, ProQuest, Web of Science, and SCOPUS), from January 2000 through to January 2017. A total of 16 interventional studies met the inclusion criteria.

Results/Conclusions: PA practise of 20–30 minutes (intensity 40–75%) produces a positive acute effect on processing speed, working memory, planning and problem solving in young people with ADHD. However, these effects on behaviour are contradictory and vary depending on age. Chronic PA practise (≥30 minutes per day, ≥40% intensity, ≥three days per week, ≥five weeks) further improves attention, inhibition, emotional control, behaviour and motor control. The results must be treated with caution, because only 25% of the studies used confounders.

Implication: More research is needed to justify the causes of these effects. It is necessary to establish programs with regard to the duration, intensity, kind of exercise, and time of PA to improve cognition and behaviour in young people with ADHD taking into account potential confounders.

Keywords: Physical exercise; attention deficit; cognitive performance; physical fitness; adolescent; confounder.

What this paper adds?

This systematic review shows that physical activity practice has a positive effect on cognition of children with ADHD, and in 35% of analyzed studies also appear an improvement on the behaviour in these young people. However, these results show differences between short and long-term effects, and they could differ according to duration, intensity, kind of exercise and time of the working day. These important findings should be highlighted in the neurophysiological understanding of ADHD. In school context, it is necessary to find more periods of physical activity during school hours and new ways for interdisciplinary combination between subjects.

1. Introduction

Attention deficit hyperactivity disorder (ADHD) is characterized by a persistent pattern of inattention and/or hyperactivity/impulsivity (ICD10, 1992). This pathology is considered one of the most common neurodevelopmental disorders in children, and it is frequently associated with other psychiatric conditions such as defiant opposition/negative disorder, conduct disorder, learning disabilities and anxiety (Van der Oord, Prins, Oosterlaan, & Emmelkamp, 2008).The global prevalence rate of ADHD in young people ≤18 years is between 5.3% (Polanczyk, Salum, Sugaya, Caye, & Rohde, 2015), being nearly three times more common in boys than in girls (9.2% versus 3.0%), independent of age (Wittchen et al., 2011).

The main conditions of ADHD in schoolchildren are related to two key elements for learning: deficits in cognition and behaviour problems (Gapin, & Etnier, 2010). Cognition refers to cognitive performance (CP) —including mainly executive functions such as memory, attention or mental planning/organization (Diamond, 2013)—. Behaviour problems, are characterized by persistent impulsive or emotional behaviour that disrupts the educational process and harms the CP of these children (Polanczyk, de Lima, Horta; Wittchen et al., 2011).

Currently, to treat ADHD the first strategie is used medication, because ADHD is mainly associated with low dopamine levels in the frontal lobe and the striatum (Vaidya et al., 1998). However, some children reflect a partial response to treatment or suffer secondary effects (Westover & Halm, 2012). The second strategy is based on behaviour modification to teach young people with ADHD to control their impulsive or emotional behaviour and take advantage of the cognitive abilities required for successful AP, such as sustained attention or concentration on the task (Watson, Richels, Michalek, & Raymer, 2015). It has been found that medication is less effective for social skills and executive functions (Hoza et al., 2005). Other studies indicate that psychosocial interventions are not as effective as medication in reducing the basic symptoms of ADHD, although they do positively improve the associated deficiencies, like oppositional and defiant behaviour (Van der Oord et al., 2008). However, the benefits of psychosocial interventions decrease rapidly after the intervention (Westover & Halm, 2012).

As an complement to the above strategies, treatments based on PA have recently emerged. Recent studies have shown that the PA practice is associated with an improvement in processing speed, working memory, planning and problem solving (Chuang, Tsai, Chang, Huang, & Hung, 2015; Piepmeier et al., 2015; Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013). Katz et al. (2010), observed that children with ADHD who performed high-intensity exercise in Physical Education (PE) class were able to reduce their stimulant medication intake. This was due to an increase in norepinephrine and dopamine levels in the brain, and a biological adaptive response of brain function to the stimulus generated by exercise (Wigal, Emmerson, Gehricke, & Galassetti, 2012.

This study raised the following question: `Can PA produce short- and long-term improvements on cognition and behaviour in young people with ADHD?´. Understanding the effects of PA on cognition and behaviour in young people with ADHD could clarify the discussion of the importance of PA in this population, and help in making decisions about the level of PA integration in education systems. This study aims to carry out a systematic review of the results of studies that have examined the acute and chronic effect of PA on cognition and behaviour in children and adolescents with ADHD. Additionally, this paper also reviews potential mediators and moderators that could influence this relationship.

2. **Methods**

The study was designed following the structure and recommendation of other systematic reviews (Cerrillo-Urbina et al., 2015), the treatment used by PRISMA guidance for reports and studies (Beller et al., 2013) and AERA guidelines for reviews (http://www.aera.net/). Databases, search strategies and limits, and filtered papers are detailed in Table 1. The above allows replication of the search (Higgins & Green, 2013).

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2.1.Search limits

A comprehensive search of five databases (PubMed, SPORTDiscus, Web of Science, ProQuest and SCOPUS) from January 2000 to January 2017 was undertaken. Additionally, reference lists of the selected papers were reviewed. The principal categories of search terms were identified and used in different combinations: 1) Physical activity (physical fitness, cardiovascular fitness, physical activity, physical education, fitness, exercise, physical exercise, acute exercise, chronic exercise, healthy exercise, aerobic exercise, resistance exercise, anaerobic exercise). 2) Attention deficit hyperactivity disorder (attention-deficit hyperactivity disorder, ADHD, attention deficit disorder, ADD). 3) Children and adolescents (children, childhood, school-age, youth, adolescents, teenagers, students, school, high school).

