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Review

The effects of physical exercise in children with attention deficit hyperactivity disorder: a systematic review and meta-analysis of randomized control trials

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Abstract

Objective The aim of this systematic review and meta-analysis was to examine the evidence for the effectiveness of exercise interventions on attention deficit hyperactivity disorder (ADHD)-related symptoms such as inattention, hyperactivity/impulsivity, anxiety and cognitive functions in children and adolescents.

Method Five databases covering the period up to November 2014 (PubMed, Scopus, EMBASE, EBSCO [E-journal, CINAHL, SportDiscus] and The Cochrane Library) were searched. Methodological quality was assessed using the Cochrane tool of bias. Standardized mean differences (SMD) and 95% confidence intervals were calculated, and the heterogeneity of the studies was estimated using Cochran's *Q*-statistic.

Results Eight randomized controlled trials ($n = 249$) satisfied the inclusion criteria. The studies were grouped according to the intervention programme: aerobic and yoga exercise.The meta-analysis suggests that aerobic exercise had a moderate to large effect on core symptoms such as attention (SMD = 0.84), hyperactivity (SMD = 0.56) and impulsivity (SMD = 0.56) and related symptoms such as anxiety (SMD = 0.66), executive function (SMD = 0.58) and social disorders (SMD = 0.59) in children with ADHD. Yoga exercise suggests an improvement in the core symptoms of ADHD.

Conclusions The main cumulative evidence indicates that short-term aerobic exercise, based on several aerobic intervention formats, seems to be effective for mitigating symptoms such as attention, hyperactivity, impulsivity, anxiety, executive function and social disorders in children with ADHD.

Introduction

Attention deficit hyperactivity disorder (ADHD) is considered the most common neurodevelopmental disorder in children (Goldman *et al.* 1998; Polanczyk *et al.* 2007). According to the *Diagnostic and Statistical Manual of Mental Disorders*, fifth edition (DSM-5) (American Psychiatric Association, 2013), ADHD is characterized by a persistent and impairing pattern of inattention and/or hyperactivity/impulsivity. ADHD is often co-morbid with other psychiatric conditions, such as oppositional defiant disorder, conduct disorder, specific learning disorders and mood and anxiety disorders (Biederman & Faraone 2005). The global prevalence rate of ADHD is around 5% (Polanczyk et al. 2007; Wittchen et al. 2011), about three times more common in men than in women (9.2% vs. 3.0%), independent of age (Guevara & Stein 2001), although variability depending on the target population has been described (Pineda et al. 1999). Aetiology of ADHD is complex and multidimensional, combining genetic and environmental factors (Faraone et al. 2000; Biederman & Faraone 2005).

Overall, treatment of ADHD is focused on pharmacological (psychostimulant medication) and non-pharmacological (school-based intervention strategies, psychotherapy and cognitive-behavioural techniques) interventions (Power et al. 2009); sometimes, pharmacotherapy has been associated with side effects (poor tolerance, non-response to treatment and even dependence) (Spencer et al. 1996; Loro-Lopez et al. 2009; Lee et al. 2011; Mulas et al. 2012; Westover & Halm 2012). The influence of physical exercise (PE) on the same catecholaminergic systems targeted by stimulant medications for this disorder has been described (Tomporowski et al. 2008; Wigal et al. 2013), and therefore, interventions focused on PE might be effective in managing the core symptoms of ADHD. In this way, some studies support the positive effects of exercise in children with ADHD (Tomporowski et al. 2008). Studies reported that catecholamine response to exercise was markedly reduced in children with ADHD; however, a study suggested that catecholamine excretion after exercise challenges in children with ADHD is deficient. These preliminary data are consistent with previous studies indicating that children with ADHD have lower catecholamine responses to pharmacologic, physiologic and cognitive challenges (Wigal et al. 2003). For this reason, exercise could be considered an adjunct to medication that helps to reduce behaviour problems that interfere with learning and academic progress and benefit cognitive performance of children with ADHD (Barnard-Brak et al. 2011; Gapin et al. 2011; Wigal et al. 2013).

