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A Narrative Review of the Effect of Sport and Exercise on ADHD Symptomatology in Young People with ADHD

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Abstract

Attention Deficit Hyperactivity Disorder (ADHD) is a common neurodevelopmental condition with community prevalence globally of 2%-7% (M=5%). Clinicians are routinely encouraged to explain to children and young people the benefits of a healthy lifestyle, including exercise. Exercise has been proposed as a safe and low-cost adjunctive approach for ADHD and is reported to be accompanied by positive effects on several aspects of executive functioning. The aim of this narrative review was to synthesise the contemporary Randomised-Control Trial [RCT] studies that examine the effect of sport, physical activity and movement on executive functioning in children and adolescents with ADHD. The results identified three RCT meta-analyses and findings showed that children and adolescents with lower baseline cognitive performance demonstrated greater improvements in functioning after physical activity interventions, particularly for tasks with higher executive function demands, where baseline performance reaches an optimal level. Findings suggest that 10 minutes-20 minutes of acute moderate-high intensity exercise interventions (cycling/running) appeared to have positive effects on indices of inhibitory control. Preliminary evidence suggests that as little as 5 minutes of jumping exercises improved inhibitory control. 60-80 minutes of moderately intense, repeated (chronic) exercise appeared to demonstrate the greatest beneficial impact on selection attention. There is also some evidence to suggest that exercise with progressively increasing cognitive demands may have positive effects for children with ADHD, specifically in terms of improving cognitive flexibility. Further large-scale clinical trials are needed to confirm the positive effects of physical exercise on cognitive functioning in children with ADHD

Keywords: ADHD; Physical activity; Adolescents; Sports and exercise;

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Introduction

TAttention Deficit Hyperactivity Disorder (ADHD) is a neurodevelopmental condition that manifests in childhood and continues throughout an individual's life [1]. People with the condition present with numerous cognitive, emotional and behavioural challenges [2]. The core features of ADHD are a persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development as characterised by (i) inattention; and/or (ii) hyperactivity. These symptoms should present prior to the age of 12 years in two or more settings, interfere with quality of functioning and not occur exclusively in the context of an acute psychotic condition or be better explained by another mental disorder (DSM-5; 2013).

The current evidence-based treatment approaches for neurodevelopmental disorders generally seek to alleviate core behavioural symptoms (Ismail & Shapiro, 2019) and informs the National Institute for Health and Care Excellent (NICE) guidelines in the United Kingdom (UK). For children and young people, parent-training is the first line treatment recommendation for ADHD, and medication is recommended if significant impairment maintain despite environmental modifications. Clinicians are also encouraged to explain to children and young people the benefits of a healthy lifestyle, including exercise (NICE NG97, 2018).

Young people with ADHD may also have high levels of co-morbidity including attachment difficulties, developmental trauma, learning difficulties and additional neurodevelopment conditions including autism spectrum disorder [3]. Given that some children and young people with ADHD may report a reluctance to commence long-term medication use and [parenting treatment in some contexts may be challenging] reviewing alternative treatment methods is important. For example, there is emerging evidence

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from Randomised Control Trials (RCTs) with young people with ADHD that support sport, physical activity or movement as an effective, non-pharmaceutical treatment [4]. This evidence argues that physical activity can impact neural (PS300 response), cognitive (executive functioning, working memory and response inhibition) and social (relationships) factors that underpin the challenges for children with ADHD. Physical activity has been shown to positively effect cognitive and executive functioning factors such as working memory, inhibition, attention-switching, cognitive flexibility and fluency in children and adolescents with ADHD [4]. Moreover, the typical low baseline executive function ability in those with ADHD likely translates into an increased adaptation reserve and an absence of ceiling effects. Ishihara et al. found support for this claim by pooling meta-analysis findings which showed that children and adolescents with lower (than the population mean) baseline executive functioning performance demonstrated greater improvements in functioning after physical activity interventions [5]. Therefore, the efficacy of exercise interventions appears to increase as a function of baseline executive functioning.

Neurophysiological outcomes

Neuroscientific approaches in research with ADHD populations suggest that neural changes occur during and following exercise [6]. One important neural index is the P300 latency, which is an index for cognitive processing speeds and P300 amplitudes also reflect the deliberate allocation of attentional resources and working memory [7]. These factors are likely to impact both behaviour and core symptoms (impulse, attentional and emotional control) of ADHD. Research shows that physical activity results in a reduced amplitude and/or delayed latency of the P300 component in event-related potentials for young people with ADHD [6,8]. These neural changes are likely to impact both behaviour and core symptoms (impulse, attentional and emotional control) of ADHD.