2.2.Selection criteria

The relevant papers selected for inclusion in the review were checked against the following criteria: 1. The study was a full report published in a peer-reviewed journal. 2. The study population was young people with ADHD. 3. The study included papers written in English, with a population of school and high-school students aged between six and eighteen years. 4. The study used an interventional design. 5. There were no exclusion criteria with regard to ethnic origin.

2.3.Data extraction and reliability

Information on author, title, aim, sample size, age, country, design, PA measurement, ADHD measurement, confounders and main results/conclusions was extracted from all studies. The search process was carried out by three independent reviewers (SSM, ARA and EJML). They read every title and all the abstracts; a consensus meeting was arranged to resolve any differences between them. The results of the most recent reviews were summarised first, then studies that were potentially relevant for the selected topics were screened for retrieval.

2.4.Quality assessment and level of evidence

The quality assessment of the question was carried out on the basis of other standardized assessment lists (Ruiz et al., 2009; Ruiz-Ariza, Grao-Cruces, Loureiro, Martínez-López,

2017) and on our selection criteria. The list included six items on population, measurements, design, confounders and reporting of the results. Each item was rated as "2" (fully reported), "1" (moderately reported) or "0" (not reported or unclear). For all studies, a total quality score was calculated by adding up the number of positive items (a total score between 0 and 12). Three levels of evidence were constructed. Studies were defined as high quality (HQ) if they had a total score of nine or higher. A total score of five to eight was defined as medium quality (MQ), and a score of less than five was defined as low quality (LQ) (see Table 2).

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3. **Results**

3.1.General findings

The flow of search results through the systematic review process is shown in Figure 1. Finally, 16 articles were included in the systematic review. A detailed analysis of these studies showed that 16 (100%) were intervention studies, of which seven studies (44%) are acute exercise intervention (Chang et al., 2012; Chuang et al., 2015; Flohr, Saunders, Evans, & Raggi, 2004; Labban et al., 2009; Piepmeier et al., 2015; Pontifex et al., 2013; Tantillo et al., 2002) , and nine studies (56%) are chronic exercise intervention (Choi et al., 2015; Hoza et al., 2015; Huang et al., 2014; Jensen & Kenny, 2004; McKune et al., 2004; Pan et al., 2015; Smith et al., 2013; Verret et al., 2012; Ziereis & Jansen, 2015). All used a group-randomized controlled trial, except Huang et al. (2014) and Pontifex et al. (2013), who used a non-randomized controlled trial. With regard to quality assessment, 14 papers had high quality and two had medium quality (Flohr et al., 2004; Labban et al., 2009). This review includes data from 728 individuals and the sample size of the studies varied from 13 (McKune et al., 2004) to 202 (Hoza et al., 2015) participants. The samples were from eight different countries: One study was conducted in Georgia (Tantillo et al., 2002), one in South Africa (McKune et al., 2004), one in Australia (Jensen & Kenny, 2004), one in Canada (Verret et al., 2012), four in China (Chang et al., 2012; Chuang et al., 2015; Huang et al., 2014; Pan et al., 2015), one in South Korea (Choi et al., 2015), six in the USA (Flohr et al., 2004; Hoza et al., 2015; Labban et al., 2009; Piepmeier et al., 2015; Pontifex et al., 2013; Smith et al., 2013) and one in Germany (Ziereis & Jansen, 2015). Detailed information about all the studies is presented in Table 3.

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3.2.Measurements of physical activity, cognition and behaviour

PA measures used in each study are shown in Table 3. Eight studies used objective measures to assess physical fitness level. Of them, one study used motor impersistence battery [MIB] ―tests requiring the maintenance of a movement or posture― (Tantillo et al., 2002); two used the test of gross motor development ―gross motor abilities that develop early in life― (Pan et al., 2015; Verret et al., 2012); one carried out the Bruininks-Oseretsky test of motor proficiency ―motor skills― (Smith et al., 2013), and two used the movement assessment battery for children ―identifies, describes and guides treatment of motor impairment― (Chuang et al., 2015; Ziereis & Jansen, 2015). In contrast, the other eight studies registered the PA programme effect, but they did not analyse physical fitness measures. Finally, one study used accelerometry through motion logger actigraph (Jensen & Kenny, 2004).

To assess cognition, a wide variety of direct tests of brain functioning were used, including electroencephalographic (Chuang et al., 2015; Huang et al., 2014; Tantillo et al., 2002), neuroscan STIM system (Pontifex et al., 2013), or functional magnetic resonance imaging (Choi et al., 2015), as well as indirect measures —, i. e., questionnaires or validated cognitive tests— (Chuang et al., 2015; Hoza et al., 2015; Piepmeier et al., 2015; Smith et al., 2013; Tantillo et al., 2002; Ziereis & Jansen, 2015). In all studies, the AP was measured indirectly from improvements in memory tests, attention, behaviour, arithmetic tests or numeracy. Only two studies directly measured the AP and they found no significant improvements (Flohr et al., 2004; Smith et al., 2013).