Findings from the effects of PE on children's and adults' (with or without ADHD) intellectual function, cognitive ability and academic achievement suggest that regular exercise training may alter brain functions that underlie cognition and behaviour, as well as the underlying physiology present in ADHD (Tomporowski et al. 2008; Pontifex et al. 2013; Wigal et al. 2013). PE leads to a number of biological responses in muscles and organs that, at the same time, modify and regulate the structure and functions of the brain (Dishman et al. 2006). Exercise may have positive effects on aspects of neurocognitive function and inhibitory control. Exercise is not only essential to improve and maintain physical fitness and a healthy lifestyle but also has beneficial effects on people's psychological functioning and mental health, particularly for those with ADHD (Pontifex et al. 2013; Wigal et al. 2013).

The benefits of PE for people with ADHD have been shown in several studies (Tomporowski et al. 2008; Barnard-Brak et al. 2011; Pontifex et al. 2013; Smith et al. 2013; Wigal et al. 2013; Grassmann et al. 2014), including a recent systematic review that evaluated the benefit of PE to the cognitive function in this population (Grassmann et al. 2014), but, to our knowledge, no studies have evaluated the entire set of cognitive and behavioural dimensions affected in ADHD by using a meta-analysis of randomized control trials (RCTs). Therefore, the purpose of this meta-analysis is to examine the evidence for the effectiveness of PE interventions on symptoms such as inattention, hyperactivity/impulsivity, anxiety and cognitive functions in children and adolescents with ADHD.

Materials and methods

The review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses statement for quality of reporting a meta-analysis (Liberati et al. 2009).

Literature search

Five databases covering the period up to November 2014 (PubMed, Scopus, EMBASE, EBSCO [E-journal, CINAHL and SportDiscus] and The Cochrane Library) were searched. In addition, the reference lists and related links of retrieved articles were examined to detect studies' potentially eligible references for inclusion. Grey literature search was conducted in congress articles, university research and other electronic media. We developed a sensitive search strategy for each individual database (Supporting Information File 1).

Study selection

The criteria for inclusion were as follows: (i) patients (children and/or adolescents aged 6–18 years diagnosed with ADHD and regular medication); (ii) type of study (RCT, in which the control group received no PE intervention); (iii) type of intervention (PE programmes); (iv) main outcome (we selected those studies evaluating ADHD symptoms, taking into account primary outcomes, such as inattention, hyperactivity and impulsivity, and secondary outcomes that include related ADHD symptoms such as anxiety, executive function, social disorders and cognitive performance); (v) diagnostic criteria (Conners or DSM in any of its editions); and (vi) language (alllanguages were accepted). Because of the intensity and type of exercises, we decided to categorize programmes in aerobic and yoga (considered as complementary and alternative medicine) (Barnes *et al.* 2008). Finally, no restrictions on frequency or duration of training were imposed. The exclusion criteria were as follows: (i) interventions in which exercise was part of a multicomponent therapy involving a combination of exercise and alternative therapy; (ii) studies with a low quality (four or more high-risk bias points); and (iii) those studies that were limited to testing the effect of exercise on improving physical ability or aerobic or gross motor. The search was conducted between 20 and 30 November 2014.

Two authors (A. J. C. and A. G.) independently screened the titles and abstracts of retrieved studies identified by the search strategy; in a second step, these potentially eligible studies were re-evaluated in the full text. In case of disagreement, a third author (M. S.) proceeded to read the entire article and resolved the discrepancy.

Data extraction

One author (A. J. C.) extracted data, and the data were checked later by a second author (A. G.). Later, the authors extracted the following data from each candidate selectable article: (i) characteristics of trial participants (number, sex and age); (ii) intervention features (type, duration, frequency, intensity of PE, adherence, dropouts and adverse effect); (iii) methods to evaluate the results (questionnaires and scales to assess symptoms); and (iv) results of outcomes.

Quality assessment

Two review authors (A. J. C. and A. G.) independently assessed the risk of bias of each included study in accordance with methods recommended by The Cochrane Collaboration (Higgins *et al.* 2011). The quality assessment was performed using the Review Manager program (Update Software, Oxford) for assessing the risk of bias in RCT (Higgins *et al.* 2011; Savovic *et al.* 2014). This technique sets seven criteria as indicators of the quality of trials according to the responses 'low risk', 'high risk' or 'unclear' to the following domains: (i) selection bias [i.a] random sequence generation and [i.b] allocation concealment; (ii) performance bias (blinding of participants and personnel); (iii) detection bias (blinding of outcome assessment); (iv) attrition bias (incomplete outcome data); (v) reporting bias (selective reporting); and (vi) detection attrition bias (incomplete outcome data), reporting bias (selective reporting) and other bias. Finally, authors resolved disagreements by consensus, and a third author (M. S.) was consulted to resolve disagreements when necessary.