There is also evidence from research within the general population which suggests that an increase in central arousal (e.g., from physical activity) is associated with increases in fronto-striatal neurotransmitters such as dopamine, epinephrine, norepinephrine and serotonin [9,10]. ADHD populations tend to present with hypoactivity in dopaminergic and noradrenergic systems, which are associated with attention and executive impairments [11,12]. Therefore, the neurophysiological mechanisms that underpin ADHD challenges may be compensated by the neurophysiological changes that occur as a consequence of physical activity or movement. Research has also found that exercise can also compensate for the dysregulation of catecholamine levels in ADHD and improve both cognitive and behavioural or social functioning. In a similar way, exercise might compensate for dysregulated catecholamine levels in ADHD and thereby improve cognitive and behavioural functioning [13].

Social-cognitive outcomes

The Executive Functioning (EF) challenges associated with ADHD can present challenges with time-management, organisation, planning and working memory [14]. Researchers have suggested that a deficit in working memory capacity is the primary mechanism underlying these EF challenges. Working memory deficits could further explain behavioural social challenges related to impulse control, co-operating or collaborating with others, social decoding in dynamic situations and delaying gratification or the tolerance of distress [15].

The social cognitive challenges associated with ADHD typically relate to challenges maintaining relationships and prioritising or managing different social-cognitive demands [16]. Sonuga-Barke suggest that deficient reward mechanisms may explain these challenges in that those with ADHD require contingent and continuous rewards that are frequently experienced. From this perspective it is assumed that those with ADHD need salient reinforcement to maintain motivation and performance in comparison to matched controls. The Cognitive Energetic Model (CEM) suggests that information processing efficiency is a consequence of the interaction of attention with state factors (adjusted effort and arousal) and executive functioning ability. The CEM model underlies the social-cognitive mechanisms of ADHD deficits in that people with the condition experience deficits information processing efficiency, which may be due to executive functioning and attention regulation challenges. Sergeant therefore suggest that the ability to adjust one's energetic state is responsible for the consistency and performance challenges of those with ADHD, rather than executive functioning dysfunction alone. Therefore, frequent reinforcement or reward may bring about performance improvements for those with ADHD, comparable to matched control individuals.

There are recent meta-analyses and systematic reviews of studies that examine the effect of acute and chronic sport and physical activity on ADHD and executive functioning symptoms of young people with ADHD [4,8]. Acute exercise is defined as a single bout of exercise, whereas chronic exercise is defined as numerous bouts of exercise across a period of time. There is a need to provide a more nuanced review of the study design, exercise protocol (nature, type, intensity, cognitive demands) and effect sizes for specific interventions (e.g., acute vs. chronic) on outcomes (e.g., inhibition vs. cognitive fluency). Moreover, there is a need to provide an accessible framework to outline sport or physical activity interventions that include motor movement or motor skill acquisition components, in order to inform future intervention development, research and applied clinical practice. This narrative review was designed to extrapolate and synthesise the research evidence on the effects of physical activity on neural and cognitive functioning in children and adolescents with ADHD.

Materials and Methods

Ethical approval for the present study was waivered by the committee as it includes published secondary data. The Cochrane and PubMed databases were searched between January 2019 and January 2022 for systematic reviews and meta-analysis journal articles. The publication date was set to <2 years in order to capture the most contemporary research in the area. The keywords ("ADHD" or "Attention Deficit and Hyperactivity Disorder") and ("child" or "adolescent") and ("physical activity" or "physical exercise" or "sport"). And ("executive functioning" or "ADHD symptoms" or "inhibition" or "working memory". The scope of the papers included in the analysis were meta-analyses and systematic review papers.

The study abstracts were initially screened for suitability and then studies included in the meta-analysis were checked against the following inclusion criteria (1) RCT or cross-over study, (2) inclusion of child or adolescent participants who had been clinically diagnosed with ADHD (3) acute (defined as a single bout of exercise) or chronic (defined as numerous bouts of exercise across a period of time) exercise interventions (4) inclusion of a control group (5) the inclusion of outcome measures of executive functioning or cognitive functioning e.g., response inhibition or working memory or ADHD symptoms and (6) the inclusion of effect sizes or descriptive statistics that allow for effect sizes to be calculated and (7) PRISMA or PEDro had been used in the meta-analysis to guide study selection and inclusion.

Following interrogation of the peer-review journals returned in the key word search, four meta-analyses were retained for review [4,17,18].