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In the majority of studies, the behaviour of young people with ADHD was measured using standardized parental questionnaires (Child Behaviour Checklist) and teacher questionnaires (Conner’s Teacher Rating Scale) (Flohr et al., 2004; Hoza et al., 2015; Jensen & Kenny, 2004; McKune et al., 2004; Tantillo et al., 2002; Verret et al., 2012). To a lesser extent, observational techniques such as classroom observation, the IOWA Conner’s Rating Scale (Flohr et al., 2004) and daily observations of behaviour (Smith et al., 2013) were used.

Only 25% of the 16 studies used confounders. Among them, brain activity (Choi et al., 2015), number of sessions and number of days practising yoga at home (Jensen & Kenny, 2004), quality of sleep, VO2 peak, state of anxiety and psychoticism (Tantillo et al., 2002), Tanner Kaufman stage and socioeconomic status (Pontifex et al., 2013) were controlled.

3.3.Acute effect of physical activity on cognition and behaviour

The seven studies that analysed the acute effect of PA on cognition were longitudinal studies with intervention, all of them controlled by exercise intensity. Five used treadmills (Chang et al., 2012; Chuang et al., 2015; Labban et al., 2009; Pontifex et al., 2013; Tantillo et al., 2002) and two used a cycloergometer (Flohr et al., 2004; Piepmeier et al., 2015). Tantillo et al. (2002) submitted young people with ADHD (8–12 years) to a maximum stimulus and another submaximal stimulus of 5–25 minutes. In boys, a significant increase in frequency of spontaneous blinking and a decrease in latency of acoustic startle eye blink response (ASER) and motor persistence after maximal exercise were seen. In girls, there was a perceived increase in the amplitude and decrease in the latency ASER after submaximal exercise. Pontifex et al. (2013) and Chuang et al. (2015) concluded a similar effect to Tantillo et al. (2002) on brain activity of young people with ADHD. The results showed a significant increase in the speed reaction and precision of response after an intervention of 20 to 30 minutes, but at moderate intensity (50–75%). However, for Flohr et al. (2004) there was no improvement in the simple mathematical problems solving of children with ADHD after a 25 minute cycloergometer intervention at low (40–50%) or moderate intensity (65–75%). Finally, three other studies with interventions of 20 to 30 minutes of exercise in children (Chang et al., 2012; Labban et al., 2009) and adolescents (Piepmeier et al., 2015) obtained benefits in executive functions and planning and organization processes.

3.4.Chronic effect of physical activity on cognition and behaviour

A total of nine longitudinal intervention studies analysed the chronic effect of PA on cognition. Jensen and Kenny (2004) found that young people with ADHD attending a yoga session weekly for 20 weeks improved attention and school behaviour. McKune et al. (2004) revealed that an intervention of MVPA —at 50–70%— improved the behaviour of young people with ADHD from the third week of treatment. In addition, at the end of five weeks, they observed improvements in emotional and attentional control, and in motor skills. These results are similar to three more recent studies which also used MVPA. On the one hand, Smith et al. (2013), observed improvements in behaviour, reponse inhibition, Conner's score, oppositional score, and a decrease of inattention after eight weeks of 30 minutes a day at the beginning of each school day. Hoza et al. (2015), after 12 weeks of aerobic PA, obtained improvements in ADHD symptoms such as behaviour, decrease of inattention and bad mood. Furthermore, Verret et al. (2012), found improvement in muscle capacity and motor skills, attention functions, reponse inhibition, and information processing after 10 weeks of MVPA after three 45 minute sessions per week.

On the other hand, Ziereis and Jansen (2015) observed that PA and sports programmes applied for 12 weeks —one 60 minute session per week— improved motor performance, visuospatial performance and working memory. Pan et al. (2015) applied a table tennis programme —two 70 minute sessions per week— for 12 weeks. The results showed improvements in locomotor and object-control skills, and in executive function and planning. Finally, two studies observed a significant increase in brain activity. Huang et al. (2014) conducted MVPA in a waterway for eight weeks —two 60 minute sessions per week— and Choi et al. (2015) conducted MVPA in a terrestrial environment for six weeks —three 90 minute sessions per week—. The results of both studies showed higher activation in the right frontal lobe and right temporal lobe in children, and a decrease in theta/alpha ratios in male adolescents, respectively.

4. Discussion

This systematic review has investigated the acute or chronic effects of PA on cognition and behaviour in children and adolescents with ADHD. The main results showed that PA improves executive functions, increases attention, contributes to greater planning capacity and processing speed and working memory, improves the behaviour of students with ADHD in the learning context, and consequently improves AP.

All the studies that used treadmills or cycloergometer with interventions of between 20-30 minutes of moderate-vigorous intensity (40–75%), showed acute effects on improvement of cognition in young people with ADHD. However, the immediate effects on behaviour show greater controversy. Chang et al. (2012) established that 30 minutes of MVPA on a treadmill (intensity of 50–70% heart rate reserve) improves executive function and planning/processing in young people aged 8–15 years. Also, performing 25 minutes of MVPA on a cycloergometer (intensity of 40–50% or 65–75%) can provide benefits to behaviour, with no significant differences between both (Flohr et al., 2004). Nevertheless, Tantillo et al. (2002), using 20-30 minutes at moderate intensity (50–75%) did not detect an effect on behaviour and anxiety level. Chang et al. (2012) and Labban et al. (2009) both indicate that acute positive effects of PA on CP are weak in primary school children and stronger in young adults.