Data analysis

For the data analysis, we used Review Manager (Update Software, Oxford) to calculate standardized mean differences (SMD), and confidence intervals (CI) were calculated for each study by means of *t* scores, number of participants and standard deviation (SD) (Thalheimer 2014) using Glass's method (Egger *et al.* 1997; Egger & Altman 2008) and the random-effects model. When the SD was unavailable, it was calculated from the standard error (SE; $SD = SE\sqrt{n}$).

Cohen's categories were used to evaluate the magnitude of the effect size, calculated according to the SMD statistic and considering scores of $d \geq |0.8|$ as a large effect, scores from $\geq |0.5|$ to $< |0.8|$ as medium, scores from $\geq |0.2|$ to $< |0.5|$ as small and scores $\geq |0.1|$ to $|0.2|$ as trivial (Cohen 1988).

Assessment of heterogeneity

The heterogeneity of the studies was assessed using Cochran's *Q*-statistic applied to the SMD (Higgins *et al.* 2003) and χ^2 test. The percentage of total variation across the studies due to heterogeneity was determined using I^2. The magnitude of the inconsistency was assessed as follows: small if $0 \leq I^2 \leq 25\%$, medium if $25\% < I^2 \leq 50\%$ and large if $I^2 > 50\%$ (Higgins & Thompson 2002).

Results

Study selection

After screening all 576 studies identified by the literature search strategy, 45 duplicates were removed, and it was determined that 487 did not meet the inclusion criteria. Thus, 44 potentially relevant studies were included in full text. Thirty-six studies were subsequently rejected, and the remaining eight RCTs were grouped, according to the content of the intervention, into aerobic exercise and yoga therapies (Fig. 1). Aerobic programmes included exercises like walking, jogging, swimming and dancing. Yoga programmes were less intense exercises and were related to the wellness of mind and body.

Participants

The systematic review included a total of 249 children diagnosed with ADHD. Subjects were diagnosed with ADHD by psychiatrists or psychologists by clinical or using standardized

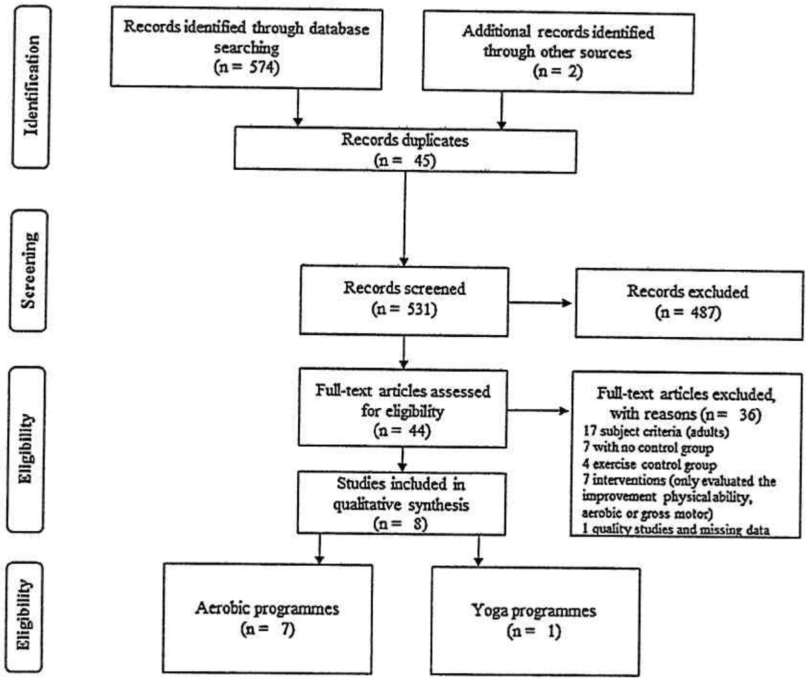

Figure 1. Flowchart for the selection of studies.