Results

The study abstracts were initially screened for suitability and then studies included in the meta-analysis were checked against the following inclusion criteria (1) acute (defined as a single bout of exercise) or chronic (defined as numerous bouts of exercise across a period of time) exercise interventions RCT or cross-over study, (2) inclusion of child or adolescent participants who had been clinically diagnosed with ADHD (3) systematic review or meta-analysis (4) the inclusion of outcome measures of executive or cognitive functioning e.g., response inhibition, attention, and/or working memory and/or ADHD symptoms and (6) the inclusion of effect sizes or descriptive statistics that allow for effect sizes to be calculated in the review and (7) PRISMA and/or PEDro had been used in the meta-analysis to guide study selection and inclusion.

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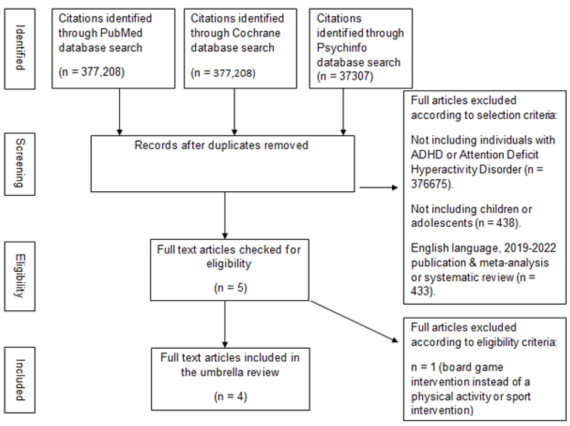

Figure 1 PRISMA Flow diagram of the literature search and screening process.

The PRISMA Flow chart (Figure 1) displays the selection process resulting in the final 4 meta-analyses/systematic reviews that were included in this umbrella review (Tables 1-3).

Search number	Field	Search terms	Database results
S1	SU (subjects)	Physical activity, exercise OR Sport and ADHD	
S2	SU (subjects)	Child or Adolescent	
S3	Open	Systematic review OR meta-analysis	5

Table 1: Displays search terms and results for Cochrane

Search number	Field	Search terms	Database results
S1	SU (subjects)	Physical activity, exercise OR sport and ADHD	
S2	SU (subjects)	Child or adolescent	
S3	Open	Systematic review OR meta-analysis	5

Table 2: Displays search terms and results for PubMed

	Criteria	As defined in the present review
P	Population	Children or adolescents (aged 5 years-18 years)
I	Phenomena of interest/intervention	Intentionally planned sport, exercise or physical activity interventions
C	Context	Sport or physical activity settings in a range of indoor environments
O	Outcome/end point	ADHD symptoms and executive functioning
S	Study design	Systematic review and meta analysis only

Table 3: PICOS modified statement of eligibility for inclusion

The methodological characteristics of the individual RCT and cross-over trial studies included in the 4 systematic reviews and/or meta-analyses (24 individual studies across the 4 reviews) are summarised in Table 4 and the key findings are summarised in Table 5 (Tables 4 and 5). N.B.: Cognitive demands includes components such as responses to dynamic visual and/or auditory/kinaesthetic stimuli, stimulus-response selection (and may include the presence of an opponent via an exergaming avatar or real world opponent).

Acute exercise

Christiansen et al. reviewed the effects of acute and chronic exercise on executive and cognitive functioning outcomes for children and adolescents with ADHD [4]. Their review included 10 acute exercise studies [19-23]. The exercise interventions included cycling, exergaming, swimming and perceptual motor training, aerobic exercises, ball-games, table-tennis and yoga. These studies examined the impact of physical activity on executive functioning using several experimental outcome measures: psychomotor speed (n=5), cognitive-flexibility (n=4), cognitive fluency (n=1) WM (n=2), inhibition (n=6), selective attention (n=1). The experimental cognitive tasks included: Stroop task (Inhibition), Wisconsin card-sorting task (overall

