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A systematic review of acute exercise as a coadjuvant treatment of ADHD in young people

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Abstract

Background: There are studies that show preliminary evidence of the benefits of physical exercise for people with Attention Deficit Hyperactivity Disorder (ADHD). The objective of the research being reported here was to carry out a systematic review of articles relating to the effects that exercise sessions have on children and adolescents with this pathology. **Method:** The total sample of studies considered was 1,723, of which only 11 met the eligibility criteria. **Results:** The research included in this review showed that children with ADHD undertaking exercise experienced improvements in their characteristic symptoms, mainly attention deficit and hyperactivity, in comparison to other sedentary tasks such as watching a video. Five minutes of jumping or thirty minutes on a treadmill or static bicycle were enough to produce appreciable improvements in inhibitory control or in cognitive and executive functions. Benefits following exercise were also seen in other aspects such as reaction times and preparation for response, motor skills or brain activity. **Conclusion:** The findings make us optimistic that in the future physical exercise may become an alternative, or at least an effective complement, to the pharmacological treatments currently used for this pathology.

Keywords: ADHD, exercise, physical activity, children, youth.

Resumen

Revisión sistemática del ejercicio agudo como tratamiento coadyuvante del TDAH en jóvenes. **Antecedentes:** existen estudios que muestran evidencia preliminar acerca de los beneficios de la práctica de ejercicio físico en personas con Trastorno por Déficit de Atención e Hiperactividad (TDAH). El objetivo de esta investigación es realizar una revisión sistemática de los efectos que tiene una sesión de ejercicio en niños y adolescentes con esta patología. **Método:** la muestra total de estudios fue de 1.723, de los cuales solo 11 cumplieron los criterios de elegibilidad. **Resultados:** las investigaciones incluidas en esta revisión muestran que los niños/as con TDAH experimentan mejoras en sus síntomas característicos, principalmente déficit de atención e hiperactividad, en comparación a otro tipo de tareas sedentarias como la visualización de un vídeo. Desde 5 minutos de saltos, hasta 30 de cinta o bicicleta estática, fueron suficientes para apreciar mejoras en el control inhibitorio o en las funciones cognitivas y ejecutivas. También se apreciaron beneficios después del ejercicio en otros aspectos como el tiempo de reacción y la preparación para la respuesta, las habilidades motoras o la actividad cerebral. **Conclusión:** los hallazgos encontrados nos permiten ser optimistas y pensar que en el futuro el ejercicio físico puede convertirse en una alternativa, o al menos en un complemento eficaz, al tratamiento farmacológico utilizado para tratar esta patología.

Palabras clave: TDAH, ejercicio, actividad física, niños, jóvenes.

The main characteristic of Attention Deficit Hyperactivity Disorder (ADHD) is a persistent pattern of lack of attention, hyperactivity and impulsive behaviour, which appears more frequently and more markedly than in unaffected individuals at the same level of development. These symptoms are often accompanied by other comorbid disorders. These range from mental features such as inhibitory control, depression or anxiety, through behavioural and learning disorders, to social interaction and lesser physical abilities than those of control peers of the same age (American Psychiatric Association, 2013). All of these aspects lead this pathology to be one of the primary causes of children's failure at school (Rappley, 2005).

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At the present time, ADHD is the most frequently diagnosed neuro-behavioural disorder in childhood. It has a prevalence of 5% of the school-age population and 2.5% of adults, although percentages may vary depending on the region studied (Polanczyk, De Lima, Horta, Biederman, & Rohde, 2007).