instruments such as DSM III-R (Tantillo *et al.* 2002; Mackune *et al.* 2003) and DSM-IV (Jensen & Kenny 2004; Kang *et al.* 2011; Chang *et al.* 2012; Verret *et al.* 2012; Pontifex *et al.* 2013). The mean age of children was 10.60 years (SD 1.22 years) (Table 1). Of these, 230 participated in aerobic exercises and 19 in yoga exercises. The average sample size of all groups was 31.13 subjects (Table 1); however, two studies included less than 10 children (Mackune *et al.* 2003; Jensen & Kenny 2004).

Study characteristics and interventions

The characteristics of the eight studies included in this review (Tantillo *et al.* 2002; Mackune *et al.* 2003; Jensen & Kenny 2004; Kang *et al.* 2011; Chang *et al.* 2012; Verret *et al.* 2012; Pontifex *et al.* 2013; Choi *et al.* 2015) are detailed in Table 1.

Aerobic programmes

Seven studies evaluated the effect of aerobic exercise in children with ADHD (Tantillo *et al.* 2002; Mackune *et al.* 2003; Kang *et al.* 2011; Chang *et al.* 2012; Verret *et al.* 2012; Pontifex *et al.* 2013; Choi *et al.* 2015). Table 1 summarizes the study characteristics. The mean duration of the interventions was around 5 weeks; the mean duration of sessions was 50 min, with an average frequency of two to three times per week. Intensity was monitored by a heart rate monitor in five studies (Mackune *et al.* 2003; Chang *et al.* 2012; Verret *et al.* 2012; Pontifex *et al.* 2013; Choi *et al.* 2015) and by VO_2peak in one study (Tantillo *et al.* 2002). The ranges of intensity were similar: 50–75% maximum heart rate and 65–75% of VO_2peak. Only one study did not report exercise intensity (Kang *et al.* 2011).

Yoga programmes

Only one yoga study met the inclusion criteria for children with ADHD (Jensen & Kenny 2004) and evaluated standard yogic practices and comprised respiratory, postural, relaxation and concentration training. The duration of the programme was one 60-min session a week for 20 weeks.

Methodological quality of studies

The overall quality of the studies that met the inclusion criteria is low; two studies that have quality indicators that are all 'low risk' or 'unclear' bias are considered as average quality (Chang *et al.* 2012; Choi *et al.* 2015), and the remaining six studies that have some quality indicators that are 'high risk' are considered as low quality (Tantillo *et al.* 2002; Mackune *et al.* 2003; Jensen & Kenny 2004; Kang *et al.* 2011; Verret *et al.* 2012; Pontifex *et al.* 2013). Table 2 and Supporting Information File 2 outline the risk of bias assessments in domains for the included studies.

Table 1. Characteristics of the studies included in the systematic review

Study	EG			CG			Intervention features					Diagnostic criteria
	n	Age, year (SD)	Type	*n*	Age, year (SD)	Type	Duration (weeks)	Frequency (Se/week)	Se duration (min)	Intensity (MHR) (%)	Adh (%)	ADHD
Aerobic programmes												
Tantillo and colleagues (2002)	18	10.02 (1.66)	Motor driven†	25	9.99 (1.55)	None	1	2	MET‡	65–75§	100	DSM III-R
Kang and colleagues (2011)	16	8.4 (0.9)	Running	16	8.6 (1.2)	Edu	6	2	90	NR	87.50	DSM IV
Chang and colleagues (2012)	20	10.45 (0.95)	Motor driven†	20	10.42 (0.87)	None	1	1	30	50–70¶	100	DSM IV
Verret and colleagues (2012)	10	9.1 (1.1)	Multi-sports	11	9.1 (1.1)	None	10	3	45	77	85.71	DSM IV
Mackune and colleagues (2003)	13	10.8 (1.9)	Running	6	11.2 (1.5)	None	5	5	55	50–75	100	DSM III-R
Pontifex and colleagues (2013)	20	9.46 (0.4)	Motor driven†	20	9.6 (0.9)	None	1	1	20	65–75	100	DSM IV
Choi and colleagues (2015)	13	15.8 (1.7)	Running sports	17	16.0 (1.2)	Edu	6	3	90	60	85.71	DSM IV
Yoga programmes												
Jensen and Kenny (2004)	11	10.63 (1.78)	Yoga	8	9.35 (1.70)	None	20	1	60	NR	73.68	DSM IV