On the other hand, the systematic practice of PA between 5-20 weeks (aerobic exercise, water activity, yoga, sports skills or practice of sport, 30-90 minutes at moderate-vigorous intensity (40–75%), produces a chronic effect that improves cognition and behaviour in young people with ADHD. All studies showed a positive effect of PA on cognition and five of them on behaviour. No study revealed a negative association. Some mechanisms to explain the acute and chronic effects of PA on cognition and behaviour in children and adolescents have been discussed (Ruiz-Ariza et al., 2017). However, this has not yet been scientifically proved in young people with ADHD. The effort, excitement, activation and alert produced by PA, especially at vigorous intensity, could also mitigate the etiological factors of ADHD (Chuang et al., 2015). At the chronic level, MVPA stimulates expression of the FNDC5 gene in the hippocampus through transcription complex PGC-1α/Errα. Improvements in this gene stimulate BDNF, a master regulator of cell survival, differentiation and plasticity in the brain, which improves cognitive function (Chang & Etnier, 2015; Piepmeier & Etnier, 2015). Secondly, MVPA prolonged over time improves the microstructure of the brain’s white matter, increasing the speed and efficiency of neuronal activity (Chaddock-Heyman et al.,

2014) and the levels of norepinephrine and dopamine in the brain, improving brain activity (Wigal et al., 2012).

It has also been found that PA practice has higher effects on CP in girls with ADHD than in boys (Tantillo et al., 2002). The cause of this effect is not demonstrated in children with ADHD, this difference in favour of the girls could be explained by the dose-response effect (Ruiz-Ariza et al., 2017). That is, boys are generally more active than girls (Verloigne et al., 2012) and therefore the activation achieved from the lower levels of PA may not be enough to cause the same effect on cognition in both sexes. A controversial example was obtained by Jensen and Kenny (2004). These authors obtained a positive cognitive and behavioural effect, proportional to the number of sessions and days per week, in boys with ADHD after an unusual PA in children like yoga. The dose-response effect could also justify larger effects on young people with ADHD compared to their non-ADHD peers. Verret (2010) examined associations between body composition and musculoskeletal skills. The results showed that comparing boys without ADHD, boys with ADHD on medication and boys with AHDH not on medication, there were no significant differences in the variables measured except in children with ADHD, who have significantly lower locomotion levels. Therefore, girls and generally young people with ADHD may have a higher level of neuronal activation after systematic application of PA, and may obtain greater cognitive effects within the school.

In spite of this exposition, we consider that the results of cause-effect of PA regarding cognition and behaviour in young people with ADHD must be treated with caution. This systematic review has found that only 25% of the analysed studies used confounders. Most studies focus on the direct effects of PA on cognition and behaviour, generating potentially dependent results. However, recent studies conducted in students without ADHD have analysed many covariates that may mediate the cognitive and behavioural effects, such as the education of both parents (Chen, Fox, Ku, & Taun, 2013); indicators of fatness, especially

BMI (Sardinha, Marques, Martins, Palmeira, & Minderico, 2014), time of breastfeeding (Luby, Belden, Whalen, Harms, & Barch, 2016) or time of active commuting to school (Ruiz-Ariza, Torre-Cruz, Redecillas-Peiró, & Martínez-López, 2015).

Some studies suggest that physical activity may improve school commitment (Owen et al., 2016). The benefits of PA in young people, especially in those with ADHD, produce acute effects within the school day and these benefits expand over time. Cognitive outcomes in young people with ADHD have greater effects when specific parameters are used. The kind of PA (especially cardiovascular endurance and motor skills), the weekly frequency (up to five days per week) and the intensity of the stimuli (especially high character) significantly increase the cognitive and behavioural improvements.

5. Conclusions

The present review selected a total of 16 interventional studies. All studies have shown positive effects of PA on cognition and 35.5% on the behaviour of young with ADHD. The benefits of PA differ according to the intervention time. A PA session of 20 to 30 minutes (intensity 40–75%) will have a positive acute effect on processing speed, working memory, planning and problem solving. However, the duration of these effects on behaviour can be contradictory and vary depending on age. Systematic PA (≥30 minutes per day, ≥40% intensity, ≥three days per week, ≥five weeks) further improves attention, inhibition, emotional control, behaviour and motor control. More research is needed to justify the acute and chronic effect on the cognition and behaviour of young people with ADHD.

Highlights

20-30 minutes (40–75% intensity) showed acute effects on improvement in cognition.

The immediate effects of physical activity on behaviour show greater controversy.

5-20 weeks (30-90 minutes/day) produces a chronic effect that improves cognition.

No study revealed a negative association between physical activity and cognition.

Only 25% of the studies used confounders. Thus, results must be treated with caution.

Conflict of interest

The authors have no conflict of interest to declare.