The aetiology of this disorder has a considerable genetic component, certain studies highlighting that ADHD runs in families and is inheritable. Genetic contributions increase the probability of ADHD but do not determine the presence of the disorder (Thompson et al., 2009; Froehlich et al., 2011; Johnston, Mash, Miller, & Ninowski, 2012; Oudin et al., 2019). Recent findings suggest that it contributes to the development of abnormal brain networks related to cognition, attention, emotion and sensorimotor functions (Cortese, 2012). There are structural and functional brain alterations, individuals with ADHD showing a significant reduction in grey matter volumes (Nakao, Radua, Rubia, & Mataix-Cols, 2011), global thinning of the cortex, reductions in the density of the dorsolateral prefrontal cortex, a lessening of surface area, and decreased cortical folding (Shaw et al., 2006); At a molecular level, ADHD has been linked to alterations in the regulation of the main catecholamine systems. The dopaminergic, adrenergic, serotoninergic and cholinergic pathways show alterations linked with an inhibition of executive control, including the cognitive processes needed to perform novel or complex tasks, physical behaviours, and the control of unwanted impulses (Sharma & Couture, 2014). In this review, the cognitive functions were considered as a whole, rather than following the theory distinguishing seven dependent measures of the cognitive (Miyake et al., 2000)

Medication is the prime treatment for ADHD, proving effective for most children, with the usual protocol being focused on restoring levels of the concentrations of dopamine, norepinephrine and serotonin. However, it would appear that the use of stimulant drugs sometimes leads to side effects in children. such as loss of appetite, sleep problems or changes in behaviour (National Collaborating Centre for Mental Health, 2018). Hence, because of these potential comorbid symptoms, research has focused on novel approaches with non-pharmacological treatment protocols acting as auxiliaries to medication, in order to reduce the doses administered and provide a better environment for the children's health. The therapeutic potential of antioxidant compounds combined with exercise as an ancillary treatment for ADHD was discussed by Juárez-Olguín, Calderón-Guzmán, Hernández-García, and Barragán-Mejía (2016). Moreover, Gapin and Etnier (2014) concluded that physical exercise combined with medication is more effective, rather than medication alone. Both intense and steady regular exercise interventions have shown positive effects on most of the changes in these patients (Chang, Hung, Huang, Hatfield, & Hung, 2014; Chang, Liu, Yu, & Lee, 2012; Choi, Han, Kang, Jung, & Renshaw, 2015; Pan et al., 2014; Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013) physical exercise is able to mimic the functions of medicines to modulate the regulation of the main neurotransmitters, enhancing levels of serotonin, dopamine and norepinephrine in the brain (Ma, 2008). Recent research on this topic suggests that exercise can play an important role in the management of ADHD symptoms by stimulating neurobiological processes and consequently improving executive functions (Gapin, Labban, & Etnier, 2011; Verret, Guay, Berthiaume, Gardiner, & Béliveau, 2012). It should be understood that executive functions are complex mental activities, necessary for planning, organizing, guiding, reviewing, regularizing and evaluating the behaviour necessary to adapt effectively to the environment and to achieve goals (Eisenberg & Zhou, 2016).

Regular exercise is able to promote the release of neurotransmitters that coincide with those involved in regulating mental processes. This may thus be the explanation why physical exercise produces beneficial effects in children with the condition (Drobnic et al., 2013). Similarly, it would appear that a single session of moderate exercise can enhance cognition, attention and response inhibition in youths with ADHD (Chang et al., 2012; Chuang, Tsai, Chang, Huang, & Hung, 2015; Gawrilow, Stadler, Langguth, Naumann, & Boeck, 2016; Huang et al., 2018; Ludyga et al., 2018; Piepmeier et al., 2015; Pontifex et al., 2013; Silva et al., 2015; Tantillo, Kesick, Hynd, & Dishman, 2002; Wigal et al., 2003). As an example, Pontifex et al. (2013) described improvements in teenagers with ADHD in a reading and mathematics test after twenty minutes of running. Chang et al. (2012) evaluated the executive functions and selective attention based on Wisconsin and Stroop test, respectively. The authors reported an effect size in exercise group to Wisconsin test (ES range from .34 to -.74) and to Stroop test (ES range from -.28 to -1.26).

At the present time evidence has been provided in the scientific literature to support this theory, with a number of researchers having recorded interesting findings. Reviews have been published that offer an excellent overview of changes in attention, hyperactivity and impulsivity that exercise programmes can trigger in young people and adults with ADHD (Neudecker, Mewes, Reimers, & Woll, 2015; Wigal, Emmerson, Gehricke, & Galassetti, 2013). However, the present systematic review adumbrates the very latest results in this area, focusing exclusively on studies that investigated the effects of intense exercise on young people clinically diagnosed with ADHD in relation to health outcomes.