Adh, adherence; CG, control group; Edu, education; EG, experimental group; MHR, maximum heart rate; None, no intervention; NR, not reported; SD, standard deviation; Se, session.
† Treadmills.
‡ Time required to complete the Maximal Exercise Test (MET).
§ VO_2peak.
¶ Heart rate reserve.

Support for judgments is provided in Supporting Information File 3. Only four studies reported a process of randomization (Jensen & Kenny 2004; Kang *et al.* 2011; Chang *et al.* 2012; Choi *et al.* 2015). Blinding is unknown in all studies, and this may be an important bias; a recent study showed that effective non-pharmacological treatments for ADHD are influenced significantly by the nature of the evaluator so that unblinded interventions are not effective (Sonuga-Barke *et al.* 2013). In one study (Mackune *et al.* 2003), the number of result data was insufficient. In four studies (Kang *et al.* 2011; Chang *et al.* 2012; Pontifex *et al.* 2013; Choi *et al.* 2015), other inconveniences that might pose a risk of serious bias is not found.

Adherence, dropouts and adverse effect

The adherence rate was high in all studies (>70%). Most studies reported no dropouts, but two informed about physical problems in the children (nausea and headache) (Kang *et al.* 2011; Choi *et al.* 2015).

Outcomes measures

There was much variability in outcomes measures and symptoms evaluated. The benefits, symptoms or problems that have been studied were (in frequency order) as follows: attention (Mackune *et al.* 2003; Jensen & Kenny 2004; Kang *et al.* 2011; Verret *et al.* 2012; Pontifex *et al.* 2013; Choi *et al.* 2015), impulsiveness (Tantillo *et al.* 2002; Jensen & Kenny 2004; Kang *et al.* 2011; Pontifex *et al.* 2013; Choi *et al.* 2015), hyperactivity (Jensen & Kenny 2004; Kang *et al.* 2011; Pontifex *et al.* 2013; Choi *et al.* 2015), anxiety (Tantillo *et al.* 2002; Jensen & Kenny 2004; Verret *et al.* 2012), executive function (Kang *et al.* 2011; Chang *et al.* 2012; Choi *et al.* 2015), social disorders (Jensen & Kenny 2004; Kang *et al.* 2011; Verret *et al.* 2012), behaviour disorders (Mackune *et al.* 2003; Verret *et al.* 2012), cognitive performance (Jensen & Kenny 2004; Pontifex *et al.* 2013), emotional disorders (Mackune *et al.* 2003; Jensen & Kenny 2004), somatic disorders (Jensen & Kenny 2004; Verret *et al.* 2012), aggressiveness (Verret *et al.* 2012), conduct (Mackune *et al.* 2003), depression (Verret *et al.* 2012), oppositional (Jensen & Kenny 2004) and sleep (Tantillo *et al.* 2002). The scales that had been more often used were Conners' Parent Rating Scale (CPRS) (Mackune *et al.* 2003; Jensen & Kenny 2004).

Summary of results (meta-analysis)

Figure 2 shows the SMD (95% CI) for each study grouped according to symptoms and/or problems. Results showed that

Table 2. Risk of bias summary: review authors' judgements about each risk of bias item for each included study

Study	Random sequence generation (selected bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Aerobic programmes							
Tantillo and colleagues (2002)	High risk	Unclear	Unclear	Unclear	Low risk	High risk	Unclear
Kang and colleagues (2011)	Low risk	Unclear	Unclear	Unclear	Low risk	High risk	Low risk
Chang and colleagues (2012)	Low risk	Unclear	Unclear	Unclear	Low risk	Low risk	Low risk
Verret and colleagues (2012)	Unclear	Unclear	Unclear	Unclear	Low risk	Unclear	High risk
Mackune and colleagues (2003)	High risk	Unclear	Unclear	Unclear	Unclear	High risk	High risk
Pontifex and colleagues (2013)	High risk	Unclear	Unclear	Unclear	Low risk	High risk	Low risk
Choi and colleagues (2015)	Low risk	Unclear	Unclear	Unclear	Low risk	Low risk	Low risk
Yoga programmes							
Jensen and Kenny (2004)	Low risk	Unclear	Unclear	Unclear	Low risk	High risk	High risk