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Figure 1. Flow of articles through the search process
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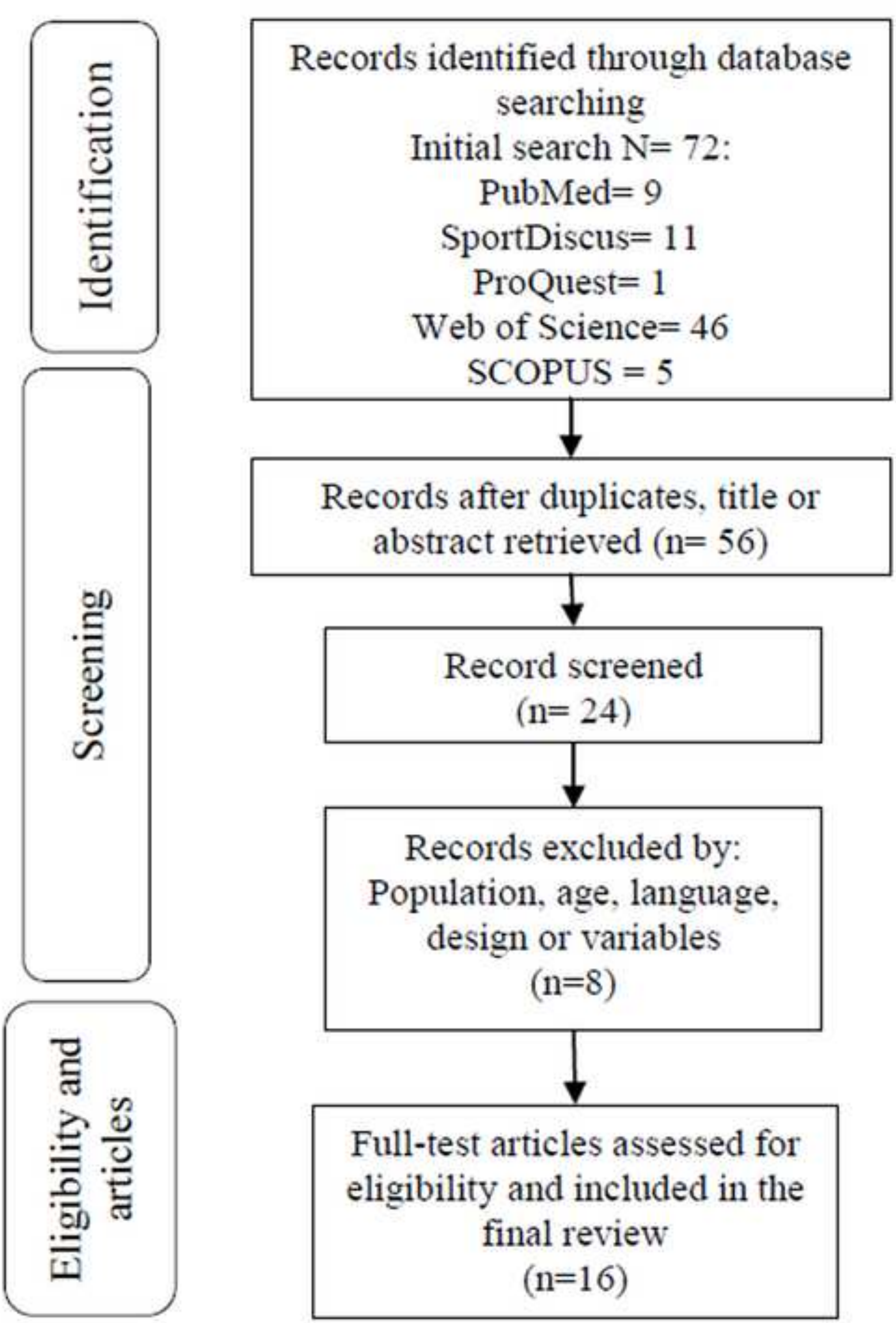

Table 1

Table 1. Search strategy in databases

Database	Search Strategy	Limits	Filter
PubMed	((("physical fitness"[Title] OR "physical activity"[Title] OR "physical education"[Title] OR "fitness"[Title] OR "exercise", "physical exercise"[Title] OR "acute exercise"[Title] OR "chronic exercise"[Title] OR "healthy exercise"[Title] OR "aerobic exercise"[Title] OR "resistance exercise"[Title] OR "anaerobic exercise"[Title])) AND ("attention deficit hyperactivity disorder"[Title] OR "ADHD"[Title] OR "attention deficit disorder"[Title])) AND ("children"[Title] OR "childhood"[Title] OR "school-age youth"[Title] OR "adolescent"[Title] OR "teenagers"[Title] OR "student"[Title] OR "school"[Title] OR "high school"[Title])	Publication date from 2000/01/01 to 2016/01/31 -Humans Children: 6-12 years Adolescent: 13-18 years -English language	9 items filtered
SportDiscus (EBSCO)	TI ("physical fitness" OR "physical activity" OR "physical education" OR "fitness" OR "exercise", "physical exercise" OR "acute exercise" OR "chronic exercise" OR "healthy exercise" OR "aerobic exercise" OR "resistance exercise" OR "anaerobic exercise") AND TI: ("attention deficit hyperactivity disorder" OR "ADHD" OR "attention deficit disorder") AND TI: ("children" OR "childhood" OR "school-age youth" OR "adolescent" OR "teenagers" OR "student" OR "school" OR "high school")	Publication date from 2000/01/01 to 2016/01/31 -Humans Children: 6-12 years Adolescent: 13-18 years -English language	11 items filtered
Web of Science	Title: (("physical fitness" OR "physical activity" OR "physical education" OR "fitness" OR "exercise", "physical exercise" OR "acute exercise" OR "chronic exercise" OR "healthy exercise" OR "aerobic exercise" OR "resistance exercise" OR "anaerobic exercise")) *AND* Title: (("attention deficit hyperactivity disorder" OR "ADHD" OR "attention deficit disorder")) *AND* Title: (("children" OR "childhood" OR "school-age youth" OR "adolescent" OR "teenagers" OR "student" OR "school" OR "high school"))	Publication date from 2000/01/01 to 2016/01/31 -Humans Children: 6-12 years Adolescent: 13-18 years -English language	46 items filtered
PRoQuest ERIC	(ti(physical fitness OR physical activity OR physical education OR fitness OR exercise, physical exercise OR acute exercise OR chronic exercise OR healthy exercise OR aerobic exercise OR resistance exercise OR anaerobic exercise)) AND (ti (attention deficit hyperactivity disorder OR ADHD OR attention deficit disorder)) AND (ti(children OR childhood OR schoolmate youth OR adolescent OR teenagers OR student OR school OR high school))	Publication date from 2000/01/01 to 2016/01/31 -Humans Children: 6-12 years Adolescent: 13-18 years -English language	1 items filtered
SCOPUS	(TITLE ("physical fitness" OR "physical activity" OR "physical education" OR "fitness" OR "exercise" , "physical exercise" OR "acute exercise" OR "chronic exercise" OR "healthy exercise" OR "aerobic exercise" OR "resistance exercise" OR "anaerobic exercise") AND TITLE ("attention deficit hyperactivity disorder" OR "ADHD" OR "attention deficit disorder") AND TITLE ("children" OR "childhood" OR "school-age youth" OR "adolescent" OR "teenagers" OR "student" OR "school" OR "high school"))	Publication date from 2000/01/01 to 2016/01/31 -Humans Children: 6-12 years Adolescent: 13-18 years -English language	5 items filtered