Method

Study design

The search for studies was carried out in accordance with the statements of PRISMA-P (Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols).

Sample studies

The final literature search was conducted in October 2019. The trawl for articles was carried out using the electronic databases PubMed, Scopus and Cochrane. No time limits were imposed on the studies. The electronic search was undertaken by two reviewers (RV and HO), who independently assessed the eligibility of each article. The search terms used are shown in Table 1. Searches were limited to English language articles. The first step was for titles and abstracts of any articles identified to be analysed by the two reviewers. Once a first trawl had been made on the basis of this criterion, the reviewers examined the full texts of the articles still remaining in order to evaluate their possible inclusion in the systematic review. Any disagreements between reviewers were settled through discussion with a third reviewer (IC). Figure 1 provides a diagram showing the entire procedure for selecting studies.

In performing the search, the same procedure was followed in all cases. In order to ensure that as many results as possible were obtained, the search was conducted in English. The nominal groups chosen were: "ADHD OR attention deficit hyperactivity disorder", "Hyperactivity" and "Impulsivity". These were cross-referenced

Table 1
PubMed/Medline Search Strategy (Literature Search performed: October 30, 2019)

	PubMed/MEDLINE
#1	"Attention Deficit Disorders with Hyperactivity"[Mesh] OR ADHD[Mesh]
#2	"Attention Deficit Disorders with Hyperactivity"[tiab] OR ADHD[tiab] OR Hyperactivity[tiab] OR Impulsivity[tiab]
#3	#1 OR #2
#4	"Physical Activity"[Mesh] OR Exercise[Mesh]
#5	"Physical Activity"[tiab] OR Exercise[tiab]
#6	#3 OR #4
#7	#3 AND #6

with "physical activity" and "exercise" using the Boolean operator AND.

The search as described above yielded a total of 1,723 results: 1,156 in PubMed, 401 in Scopus, 93 in Cochrane and 2 records were identified reviewing references cited in selected retrieved articles.

Search for Studies: Inclusion Criteria

The following criteria were taken into account for the selection of studies:

- Type of study: only prospective interventional studies and trials.
- Participants were to be children and adolescents under eighteen years of age who undertook a session of intense physical exercise, compared with a control group that did not exercise.
- Reviews were excluded.
- All participants had to have been diagnosed clinically as having ADHD.

A total of 1,723 articles were found (Figure 1). Of these, 20 were eliminated because they were duplicates. This yielded 1,703 potentially relevant items, of which 255 were discarded after the title and summary had been read. Of the 1,448 studies remaining, 1,437 were excluded on the basis of the criteria for inclusion and