Authors	Sample	Physical activity intervention	Duration	Cognitive demands	Outcome measures
Benzing et al. [19]	46 (M age=10.48)	Exergaming	Acute RCT	Yes	Colour Span backwards Task (Working memory)
			Acute		A single modified Flanker Task (inhibition)
			15 mins moderate-high intensity		
Benzing and Schmidt [20]	51 (age= 8-12)	Exergaming	Chronic RCT 30 mins x 3 times per week for 8 weeks	Yes	Core executive functions (1. Inhibition: Simon Task, 2. Switching: colour span backward task, 3. Updating; Flanker task. Parent ratings of symptoms, and motor abilities
Bustamante et al.	34 (6-12 years, Mage9.1., S.D.=2.1)	Co-operative games and sports	Chronic RCT 90 mins x 6 weeks (60% HR max, light intensity)	No	Visuospatial working memory, Verbal working memory (Inhibition)
Chang et al.	40 (8-13 years)	Running	Acute		
		Control group: Watching a video of running	30 mins		
			Moderate intensity		
		Aquatic exercise	Chronic	No	Go/No-Go Task
Chang et al.	27 (5-10 years)		nRCT		Basic Motor Ability Test-Revised
			90 mins x 6 weeks (60% HR max, light intensity)		
Choi et al.	30 (13-18 years)	Sports therapy	Chronic	Yes	Dupaul ADHD rating scale, Korean version
					Wisconsin Card Sorting Test stimulation with Fmri
Chuang et al. [21]	19 (8-12 years)		Acute cross-over	No	Inhibition Go/No Go Task
			30 mins moderate treadmill running/		
			Video watching		
Da Silva et al.	20 Mage=12 (1.2)	Taekwondo	Chronic 2 x 50 mins 78 weeks	Yes	Stroop test
Hung et al.	34 (8-12 years)	Running	Acute	No	Task switching paradigm: Behavioural indices and P3 component of event-related potentials
			Cross-over		
			30 mins		
			MVPA (50–70% HRR)		
Kadri et al. [22]	39: Mage=14.3 (3.25)	Swimming	Chronic 2 x 45 mins	No	TMT
			4 weeks		
Kang et al.	28 (7-12 years)	Sports therapy	Acute RCT	Not reported	TMT-B; Digit Symbol of the Korean Educational Development Institute-WISC ADHD Rating Scale; Social Skills Rating System
			90 minutes		
			6 weeks		
			Intensity not recorded		

Lee et al.	12 (6-10 years)	Chronic	Chronic	Yes	Stroop Task: Inhibition
		Jump rope and ball skills	RCT		EEG (frontal lobe)
			Jump rope & ball skills		
			60 mins 3 times per week (12 weeks)		
Ludgya et al. [23]	18 (age=11-16 years)		Cross-over	Yes (included in one experimental exercise condition)	Flanker task (inhibitory control)
			Acute		Event-potential (latency & amplitude in p300 from EEG)
			Condition 1: 20 minutes cycling ergometer		
			Condition 2: 20 min co-ordinative exercise test (object control skills and bilateral movements of upper & lower extremities)		
Ludyga et al. [24,25]	18 children with ADHD		Cross over design	No	Behavioural performance (cognitive flexibility) was assessed using the Alternate Uses task
			Acute		
	18 matched controls without ADHD (10-16 years)				
			20 mins moderate intensity (65-70%)		Heart Rate Variability (HRV)
Memarmoghaddam et al. [26]	36 (7-11 years)	AE and goal directed exercise	Chronic 90 mins 3 times per week	Yes	Stroop Task
			8 weeks		Go-No-Go test
Pan et al. [27]	32: Mage=8.9 (1.49)	Table tennis (anaerobic)	Chronic 2 x 70 mins	Yes	Stroop test (inhibition)
			12 weeks		Wisconsin Test
Pan et al. [28]	22: Mage=9.6 (1.5)	Yoga (flexibility)	Chronic 3 x 45 mins	No	Wisconsin Test
			8 weeks		
Piepmeier et al.	32 (8-13 years)	Cycling	Acute	No	Stroop task
			30 mins		Tower of London
			Moderate intensity		Trail Making Test
			RCT (matched non-ADHD control group)		
		Running	Acute	No	Erikson Flanker test EEG P300
		Control: Reading	Cross-over		WRAT3 (reading comprehension, spelling, arithmetic)
			20 minutes (65%-75% HR Max)		
Verret et al.	21 (7-12 years)	Physical activity programme	Chronic	No	Test of Everyday Attention for Children
			nRCT		
			45 mins x 3 per week		CBCL
			10 weeks		
Ziereis and Jansen	21: M_{age}=9.3 (1.3)	Mixed aerobic physical activity including ball games	Chronic 3 x 60 mins	Yes: Manual handling/ dexterity	HAWIK-IV (LNS)
			12 weeks		

Ziereis and Jansen	22: M_{age} = 9.6 (1.5)	Mixed aerobic Physical activity including climbing	Chronic 3 x 60 mins	Yes	HAWIK-IV (LNS)
			12 weeks		
Ziereis and Jansen	39 (7-12 years)	Gym	Chronic	No	HAWIK-IV
			60 mins for 12 weeks		
Chan and Ho [29]	37 (8-11 years)	Gym	Chronic	Yes	
			60 mins x 2 per week for 8 weeks		Two joystick tests (simple reaction time; SRT and choice reaction time; CRT)
			Aerobic and perceptual-motor exercise characteristics.		
Durgut et al. [30]	30 (7-11 years)	Gym	45 mins x 3 per week for 8 weeks of moderate intensity exercise: Treadmill (control) & Treadmill and whole body vibration training (experimental)	No	Stroop Test TBAG form, Behavior Rating Inventory of Executive Function (BRIEF), Conners' Rating Scale (CRS) and Pediatric Quality of Life Inventory (PedsQL)
Miklós et al. [31]	150 (6-12 years)	Laboratory	Acute high intensity Control condition (cartoon video while seated) Experimental condition (20 minutes 60-80% maximum HR exercise while observing a cartoon).	No	Executive functioning and attentional performance (Test of Attentional Performance; KiTAP).
	Non-medicated group = 50 (25 exercise and 25 control).				ADHD symptoms (Mini International Neuropsychiatric Interview for Children and Adolescents; MINI Kid)
	Medicated group = 50 (25 exercise and 25 control).				
	Control group = 50 (25 exercise and 25 control).				