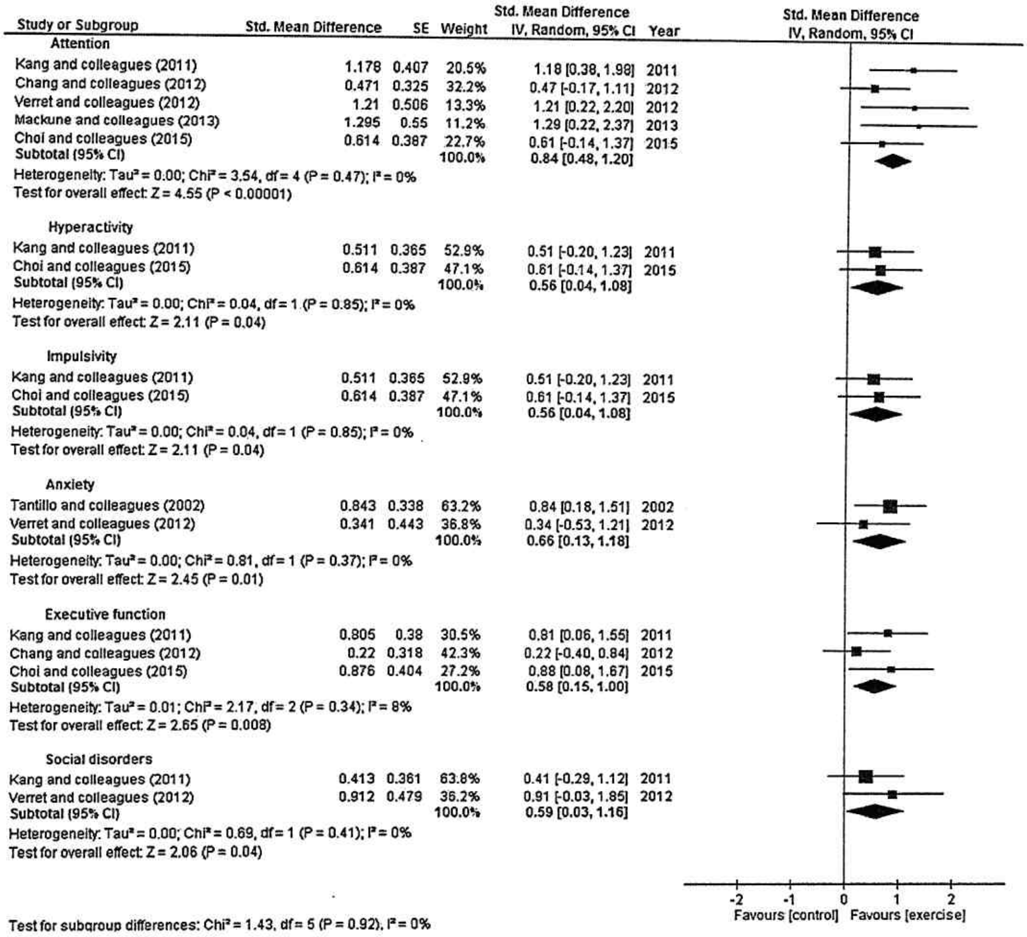

Figure 2. Effects of the aerobic exercise programmes on symptoms and/or problems.

aerobic exercise improved attention (SMD = 0.84, 95% CI, 0.48 to 1.20), hyperactivity (SMD = 0.56, 95% CI, 0.04 to 1.08), impulsivity (SMD = 0.56, 95% CI, 0.04 to 1.08), anxiety (SMD = 0.66, 95% CI, 0.13 to 1.18), executive function (SMD = 0.58, 95% CI, 0.15 to 1.00) and social disorders (SMD = 0.59, 95% CI, 0.03 to 1.16). No statistically significant within-group heterogeneity was found in any of the parameters or in the overall analysis ($\chi^2 = 1.43$; df = 5; $P = 0.92$; $I^2 = 0\%$).