Table 2

Table 2. List of included studies with quality scores

Authors and variables	A	B	C	D	E	F	Total score	Quality level
Tantillo et al., (2002). Exercise and ADHD	2	2	2	1	2	2	11	HQ
Flohr et al., (2004). PA in AP and behavior ADHD	2	2	0	1	2	0	7	MQ
Jensen et al., (2004). Yoga and ADHD	2	2	2	1	2	1	10	HQ
McKune et al., (2004). Exercise and behavioral	2	2	1	1	2	1	10	HQ
Labban et al., (2009). PA and CP	2	2	1	1	2	0	8	MQ
Chang et al., (2012). Acute exercise and executive function	2	2	1	1	2	1	9	HQ
Verret et al., (2012). PA and behavior and cognitive functions	2	2	2	1	2	2	11	HQ
Pontifex et al., (2013). Exercise, behavioral, neurocognitive and scholastic performance	2	2	2	1	2	2	11	HQ
Smith et al., (2013). PA and ADHD	2	2	2	1	2	2	11	HQ
Huang et al., (2014). Aerobic Exercise and EEG	2	2	1	2	2	1	10	HQ
Choi et al., (2015). Aerobic exercise and ADHD	2	2	1	1	2	1	9	HQ
Chuang et al., (2015). Acute aerobic exercise and ADHD	2	2	2	1	2	2	11	HQ
Hoza et al., (2015). PA and ADHD	2	2	2	1	2	2	11	HQ
Pan et al., (2015). Physical Exercise, motor skills and Executive Functions	2	2	2	1	2	1	10	HQ
Piepmeier et al., (2015). Acute exercise and CP	2	2	1	1	2	1	9	HQ
Ziereis et al., (2015). PA, executive function and motor performance	2	2	2	1	2	2	11	HQ

Note: HQ = High quality = 9–12; MQ = Medium quality = 5–8; AP = Academic Performance; CP = Cognitive Performance; P = Physical Activity.
A. The study was a full report published in a peer-reviewed journal.
B. The study population was ADHD.
C. The selected physical activity, cognition and behavior outcomes were clearly described.
D. Population was of Primary and High Schools young between 6 and 18 years of age.
E. The study had an interventional design.
F. Data was adjusted for confounders.

Table 3

Table 3. Characteristics of the analysed studies (n=16)