Table 4: Methodological characteristics of meta-analysis studies.

Authors	Outcomes/effect sizes (ES=Control-experimental)	Effect size index
Benzing and Schmidt [19]	Modified Flanker Task (inhibition); -.66	Hedges g
	Colour span backwards; 0	
Benzing and Schmidt [20]	-.69 (Simon Task RT)	Hedges g
	-.57 (Flanker Task RT)	
	.28 (Colour span backwards, correct answers)	
Bustamante et al.	-.01; BRIEF (executive functioning)	Cohen's d
	.47; STOPIT (inhibition)	
	AWMA-S (.26; verbal & -.21; visuospatial working memory)	
	Mental health (DBD, IRS); Not reported	
	Social improvement skills (SSiS); Not reported.	
Chang et al.	Wisconsin;	Cohen's d
	Total correct; .34	
	Perseverative responses; -.56	
	Perseverative errors; -.53	
	Non-perseverative errors; -.74	

Chang et al.	-.71 (Go/no Go, RT)	Hedges g
Choi et al.	-.58 (Wisconsin card sorting task)	Hedges g
Chuang et al. [21]	Go/No-go trial (RT):	Hedges g
	Hit rate (-.13)	
	Om-error rate (.13)	
	Com-error rate (-.12)	
Hung et al.	Global switch RT cost; -.38	Hedges g
	Local non-switch RT cost, -.13	
	Local switch RT; -.09	
Kadri et al. [22]	Stroop (inhibition);	Cohen’s d
	Colour word interference; .22	
	Error rate; -.22	
	Ruff 2 and 7 (sustained and selective visual attention);	
	Automated detection; .28	
	Controlled search; -.38	
	Total speed; -.29	
Kang et al.	Digital symbol task, GCP): -.68	Hedges g
	Trail making task, cognitive functioning): .18	
Lee et al.	Stroop Task: Inhibition	Hedges g
	Incongruent (RT); .-21	
	Congruent (RT); -.12	
Ludgya et al. [23]	Incongruent (RT); -.14	Hedges g
	Congruent (RT); -.17	
Ludyga et al. [24,25]	Category; .29	Hedges g
	Fluency; .37	
	Originality; .28	
	Elaboration;0	
Memarmoghaddam et al. [26]	Stroop task	Hedges g
	Error number; -.81	
	No response; -.95	
	True number; 1.17	
Pan et al. [27]	Colour word (inhibition); .3	Hedges g
Pan et al.	Motor proficiency; .51	Partial n^2
	Fine manual control; .29	
	Manual co-ordination; .23	
	Body co-ordination; .39	
	Strength and agility; .28	
	Manual dexterity; .32	
	Bilateral co-ordination; .27	
Piepmeier et al.	Stroop (inhibition); .14	
	Tower of London (planning/problem-solving); NA	
	Trail making test (attention switching/cognitive processing); .78	Partial n^2
Pontifex et al.	Flanker test (modified):	Hedges g
	Post error time; .52	
	Response Accuracy; .29	
Verret et al.	Sky search; Time targeted pondering; 2.87	
	Attention pondering; 0.67	Hedges g
	Score pondering; 3	
	DT pondering; .28	
Ziereis and Jansen	Digit span	Hedges g
	(Forward; 0.68, backward; 0.64; Index; 0.85)	
Ziereis and Jansen	Digit span	Hedges g
	(forward; 0.08, backward; 0.75; index; 0.78)	

Ziereis and Jansen	Digit span index (0.85)	Hedges g
Chan and Ho [29]	Choice reaction time (0.42)	Hedges g
Miklós et al. [31]	Alertness task (reaction time)	Median diff (p<0.05)
	Divided attention task (error rates)	
Durgut et al. [30]	CTRS-R/L (p < 0.05) and BRIEF-Teacher (p<0.05) form > in TT+WBVT group.	Mean diff (p<0.05)

Table 5: Acute and chronic exercise effects on ADHD symptoms and cognitive functioning.

cognitive functioning), Go/No-go (Inhibition and PS), Task switching paradigm (PS, WM, cognitive functioning), alternate use task (cognitive flexibility) flanker task (Psychomotor speed, inhibition) and Connor's continuous performance test (Inhibition, psychomotor speed, selective attention). For data analysis, studies used Mean RTs, standard and/or overall error rates, accuracy 'cost' and switch time cost (ability to switch attention efficiently, i.e., without losing accuracy). Cognitive fluency (n=1) was assessed using a fluency/flexibility task and the outcomes were originality and elaboration.