Yoga study results showed that exercise improved anxious/shy ($P = 0.028$, Cohen's $d = 0.59$), hyperactivity ($P = 0.004$, Cohen's $d = 0.39$), impulsive/restless ($P = 0.008$, Cohen's $d = 0.73$), oppositional ($P = 0.003$, Cohen's $d = 0.77$), social problems ($P = 0.034$, Cohen's $d = 0.85$) and DSM-IV Total ($P = 0.024$, Cohen's $d = 0.1$).

Publication bias and sensitivity analysis

Finally, there was no significant publication bias for any of the outcome variables and the number of studies required, as evidenced by the visualization of funnel plot asymmetry and an Egger test ($P > 0.05$) (Supporting Information File 4). In addition, in the sensitivity analysis, with each study deleted from the model once, the results remained statistically significant across all deletions.

Discussion

To the best of our knowledge, the present paper is the first systematic review and meta-analysis of RCT examining the evidence for the effects of PE programmes in children and adolescents with ADHD. Overall, the findings of several RCTs reviewed show that aerobic exercise seems to reduce inattention, impulsivity or hyperactivity in children with ADHD, among others symptoms. Meanwhile, the evidence about the benefits of yoga was scarce because of the small number of articles retrieved. Most studies provide preliminary evidence of effectiveness of exercise interventions in improving both behavioural symptoms and neuropsychological function in children with ADHD. Given that these symptoms and/or problems persist from infancy to adulthood and that about 50% continue to meet the DSM-IV criteria as adults (Lara *et al.* 2009; Kessler *et al.* 2010), it is important to consider all strategies that could improve symptoms at early ages.

A recent systematic review reported the effectiveness of 30 min of PE in improving the executive functions of children with ADHD (Grassmann *et al.* 2014). Our data are consistent with these findings, reporting that executive function improves with aerobic exercise (SMD = 0.58). Other recent systematic reviews, in addition to the improvement of cognitive functions, reported improvements in measures of interference control, post-error slowing, set shifting, consistency in response speed, vigilance and impulsive control (Halperin *et al.* 2014). Exercise is probably beneficial for children with ADHD because of changes in dopamine levels and its release (Wigal *et al.* 2003; Chang *et al.* 2012). Thus, dopamine release during sports therapy helps improve attentive symptoms and decreases inattention symptoms (Kang *et al.* 2011). However, future studies should include long-term aerobic training to produce enhanced higher effects on executive functions.

It is even suggested that three or more sports, done over a long period of time, could improve symptoms of anxiety and depression in children with ADHD (Kiluk *et al.* 2009). Regarding our study, we observed that multi-sports (Verret *et al.* 2012; Choi *et al.* 2015) and running produce great improvements (Mackune *et al.* 2003; Kang *et al.* 2011; Choi *et al.* 2015). Therefore, it might be important to focus future studies on multi-sports and running to confirm these improvements. Most studies provide preliminary evidence of the effectiveness of exercise interventions in improving both behavioural symptoms and neuropsychological function in children with ADHD.

Aerobic programmes

Our findings are in accordance with previous qualitative reviews and recommendations for ADHD management in other populations (Gapin *et al.* 2011; Archer & Kostrzewa 2012; Berwid & Halperin 2012). These reviews suggest that exercise is an effective complement to medication to reduce behavioural impairments that interfere with learning and academic performance, even for children who are unresponsive to pharmacologic treatment or who want to seek alternative treatments (Gapin *et al.* 2011; Archer & Kostrzewa 2012). As has been noted, exercise programmes reduce ADHD symptoms and produce better long-term outcomes for these children (Berwid & Halperin 2012). Several RCTs included in this meta-analysis showed a reduction in impulsivity (Kang *et al.* 2011; Verret *et al.* 2012), which implies an improvement in this regard. A number of studies in children with ADHD show a high risk of developing depression (Biederman *et al.* 1998; Skirrow *et al.* 2009) and anxiety (Angold *et al.* 1999). Therefore, the inclusion of physical activity in the different treatments can be especially beneficial on mitigating several symptoms, such as mood, anxiety or deficits in executive control of these children (Kiluk *et al.* 2009). Our pooled effects showed that aerobic exercises improve anxiety (SMD = 0.66), executive function (SMD = 0.58) and impulsivity (SMD = 0.56). Besides, exercise can reduce the reaction time response tasks requiring a higher working memory capacity (Pontifex *et al.* 2009) and inattention (Mackune *et al.* 2003; Kang *et al.* 2011; Verret *et al.* 2012; Pontifex *et al.* 2013), as evidenced by our results (SMD = 0.84). In addition, aerobic exercise can be an adjunctive therapy with medication treatment for improving clinical symptoms, perseverative errors and brain activity (Choi *et al.* 2015). Therefore, it is observed that there is an obvious improvement in cognitive functioning, as well as social skills (Kang *et al.* 2011; Verret *et al.* 2012; Gomez-Pinilla & Hillman 2013).