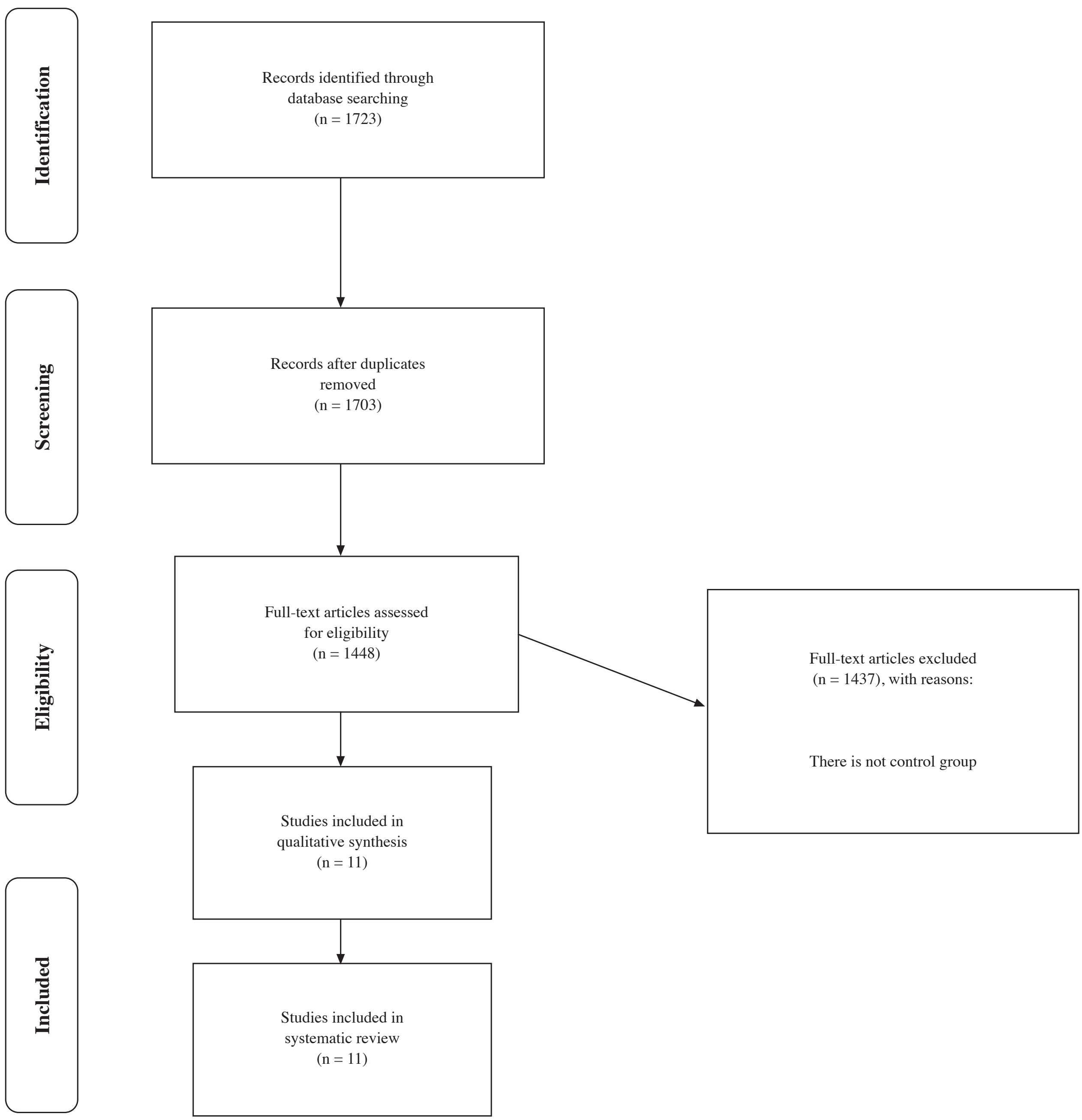

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram

exclusion. In the end, a total of 11 items were deemed eligible for the current review.

Data analysis

In order to assign appropriate weightings to the results obtained by the various studies included, each item was individually evaluated (Higgins & Green, 2011). Several aspects were taken into account: in respect of selection, the generation and concealment of the allocation sequence; with regard to procedure, the blinding of subjects and researchers; relative to detection, the blinding of evaluators of results; in terms of wastage, incomplete result data; and in respect of notification, its selective nature relative to outcomes. Each aspect was assessed as "low risk", "high risk" or "unclear risk". The results of this evaluation are shown in Table 3.

Data synthesis

Owing to the heterogeneity of studies in respect of exercise protocol, study design, and outcomes of interest, it was not possible to combine their findings into a meta-analysis. The results of this systematic review were synthesised to indicate the significance and direction of the associations observed, each study being summarized in the tables. Information on the characteristics of items was extracted so as to provide a description of studies and populations.