In terms of exercise intensity, 65% HRMax-75% HRMax (i.e., moderate intensity), 10 minutes-20 minutes (volume of 1000, i.e., time*intensity) of acute physical activity achieved the highest effect size on executive functioning outcomes (small to moderate effects). The findings found that physical activity had beneficial effects on the following outcomes, in ranked order;

1) Inhibition; 2) Psychomotor speed; 3) Cognitive functioning; 4) Working memory (ES, P value); 5) Selective attention.

Chronic exercise

Christiansen, et al. also reviewed the effects of chronic exercise and reported larger effects on outcomes in studies using exercise protocols of 60 minutes-80 minutes (with repeated bouts) at an intensity of 70% HRmax (volume=1420-1500) (ES, P value) [4]. In terms of executive functioning outcomes, larger effect sizes were found for SA, then inhibition and lastly PS. It was also found that 90 minutes duration at low intensity <60% HRmax (volume=5400) appears to have a small effect on cognitive functioning such as planning and problem-solving (d=0.2, p <0.01).

Welsch, et al. examined the effect of chronic physical activity interventions on executive functioning outcomes and included 12 studies (some of which incorporated cognitive demands) in separate meta-analyses which were split by each executive functioning domain and included subgroups of high vs. low cognitive demand, and medication vs. medication free. The systematic review showed beneficial effects of physical activity for all executive functions, with 95%-CI compatible with positive effects for shifting (SMD=-1.58; 95% CI (-3.12; -.04)) and working memory (SMD=-.99, CI (-1.8; -.18)).

Welsch et al. found that the benefits of physical activity on executive functioning were lesser for those taking MPH. The review also found that physical exercise with high cognitive demands may have greater positive effects for children with ADHD as it activates multiple neural pathways, simultaneously (Best, 2010; Drollette et al., 2014). The moderator analyses confirmed a greater beneficial effect for more cognitively demanding (e.g., table tennis) exercise interventions on inhibition. This could be due to the specific coordinative and cognitive demands that are thought to benefit response inhibition.

Liang et al. examined the effect of physical activity interventions (with and without cognitive demanding components) on cognitive functioning in children with ADHD [16]. Cognitive demands included factors such as the presence of an opponent (which could require higher-order stimulus response selection to inform decision-making) and responding to virtual visual and auditory stimuli such as those in exergaming, more complex motor skills and sequencing, such as those in taekwondo. The included outcome measures included a range of; 1) Working memory tasks; The tower of London and digit span forward and backward test, 2) inhibitory control tasks; The Go-No-Go task, Flanker task and Stroop. And also; the trail making task and 3) Cognitive flexibility which was examined using the Wisconsin card sorting test. The authors rated the study quality using the PEDro scale and study quality ranks ranged from moderate (6) to high quality (9).

The meta-analysis performed by Liang et al. integrated executive functioning tasks included in 15 ADHD studies with selected outcome variables across the three core executive functioning domains. Of the fifteen studies; 8 studies reported significant moderate-to-large training effects (g=0.780, 95% CI [0.331 to 1.228], p<0.001) on cognitive flexibility, and 11 studies found a significant moderate-to- large effects on inhibitory control (g=0.761, 95% CI [0.376 to 1.146], p<0.01) [17]. Lastly, 5 studies included working memory as the outcome variable and reported minimal-to-moderate significant effects of exercise interventions (g=0.383, 95% CI [0.033 to 0.733], p<0.05).

Montalva-Valenzuela et al. performed a systematic review of 21 eligible randomised control or cross-over trials on the effects of sport, physical activity or exercise on children and adolescents with ADHD [18]. They concluded that a 20 minutes of aerobic exercise can improve executive functioning in children and adolescents with ADHD. In terms of scientific rigour, they found that 11 of the 21 studies scored 5 out of 11 points on the PEDro scale, 7 scored 6 points, 2 scored 7 points and one scored 8 points. These studies were lacking double blinded approaches to RCTs and concealed allocation (i.e., the researcher is unaware of the group allocation intended for the participant at the recruitment stage). The authors reported that following aerobic physical activity interventions, significant improvements in inhibitory control were noted. Whereas following cognitively demanding exergaming or ball sports games improvements in processing speed, cognitive flexibility and attention were noted as a consequence of the motor co-ordination and visual-spatial skills inherent in such exercise or sport activities. Moreover, there appears to be a motor co-ordination and sensory benefit for young people with ADHD from sports such as trampolining.