Yoga programmes

Several studies have shown that alternative therapies such as yoga, massages or eurythmy are beneficial for children with ADHD (Majorek *et al.* 2004; Peck 2005; Haffner *et al.* 2006). Yoga includes a variety of poses, breath control, mental concentration and deep relaxation to positively affect mental states (Zipkin 1985). It also tends to promote self-control, attention and concentration, self-efficacy, body awareness and stress reduction (Peck 2005). The results of the RCTs included in the meta-analysis show substantial improvements such as reducing impulsivity, anxiety and social problems and a weak improvement in attention and hyperactivity (Jensen & Kenny 2004). Therefore, alternative therapies can be complementary to behavioral interventions for children with attention problems (Peck 2005). However, more RCTs are needed to determine the influence of this type of treatment in this population with ADHD.

Limitations

First, the number of RCT included was small, although their homogeneity is optimized by the stringency of the inclusion criteria. Second, the effects of the treatment were evaluated by unblinded raters, which could influence on the magnitude of the effect (Sonuga-Barke *et al.* 2013). Third, some studies did not specifically detail the type of exercise, duration and intensity of the activities. Further, most studies did not consider if participants performed some additional regular exercise, nor did they distinguish whether subjects were on some type of medication for their ADHD symptoms or stopped it during tests. Fourth, because of the short duration of the exercise interventions, we cannot predict the long-term impact on ADHD symptoms. Fifth, the present study did not take into account whether the exercise interventions were performed in a single session (acute effects) or long term (chronic); the group of studies can involve different impacts on neurobiological processes and therefore results. Sixth, overall, the quality of included studies ranged from low to moderate; however, we have not excluded any because of the small number of articles selected. Seventh, exercise settings were not mentioned in all the studies, and most of them did not report whether exercise programmes were supervised by graduates in sports science; therefore, this could affect the analysis of the effectiveness. Eighth, the strategic search was conducted only in five databases. Finally, aerobic exercises interventions were very heterogeneous regarding type, duration, frequency and intensity. Both of these characteristics of the programmes may influence the outcomes.

Finally, most studies did not specify the number and causes of dropouts.

Conclusions

This study appears to show that PE programmes (aerobic and yoga) weakly reduce several symptoms in children with ADHD. However, there is less evidence about the benefits of the yoga programmes. The meta-analysis suggests that short-term aerobic exercises (6–10 weeks), based on several aerobic interventions formats, reported a moderate to large effect on inattention, hyperactivity, impulsivity, anxiety, executive function and social disorders in children with ADHD. However, the results of this systematic review and meta-analysis should be understood with caution because of the small number of studies and the heterogeneity of their outcome measures. For this reason, more studies are required to obtain consistent clinically relevant conclusions.

Conflict of interests

There is no conflict of interest.

Key messages

- Physical exercise seems to be effective for mitigating symptoms and behavioural disorders in children with ADHD.
- The findings of several RCTs reviewed show that aerobic exercise seems to reduce inattention, impulsivity or hyperactivity in youth with ADHD, among other symptoms.
- ADHD symptoms seem to enhance in this population with short-term intervention.

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Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's web site.

Supplementary file 1. A sensitive search strategy for each individual database.

Supplementary file 2. Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies.

Supplementary file 3. Risk of bias summary: review authors' judgements about each risk of bias item for each included study.

Supplementary file 4. Funnel plot.