Results

Table 2 summarizes the characteristics of the 11 studies analysed in the preparation of this systematic review. The sample sizes of the intervention groups ranged from n = 10 (Wigal et al., 2003) to n = 52 (Huang et al., 2018). All the studies included mostly male participants, a characteristic largely conditioned by the difference between the sexes in numbers of cases diagnosed: out of every three children found to have ADHD only one is a girl (National Collaborating Centre for Mental Health, 2018). Hence, 50% of the studies included only male participants. There were no large differences in the criteria for inclusion or exclusion among the studies. In all but three (Huang et al., 2018; Pontifex et al., 2013; Silva et al., 2015) the taking of medicines was permitted, participants in those three exceptional instances suspending their usual pharmacological treatments throughout the experiment. In none of the studies did participants present associated comorbid disorders. All subjects were able to perform physical exercise. The age ranges in the various studies ran from 7 to 16 years. Finally, the main aspects evaluated were attention, cognitive and executive functions, and inhibitory control.

The length of the intensive exercise sessions ranged between five minutes (Gawrilow et al., 2016; Silva et al., 2015; Tantillo et al., 2002), and thirty minutes (Chang et al., 2012; Chuang et al., 2015; Huang et al., 2018; Piepmeier et al., 2015; Wigal et al., 2003). Similarly, the intensity of exercise in several studies was moderate, between 50% and 75% of the maximum heart rate (HR_{max}) of the participants, whilst other opted for strong intensity (Benzing et al., 2018; Gawrilow et al., 2016; Medina et al., 2010; Silva et al., 2015; Tantillo et al., 2002; Wigal et al., 2003). As for the type of physical exercise involved, subjects took part in running (Chang et al., 2012; Chuang et al., 2015; Huang et al., 2018; Pontifex et al., 2013; Silva et al., 2015; Tantillo et al., 2002), in cycling (Ludyga et al., 2018; Piepmeier et al., 2015; Wigal et al., 2003), and in jumping (Gawrilow et al., 2016) as the strong exercise used.

Gawrilow et al. (2016) reported an improvement of 17% in inhibitory responses and a 28% reduction in the number of errors after five minutes of jumping. Chang et al. (2012) showed that thirty minutes of running at between 50% and 70% of HR_{max} in forty youths with ADHD had comparable effects on executive functioning to watching running-related video. Both groups showed a significantly greater inhibition in their responses. However, the size of the effect was greater in the group taking exercise (d = -1.26 versus -.58). These results are in agreement with Benzing et al. (2018), who found that completing a concentrated exergaming activity of moderate to vigorous intensity for at least fourteen minutes had significant beneficial effects on reaction times in inhibition and switching, but not on accuracy or visual working memory performance. The results of this study suggested that intense physical activity has a mediating role in executive functions, especially cognitive function (Benzing et al., 2018).

Chuang et al. (2015) described how thirty minutes of moderate exercise at 60% of HR_{max} on a treadmill, as opposed to the same amount of time watching a video, affected a go or no-go task performed by sixteen boys and three girls with ADHD, in a randomized cross-over design. Work by Hung et al. (2013) involved an assessment test requiring inhibition in children with ADHD so as to maintain their response to specific stimuli. Briefly, their task comprised pressing a button when a given shape appeared on a screen, but not doing so when a different shape was displayed. This study showed shorter reaction times after exercise in comparison with those from the video-watching session. Similarly, attention processes also improved significantly.

The main objective of Huang et al. (2018) was to investigate the effects of thirty minutes of moderate-intensity running on brain activity as shown by electroencephalography. Children with ADHD exhibited a significantly lower theta-beta ratio in comparison with a resting control group (Monastra, 2005). While other studies indicate that around the 90% of patients diagnosed with ADHD exhibit elevated theta/beta power ratios over frontal and central midline cortical regions, while only 10% of them exhibit a lower theta/beta ratios, primarily in these same regions, which would result from a neurodevelopmentally immature cortical underarousal (Cortese, 2012; Monastra, 2008).

The most recent study included was work by Ludyga et al. (2018). The main outcomes assessed in this research were cognitive flexibility and the variability of the heart rate in sixteen subjects with ADHD after twenty minutes of cycling at moderate intensity or watching a video related to sports activities. The results indicated that performance in a task involving choices alternatives was better among those exercising than those remaining inactive. Similarly, these authors showed that parasympathetic responses decreased more than did sympathetic components, on the basis of an increased low-frequency to high-frequency ratio after aerobic exercise. Likewise, Piepmeier et al. (2015) described an improvement in cognitive function, evinced in a faster time to perform the Stroop task after thirty minutes of cycling at a moderate intensity in comparison with controls.