Authors and variables	Study design / Intervention Acute or Chronic/ Confounders/ Duration	Sample/ age (years)/ Country	Groups/ Physical Activity measures	CP, AP and behaviour measures	Results
Tantillo et al., (2002). Exercise and ADHD	Interventional, cross-over, counterbalance/ Acute/ Diagnosis DSM-III-R. Ceased MPT medication 24h before and during. Sleep quality, VO2 peak, state of anxiety and psychoticism. HR/ 2days	43 children/ 10.11/ Georgia	2 groups: EG (n=18): submaximal treadmill exercise (~65-75%VO2). CG (n=25): quiet rest in a sound attenuated. Daily PA record. MIB. VO2peak.	CP: PSQI. State-Trait Anxiety Inventory for Children. Junior Eysenck Personality Questionnaire. ASER. EMG.	Boys with ADHD had increased spontaneous blink rate, decreased ASER latency, and decreased motor impersistence after maximal exercise. Girls with ADHD had increased ASER amplitude and decreased ASER latency after submaximal exercise.
Flohr et al., (2004). PA in AP and behavior ADHD	Interventional, cross-over/ Acute/ DSM-IV. HR/ 3 test sessions at one-week intervals	90 boys/ (7-11)/ USA	3 groups: EG1-LOW (n=30): 25min cycle ergometer (40– 50% VO2 max) EG2-MOD (n=30): 25min cycle ergometer (65–75% VO2 max) CG (n=30): playing board games for 25 min	AP: reading and math items completed correctly Behavior: Classroom Observation system, and IOWA	Not significant changes in AP. IOWA revealed no significant interaction across conditions from pre to post F (1.17) = 0.489, p >0.05. The similarities of results between the LOW and MOD exercise treatments suggested that intensity of exercise did not affect behaviour. In this analysis children showed significantly improved behavior (IOWA) following exercise, while there was no difference in behavior in the nonexercising condition (F (1.18) = 5.261, p < 0.05).
Jensen et al., (2004). Yoga and ADHD	Interventional/ Chronic/ Diagnosis DSM-IV. Stabilized on medication. Number of sessions and number of days of practice/ 20weeks (weekly 1h yoga)	19 boys/ 9.99/ Australia	2 groups: EG-Yoga (n=11) 1h yoga weekly CG (n=8) no exercise Logger Actigraph.	CP: CPRS. CTRS. TOVA WISC III	Results from the Motion Logger Actigraph were inconclusive. The yoga group was significant improvement on TOVA and CTRS. Significant improvements for the yoga group on five subscales of the CPRS. Not improvements in CG.
McKune et al., (2004). Exercise	Interventional/ Chronic/ Diagnostic DSM-III-R. HR/	13 children/ 11/ South Africa	2 groups: EG (n=8): 60min (20min 50-70% of	Measures: 1week before, after 3weeks and after the	Significant improvements in the behaviour of both group immediately after the programme: total

and behavioral	5weeks		HRM, Karvonen equation), 5 days/week (Monday to Friday). CG (n=5): no exercise	5week CP and Behaviour: CPRS	behaviour (p=0.001), attention (p=0.008), emotional (p=0.01), and motor skills (p=0.004).
Labban et al., (2009). PA and CP	Interventional/ Acute/ Diagnosis and ADHD-IV. HR/ 20min	18 boys/ 10.61/ USA	2 groups: EG: 20min MPA CG: 20min watched DVD	Working memory: WISC-IV Planning and organization: TOL Processing speed: CCTT 1-2	Positive effect (ES=0.82) for exercisers over controls. Exercisers performed better on the CCTT 2 (ES=0.26), and completed the TOL in fewer moves than controls (ES=0.77), requiring the minimum number of moves (ES=0). MPA improves executive function in children with ADHD.
Chang et al., (2012). Acute exercise and executive function	Interventional/ Acute/ Diagnosis DSM-IV. HR/ 30min	40 children/ 10.43/ China	2 groups: EG: 30min MVPA (50-70% HR) CG: 30min watched video	Strategic planning, updating, shift cognitive set, modulating impulsive, and perseveration: Stroop. WCST. Executive function.	Acute exercise facilitated performance in the Stroop Test, particularly in the Stroop Color-Word condition. EG had improvement in WCST, performances in Non-perseverative Errors and Categories Completed. No found performances in the CG.
Verret et al., (2012). PA and behavior and cognitive functions	Interventional/ Chronic/ Diagnosis DSM-IV. Medication only MPT. HR/ 10weeks	21 children/ 9.10/ Canada	2 groups: EG (n=10): 45min at lunch time MVPA. 3 days/week. CG (n=11): no exercise TGMD-2	Attention and inhibition: Test of Everyday Attention for Children. information processing: Sky Search DT. Behavioral: Parents and teachers completed the Child Behavior Check- list.	Findings show that participation in a PA program improves muscular capacities, motor skills, behavior reports by parents and teachers, and level of information processing.
Pontifex et al., (2013). Exercise, behavioral, neurocognitive and scholastic performance	Interventional, counterbalance/ Acute/ Diagnosis DSM-V. Differenced subtypes ADHD. HR. Tanner Kaufman stage, and socioeconomic status / 3 separate days	40 children/ 9.5/ USA	2 groups: EG (n=20): ADHD CG (n=20): no ADHD All: 20min treadmill at 65-75% MHR WRAT3	Inhibitory Control Task: the Eriksen flanker task with a Neuroscan STIM system	Both groups exhibited greater response accuracy and stimulus-related processing, with the children with ADHD also exhibiting selective enhancements in regulatory processes, compared with after a similar duration of seated reading. In addition, greater performance in the areas of reading and arithmetic were observed