Discussion

The purpose of this narrative review was to synthesise the contemporary RCTs that examine the effect of sport, physical activity and movement on executive functioning and ADHD symptoms in children and adolescents with ADHD. The review has identified findings to suggest 10 minutes to 20 minutes of moderate intensity exercise may be beneficial for young people with ADHD, particularly in the domain of inhibition (e.g. Christiansen et al., 2019). The findings also suggest 60 minutes to 80 minutes of repeated exercise may also be beneficial particularly in the domain of selective attention [4]. Of the 15 studies included in Liang et al.'s systematic review, 8 reported significant moderate-to- large training effects (g = 0.780, 95% CI [0.331 to 1.228], p<0.001) on cognitive flexibility, and 11 studies found a significant moderate-to- large effects on inhibitory control (g = 0.761, 95% CI [0.376 to 1.146], p<0.01) [17]. Lastly, 5 studies included reported minimal-to-moderate significant effects on working memory (g =0.383, 95% CI [0.033 to 0.733], p<0.05). This further suggests potential benefits for repeated exercise over time.

Christiansen et al. reported on 13 studies that included heart rate monitoring to establish exercise intensity. This review highlights the importance for exercise interventions to consider the need to individually tailor interventions based on exercise intensity [4]. For example, Seiffer et al. specifically defined exercise intensity as [moderate to vigorous; exceeding energy expenditure of 2.99 Metabolic Equivalent Tasks (MET)]. Moreover, it is possible to calculate MET values from heart rate or VO2max values. This allows for replication of study findings and evidence-based, specific practice recommendations.

There is emerging evidence to support the inclusion of cognitively demanding physical activity, or movement, that involve progressive perceptual-motor skills or demands. For example, Pan et al. found that structured play in table tennis (characterised as a rapid, perceptual-motor movement led sport) significantly improved inhibition in young people with ADHD after 12 weeks [27,28]. Moreover, Taekwondo which has more complex cognitive and motor skills and demands that can be progressively administered in a structured environment has been shown to significantly improve inhibitory control in children with ADHD in comparison with traditional physical education delivered over an 18-month period (Da Silva, et. al., 2019).

Research in motor performance and skill acquisition has shown that while learning novel motor performance movement patterns, there is a reported reduction in activation of attentional control areas such as the middle frontal gyrus, right superior frontal gyrus and the ventral medial prefrontal cortex. It demonstrates a mechanism of cortical reorganisation that is evidenced by altered brain activity and connectivity. Therefore, motor learning is driven by reward processes (skill acquisition) and sensory prediction error (motor adaptation) which both shape future performance and behaviour. Motor skill performance can be progressed by either the complexity of the task or changes in the environment which prompt the need to adapt.

Welsch et al. predicted that physical activity with higher cognitive demands would improve cognitive functioning in children with ADHD. Young people with ADHD typically have under-functioning prefrontal-cortex (PFC) regions and this area tends to be activated while exercising and learning new things [33]. However, they found that cognitively demanding physical exercise brought about an inferior effect on working memory and a significant inferior effect on attention shifting. Cognitive over-load (i.e., a high demand on the PFC) was a suggested explanation for this finding. It is therefore important for future research to consider the need for sport interventions to implement progressive cognitive demands in a systematic and evidence-based way. Specifically, there is a need to consider the differential cognitive demands of the sensory, physical stimulation, co-ordination and movement and social stimuli such as other team-mates and opponents. Multi-disciplinary research and teams that considers skill acquisition and motor performance theory and practice could provide evidence-based and systematic interventions to improve cognitive functioning in those with ADHD.

Liang et al. reviewed the effect of physical activity with a focus on the sub-domains of cognitively vs. non-cognitively demanding sport and physical activity tasks. This is one of the first reviews to consider the need to include transparency in terms of motor skills/cognitive demands in sport and physical activity intervention designs. There is a need to develop a framework for both researchers and practitioners to provide consistency in their mapping of principles; i.e., bilateral motor movements including upper and lower limbs in sports such as swimming or running, a rating of cognitive demands (e.g., low demands=Throwing and catching, moderate demands=Movement and hand-eye co-ordination such as tennis or table-tennis, which can also have the presence of an opponent which adds an element of dynamic response selection). Taken together, the findings of this narrative review suggest that sport or moderate- high intensity physical activity that includes a component of cognitive or motor demands may significantly improve executive functioning outcomes including cognitive flexibility, attention switching, problem-solving and working memory. Cognitive flexibility, in particular, may substantially improve as a consequence of these types of physical activity or sport interventions. Moderate-high intensity exercise may significantly improve inhibitory control and this finding is consistent across the studies included in this review.