On similar lines, Pontifex et al. (2013), observed higher accuracy of responses in reading and arithmetical tasks related to inhibitory aspects of cognitive control in twenty subjects with ADHD after a twenty-minute session of running at a moderate intensity in comparison with controls not exercising but undertaking a reading task. Likewise, children with ADHD exhibited selective enhancements in regulatory processes as compared with reading task participants.

Silva et al. (2015) showed that five minutes of vigorous intensity running by fourteen youths increased their concentration by 30%. In comparison with a non-exercising group their improvement was 40%.

Tantillo et al. (2002) explored the rate of spontaneous eye blinking and the acoustic startle eye blink response (ASER) though electromyography (EMG) after maximum and sub-maximum intensity exercise in boys and girls with ADHD, comparing them

Table 2
Characteristics of the studies included

Authors	Participants		Age M(SD)	Exercise protocol	Diagnosed	Outcomes measures	Results
	N	S					
Benzing (2018)	24 (EG) 22 (CG)	♂ ♂	AR 8-12 10.5(1.35) AR 8-12 10.5(1.41)	Play 15' (65-79% HR_{max})	International Classification of Disease (ICD-10)	Ejecutive functions	Significant beneficial effects on reaction times in inhibition and switching, but not on accuracy or visual working memory performance
Chang (2012)	20 (EG) 20 (CG)	18♂ 2♀ 19♂ 1♀	AR 8-15 10.4(.87) AR 8-15 10.4(.90)	Run 30' (50-70% HR_{max})	Diagnostic and Statistical Manual of Mental Disorders (DSM-4)	Ejecutive functions	WCST and Stroop Color-Word scores were improved in the EG compared with pre-test
Chuang (2015)	19	16♂ 3♀	AR 8-12 9.42(1.38)	Run 30' (60% HR_{max})	–	Reaction time and response preparation	A shorter reaction time and smaller contingent negative variation (CNV) 2 amplitude following exercise
Gawrilow (2016)	47	♂	AR 8.3 –13.6 10.4(1.5)	Jump 5' (-)	International Classification of Disease (ICD-10)	Cognitive functions Inhibitory control	17% improvement in the inhibitory response and reduction of 28% of the errors number
Huang (2018)	24 (EG) 28 (CG)	♂ ♂	AR 7-12 9.54(1.59) A.R 7-12 9.96(1.11)	Run 30' (65-75% HR_{max})	Diagnostic and Statistical Manual of Mental Disorders (DSM-4)	Brain activity	The theta/beta ratio only decreased after acute exercise in the EG
Ludyga (2018)	16 (EG) 18 (CG)	11♂ 5♀ 11 ♂ 7♀	AR 11-16 12.8(1.8) AR 11-16 13.5(1.3)	Cycling 20' (65-70% HR_{max})	Diagnostic and Statistical Manual of Mental Disorders (DSM-5)	Cognitive flexibility Heart rate	Exercise causes benefits for cognitive flexibility in EG and CG, due in part to parasympathetic abstinence.
Piepmeier (2015)	14 (EG) 18 (CG)	9♂ 5♀ 7♂ 11♀	AR - 10.8(2.27)	Cycling 30' (62-72% HR_{max})	Diagnostic and Statistical Manual of Mental Disorders (DSM-5)	Cognitive performance	EG and CG realize benefits in speed of processing and inhibitory control post exercise, but none in planning or set shifting
Pontifex (2013)	20 (EG) 20 (CG)	14 ♂ 6 ♀ 14 ♂ 6 ♀	AR 8-12 9.5(.5) AR 8-12 9.8(.1)	Run 20' (83-87% HR_{max})	Diagnostic and Statistical Manual of Mental Disorders (DSM-4)	Inhibitory control	Improvement of 6% response accuracy
Silva (2015)	28 ADHD: 14 EG; 28 Without ADHD 14 EG;	14 CG ♂ 14 CG ♂	AR 10-16	Run 5' (-)	–	Attention	EG-EF + 30% y 40% more attention than EG Y CG-EF, respectively.
Tantillo (2002)	18 (EG): 25 (CG):	10♂ 8♀ 11♂ 14♀	AR 8-12 10.0(1.66) AR 8-12 9.99(1.56)	Exercise 5-25' (65-75% VO2max)	Diagnostic and Statistical Manual of Mental Disorders (DSM-3)	Brain activity Motor skills	Increase in blink frequency (*d*=.86), decrease in ASERlatency (*d*=-1.14) and improved MIB (*d*=1.70) after maximum test in children; Increase in ASERamplitude (*d*=.60) and decrease in $ASER_l$atency (*d*=-1.23) after the submaximal test in girls
Wigal (2003)	10 (EG) 8 (CG)	♂ ♂	AR 7-10 8.4(.4) AR 7-11 8.6(.5)	Cycling 30' (10 bouts for 2' with 1' of rest) (30-85% VO2 max)	–	Physiological response	Mean plasma levels of norepinephrine rose in both groups, with a greater increase in CG; Dopamine levels did not change in EG compared to a significant improvement in CG