					following exercise in both groups.
Smith et al., (2013). PA and ADHD	Interventional/ Chronic/ Diagnosis DSM-V. All medication naïve/ 8weeks	14 children/ 6.7/ USA	1 group. 30min MVPA before- school setting. Bruininks-Oseretsky Test of Motor Proficiency, 2nd edition Motor timing task	Shape School: The Shape School. Intelligence: WISC-III. Memory and Learning: WRAML-2 Maths: Woodcock–Johnson III	Significant improvement pre-post intervention on Bruininks-Oseretsky Test-2, Shape School Condition B (response inhibition), light proportion of inhibition failures, abbreviated Conners score, Iowa inattention/ overactivity score, Iowa oppositional/defiant score, and behavioral observations of interrupting Global ratings of overall improvement(%) of children rated as improved by: Parent 69%, Teacher 64%, Staff 71%
Huang et al., (2014). Aerobic Exercise and EEG	Interventional, cross-over/ Chronic/ Diagnosis DSM-IV. Right-hand dominant. No medications 24h before/ 8weeks	29 children /8.1/ China	2 groups: EG (n=16): 60min 2 days/week aerobic PA aquatic program. CG (n=16) no treatment	CP: EEGs Behavior Parent and teacher ratings on the Disruptive EEG	The EG showed smaller theta/alpha ratios over the frontal and central brain sites after the intervention compared with the control group
Choi et al., (2015). Aerobic exercise and ADHD	Interventional, cross-over/ Chronic/ Diagnosis Korean Kiddie Schedule and DSM-IV. HR. Brain activity/ 6weeks.	45 male adolescents/ 13-18/ Korea	3 groups: Sports-ADHD (n=13): MPT + 90min PA - 60min 60% HRM-. 3days/week. Edu-ADHD (n=17): MPT + 50min. educational sessions for behavior control. 2days/week. CG (n=15): no-ADHD	Brain Activity: 3-T functional magnetic resonance imaging Clinical symptoms of ADHD: Dupaul ADHD rating scale–Korean version. CP: WCST	Sports-ADHD improved ADHD-Korean score compared with edu-ADHD group. Right frontal lobe in the sports-ADHD group increased compared with the edu-ADHD group. Right temporal lobe in the sports-ADHD group decreased and did not change in edu-ADHD group. The change in activity within the right prefrontal cortex in all adolescents with ADHD was negatively correlated with the change in ADHD-Korean scores and perseverative errors.
Chuang et al., (2015). Acute aerobic exercise and ADHD	Interventional, cross-over, counterbalance/ Acute/ Diagnosis DSM-V. HR. Medication discontinue 24h before/7days	19 children/ 9.12/ China	Two visits, interval of 7 days. - Visit 1: Movement ABC, EEG, and intervention: 30min treadmill (60% HRM) or 30min video-	Attention: Go/No Go task Brain activation: EEG (1min resting eye-opened EEG, 1min resting eye-closed EEG, and 1min resting HR) The Movement	Shorter reaction time and smaller contingent negative variation 2 amplitude following PA relative to the video-watching. For event related potential analyses, greater contingent negative variation 1 and 2 amplitudes in response to No Go stimuli in

			watching. Go/No Go task. - Visit 2: another intervention. Go/No Go task.	ABC	comparison to Go stimuli was observed in the video-watching session only.
Hoza et al., (2015). PA and ADHD	Interventional, cross-over/ Chronic/ Diagnosis DSM-IV and ADHD-IV. differentiation ADHD-risk and TD. Medication naïve at study entry, asked if participants began medication to treat/ 12weeks	202 children/ 6.83/ USA	2 groups: EG: PA group: 31min, daily. CG: Sedentary group did art projects. PACER	Oppositional symptom severity, moodiness and peer functioning items were measured: PSQI (Parent and teacher)	In EG, ADHD had significantly lower participation that TD. CG group not differ. Increase in aerobic capacity over the course of the intervention was greater in the EG (Mincrease=2.12) than the CG (Mincrease=0.74). The symptom severity in the ADHD-risk group decreased significantly as compared with the TD group for all measures of symptom severity. The PA intervention was more effective than the Sedentary group intervention at reducing inattention and moodiness in the home context.
Pan et al., (2015). Physical Exercise, motor skills and Executive Functions	Interventional cross-over/ Chronic/ Diagnosis DSM-IV and Chinese version of the Child Behavior Checklist/ 12weeks	60 boys/ 9,04/ China	3 groups: EG ADHD (n=15): 70 min table tennis 2 days/week CG ADHD (n=15): no-exercise CG no-ADHD (n=30): TD control TGMD-2	Strategic planning, updating, shift cognitive set, modulating impulsive, and perseveration: Stroop. WCST	After the treatment, the ADHD training group scored significantly higher in the locomotor as well as object-control skills, Stroop Color-Word condition. The CG no-ADHD demonstrated an enhanced performance on the locomotor (+3.63) and object-control skills compared with the CG ADHD.
Piepmeier et al., (2015). Acute exercise and CP	Interventional, cross-over counterbalance/ Acute/ Diagnosis DSM-V. HR and OMNI scale (60-70%)/ 2days	32 adolescents/ 10.75/ USA	2 groups counterbalance: Visit 1: 30min Cycle-Ergometer (exercise) Visit 2: 30min watched a nature documentary (non-exercise)	Speed of processing and inhibitory control in response: Stroop. TOL. Planning or set shifting: Trail Making Test.	Exercise significantly benefited performance on all three conditions of the Stroop Task, but did not significantly affect performance on the TOL or the Trail Making Test.
Ziereis et al., (2015). PA, executive function and motor performan	Interventional, cross-over/ Chronic/ Diagnosis ICD-10). Subtypes of ADHD. No medication/	43 children/ 9.45/ Germany	3 groups: EG1 (n=13): 60min/week abilities ball handling, balance and manual	Working memory: Hamburg Wechsler Intelligenztest für Kinder IV. Visuo-spatial	Several measures of the EG1 and EG2s significantly improved over time. Furthermore, between group comparisons demonstrated significant improvements

ce	12weeks.	dexterity. EG2 (n=14): 60min/ week sports without a specific focus. CG (n=16): no treatment. Movement ABC-2	capacity: Digit span-task. Corsi block tapping test. Measured before, immediately after the first training week and one week after the last session.	in both EG1 and EG2 compared to the CG in variables assessing WM performance and motor performance.

Editorial Manager (TM) for Research in Developmental Disabilities

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