The integration of evidence from the motor performance and skill acquisition field (i.e., evidence that considers cognitive demands in sport tasks and environments and their importance when designing sport or physical activity programmes/interventions) suggests that activities that progressively increase (1) cognitive load (the technical difficulty of a skill and the presence of opponents and team-mates) and (2) attention focus switching (from one visual field to another or from external to internal) in a structured and focused programme are likely to increase meta cognitive attentional awareness and attentional control.

Moreover, high intensity exercise may be effective to release building stress hormones (e.g., cortisol; Gerber et al. over short periods which lends itself well to the higher base stimulation threshold of those with ADHD. High Intensity (HIIT) exercise can be progressively administered, beginning with brief intense exercise bursts and then progressing to include longer sustained periods of exercise to challenge the individual's stimulation threshold [34,35]. Lower intensity practices such as yoga and mindfulness meditation lower the reactivity of the sympathetic nervous system and associated neuro-endocrine systems in order to allow the individual to establish a lower baseline of stress hormones. They also allow for an opportunity to improve meta-cognition, i.e., increasing awareness of one's thought content. This may be particularly important for those with neuro-deficits in executive functioning. Meta-cognition is the process whereby individual' become self-aware of their perceptions, interpretations and responses and observe them [36].

Limitations and Future Directions

Further empirical studies that incorporate a high-quality RCT design are required. Moreover, exercise interventions that that manipulate intensity in a systematic and sequenced way, within the same study (light, moderate, vigorous) and duration (10, 30, 60 min) to enhance the understanding of the optimal balance between the intensity and duration of physical exercise and the effects on executive functions are required. This is particularly important as it is currently challenging to compare the effects of exercise intensity across different studies. In terms of exercise type and duration, Grassman et al. suggested a duration of 30 minutes is needed to improve EFs and this is supported by Suarez-Manzano et al. who provided 20 m–30 m of moderate intensity (40%–75%) for acute and >5 weeks of at least three days a week with >40% intensity for long-term exercise to improve cognitive functioning outcomes [37]. It has also been found that cycling is a preferable aerobic activity for acute physical exercise programmes to improve cognitive functioning [38].

There also appears to be a need for multi-disciplinary research, using RCT designs, and a clear rationale for the selection of the most appropriate outcome measures that are sensitive to the psychological changes most likely to arise from specific interventions. For example, for low intensity exercise (e.g., Yoga), emotional state or mood are likely appropriate outcome measures rather than cognitive functioning tests [39]. It is also relatively atypical for studies to include measures of Quality of Life [QoL] and self-report measures of psychological well-being in studies that examine the effect of physical activity and sport on outcomes for those with ADHD. QoL is more likely to capture the broader psychosocial changes which are often neglected in clinical trials in this area.

In other studies, such as that by Rezaei et al. whom delivered an integrated neurofeedback (theta/beta training) and Yoga exercise intervention on sustained attention and identified a significant improvement in memory and sustained attention. The integration of neuro/biofeedback interventions with physical activity may thus also be a fruitful avenue for future research. There is a need for studies to control for and consider the nature of cognitive demands that arise from different sports. For example, maintaining focus with the presence of team-mates in basketball (reported as a ball game sport in studies) and the motor skills required, places higher cognitive demands on a child than cycling. Therefore, more studies are needed that take a systematic and evidence-based approach (using motor performance and skill acquisition theory and empirical evidence) to cognitive loading in physical activity interventions for children with ADHD. The environmental context is also important to consider in physical activity programmes and specifically a need to consider the beneficial effects of outdoor activity for those with ADHD [17].

There is evidence to suggest that the attention restoration theory can explain the specific and unique benefits of outdoor or green exercise for those with ADHD. Van Den Berg found that concentration and mood were significantly improved in children with ADHD when walking within a rural woodland area in comparison to an urban city environment. The finding was further supported by Thal who demonstrated that young people who exercised in a rural area demonstrated superior cognitive performance and experiences of restoration in comparison with those exercising in urban environments [40-44].

Conclusion

Physical activity and sport have numerous physical and mental health benefits that are well documented across populations. For young people with ADHD, there may be particular benefits to physical and repeated exercise particularly in the domains of inhibition, selective attention and cognitive flexibility. Young people presenting with ADHD can present with an array of clinical complexities and therefore the potential of physical activity approaches presents a promising area to further develop and evaluate. Large scale clinical trials of exercise interventions for young people with ADHD would be exceptionally beneficial to further guide specific dose-response recommendations for clinicians.

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