Note: N= number of subjects; S, sex: ♂ - male; ♀ - female; AR= age range; M= mean; SD= standard deviation; d= Cohen's effect size; '= minutes; EG= experimental group; EF= exercise physical; CG= control group; += improvement; WCST= Wisconsin Card Sorting Test; ASER= acoustic startle eye blink response; HR_{max}= maximum heart rate; -= information not provided in the original articles

Table 3
Evaluation of the risk of bias of the included studies

Studies	Generation of the sequence	Hiding the allocation sequence	Blinding of participants and staff	Blinding of the evaluators	Incomplete outcome data	Selective notification of outcomes
Benzing et al (2018)	Unclear	Unclear	Hight	Unclear	Low	High
Chang et al. (2012)	Unclear	Unclear	High	Unclear	Low	Low
Chuang et al. (2015)	Unclear	Unclear	High	Unclear	Low	Unclear
Gawrilow et al. (2013)	Unclear	Unclear	High	Unclear	Low	Low
Huang et al. (2018)	Unclear	Unclear	High	Unclear	Low	Unclear
Ludyga et al. (2018)	Unclear	Unclear	High	Unclear	Low	Low
Piepmeier et al. (2015)	Unclear	Unclear	High	Unclear	Low	Low
Pontifex et al. (2013)	Unclear	Unclear	High	Unclear	Low	Low
Silva et al. (2015)	Unclear	Unclear	High	Unclear	Low	Low
Tantillo et al. (2002)	Unclear	Unclear	High	Unclear	Low	Low
Wigal et al. (2003)	Unclear	Unclear	High	Unclear	Low	Unclear

with a matched control group formed of healthy individuals (n = 25). This study investigated cerebral dopaminergic activity and motor impersistence. Boys showed a significantly higher blinking rate, lower ASER latency and greater motor impersistence after a maximum exercise test (VO_{2peak}), as compared to submaximal exercise (60% to 75% VO_{2peak}). However, girls performed significantly better in ASER amplitude and latency after the submaximal test.

In another piece of work (Wigal et al., 2003) studied catecholamine levels in a group of ten boys diagnosed with ADHD and eight matched controls. Subjects carried out interval training consisting of ten sessions, each of two minutes with a one-minute rest on a cycle ergometer. Epinephrine (EPI) and norepinephrine (NE) increased significantly in both groups of adolescents, but the controls showed a two-fold higher level of NE. Moreover, dopamine (DA) did not increase in the subjects with ADHD.

Discussion

ADHD is one of the most commonly diagnosed and treated psychiatric disorders in childhood, with rates having increased significantly (American Psychiatric Association, 2013; Rucklidge, Eggleston, Johnstone, Darling, & Frampton, 2018). The present systematic review suggests that intense exercise yields benefits for the main characteristics found in children with ADHD, such as lack of attention, hyperactivity and impulsive behaviours. The articles showed considerable variability in their outcomes and the tests chosen, which made the data unsuitable for meta-analyses. Thus, the general paucity of reporting led to downgrading of the quality of evidence on the basis of risk of bias for outcomes classed as low or moderate.

The main treatment for ADHD is based on pharmacological therapy, especially the use of psychostimulants, such as methylphenidate (Carriedo, 2014). However, this medicine is not free of side effects, sometimes leading parents to reject its use (National Collaborating Centre for Mental Health, 2018). With the aim of proposing alternatives to the exclusive use of this drug, various pieces of current literature have concluded that exercise acts as an auxiliary to pharmacological treatment (Bhagia, Koplin, & Halldner-Henriksson, 2017; Miranda, Fernández, & Rosel, 2006). With regard to this, Medina et al. (2010) and Pontifex et al. (2013), observed some benefits in children with ADHD that indicated there were cognitive improvements after a session of strong exercise even when there was methylphenidate treatment. The present findings provide further evidence that executive functions are enhanced after ten to fifteen minutes of aerobic exercise in childhood (Chang et al., 2012; Ludyga, Gerber, Brand, Holsboer-Trachsler, & Pühse, 2016; Ludyga et al., 2018). In particular, improvements have been reported in inhibitory control and attention resources (stimuli and processing speed), after a single twenty-minute session of intense exercise in children with and without ADHD (Pontifex et al., 2013). These two variables are critical among the cognitive abilities that are a part of the executive functions. A plausible hypothesis for explaining these results relates to an increase in the inhibitory response speed after intense exercise (Chuang et al., 2015; Ludyga et al., 2018). In brief, strong exercise particularly benefited inhibition-related executive function in the ADHD population, consequently enhancing scholastic performance in all children Chang et al. (2012) and Wigal et al. (2003). Furthermore, concentration is also improved in this population by five minutes of intense exercise, matching the results found in healthy participants. This can be explained by the secretion of catecholamines, such as noradrenaline (Silva et al., 2015). However, this hypothesis implies a requirement for further studies including an assessment of the duration of this effect. In fact, various other studies showed no benefits with regard to planning or establishing mental changes, either in adolescents with ADHD (Chang et al., 2014) or those not suffering from ADHD (Piepmeier et al., 2015). Regarding the visualization of the acute exercise video, in contrast to Chuang et al. (2015) findings, Hung et al. (2013) detected that there is a higher response speed after viewing the video.

In relation to the motor behaviours of children and adolescents with ADHD, Huang et al. (2018) provided preliminary evidence that thirty minutes of strong exercise could influence the cortical sites which typically exhibit deviance. Moreover, these authors observed a lower score for static and dynamic balance in the ADHD group, as compared to the control group. This result supported previous research of ADHD motor symptomology, highlighting the possibility of motor impairments as a feature of this disorder (Pitcher, Piek, & Hay, 2003). In relation to emotional factors, hypo-arousal is a characteristic commonly observed in this grouping that is regulated by intense exercise. Gawrilow et al. (2016) found that adolescents who were more physically active showed less depression in the evening, especially those who displaying hyperactivity. This comorbid anxiety affects the manifestation of ADHD (Rodríguez, González-Castro, García, Núñez, & Álvarez, 2014).

Finally, a field of interest for further exploration would be the relationship between the natural environment and exercise. This would investigate the influence of strong exercise in a natural environment, such as running or cycling, on executive functions (Gapin et al., 2011; Taylor & Kuo, 2009).

The present review provides evidence that intense exercise improves executive functions among youngsters with ADHD. This result is supported by research in which active children were shown to have a greater cognitive capacity and more developed brain structure than those remaining inactive (Ortega et al., 2017). In fact, the main regions affected by strong exercise correspond to those related to executive functions, and so to cognitive aspects like inhibition, attention or response speed, which are altered in children with ADHD. These findings suggest a non-invasive alternative for children who suffer from this disorder, although further research is needed to investigate how strong exercise relates to executive function.

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