Received: 9 February 2023 | Accepted: 25 September 2023

DOI: 10.1111/1471-3802.12628

ORIGINAL ARTICLE

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Evaluation of a pilot physical activity intervention for children with ADHD symptoms and reading difficulties

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Funding information
Waterloo Foundation, Grant/Award Number: 1283-1982

Abstract

Physical activity (PA) benefits children's cognition, in particular executive functions (EF). Children with Attention Deficit Hyperactivity Disorder (ADHD), Reading Difficulties (RD) and co-occurring ADHD/RD have low levels of PA and difficulties with EF. This study evaluated a PA programme to determine recruitment, attrition, feasibility (e.g. in-school or after-school hours), intensity of PA during the programme and effect sizes. Outcomes evaluated were EF, academic attainment and social and emotional behaviour. Sixty-nine children (35 males) aged 7–13 years participated in a delayed control design. The sample comprised 15 children with RD, 15 with high levels of ADHD symptoms, 15 with co-occurring RD and ADHD symptoms and 24 typically developing children. Thirty-one of the participants took part in a 12 week PA intervention designed to enhance cognition and 38 acted as a control group. The control group subsequently received the intervention and data was combined for analysis. The study was successful in recruiting participants for the intervention; more success was observed for in-school than after-school hours. Participants spent 46% (SD = 14) of the intervention in Moderate-to-Vigorous intensity PA (MVPA). A significant effect of time-point (pre- vs. post-intervention) was found for inhibition and visuospatial working memory ($\eta^2 = 0.11$ and 0.18 respectively). There was no interaction with symptomatology though; all groups had higher scores on EF tasks after the intervention. It is possible to recruit and retain participants with ADHD symptoms and reading difficulties to a school-based PA programme and adherence to measurements was good. Taking part in the programme may improve inhibition and visuospatial working memory and reduce symptomatology suggesting this is a potential source of remediation which should be explored.

KEYWORDS
ADHD, children, executive function, physical activity intervention, reading difficulties

Key Points

- Taking part in a physical activity programme improved executive function in children.
- Those with ADHD symptoms, reading difficulties and co-occurring difficulties all benefitted.
- Physical activity may also reduce symptomatology in these groups but definitive RCT's are needed.
- Physical activity should be explored as a potential source of remediation.

INTRODUCTION

Regular Physical Activity (PA) can reduce the risk of many chronic conditions, however, levels are low globally and begin to decline in childhood and adolescence (Aubert et al., 2021; Farooq et al., 2020). Moderate-to-Vigorous intensity Physical Activity (MVPA) can improve cognition and academic attainment (Barbosa et al., 2020; Biddle et al., 2019), reduce emotional and behavioural difficulties (Biddle et al., 2019) and improve social skills (Opstoel et al., 2020) in young people.

Recent reviews have reported mixed conclusions regarding the efficacy of PA interventions for cognition (Donnelly et al., 2016; Singh et al., 2018); the variety of outcomes examined, different types and intensities of PA interventions and varying cognitive load of activity may all contribute to the lack of consistency of effects reported (Pontifex et al., 2019). Biological, psychosocial and behavioural mechanisms underlying this relationship have been purported (Lubans et al., 2016) which may all have an impact on successful interventions. Executive functions (EF) are higher order cognitive processes that direct behaviour and action (Diamond, 2014). EF have been found to benefit more consistently from PA than other aspects of cognition, although there are differences depending on the aspect of EF examined (for a review see Guiney & Machado, 2013). In their recent review, Lubans et al. (2021) reported a small effect size (ES = 0.29) from chronic PA interventions on executive function in children. Impact on brain structure and function have been identified in the literature and evidence of impact on biological mechanisms such as Bran Derived Neurotropic Factor (BDNF), as well as psychosocial (e.g. mental health) and behavioural mechanisms (e.g. sleep). They also highlighted that in order to move the evidence base forward, studies should include an assessment of inhibition, working memory and cognitive flexibility (i.e. shifting), rather than a narrow focus on one aspect of EF. Furthermore, there is mixed evidence concerning these relationships in young people with developmental difficulties who have known deficits with EF, although a review by Takacs and Kassai (2019) reported greater effect sizes for 'nontypical' populations than typically developing children.

One particular group of young people with known difficulties with EF are those with Attention Deficit Hyperactivity Disorder (ADHD). ADHD affects between 4% and 11% of school children (Francés et al., 2022; Mohammadi et al., 2021), while globally, 7% of school pupils are thought to have reading difficulties (Yang, Li, et al., 2022). In addition, the prevalence of co-occurring difficulties between ADHD and reading difficulties is thought to be 15%–45% (DuPaul et al., 2016; Purvis & Tannock, 2000). These developmental difficulties are associated with numerous wide-ranging and lifelong problems, for example, poor mental health and psychosocial adjustment and deficits in academic attainment and EF (Lonergan et al., 2019; Tarver et al., 2014; Willcutt et al., 2008; Yang, Shields, et al., 2022). While hyperactivity is one of the core symptoms of ADHD, levels of PA are reported to be lower for those with ADHD (Ganjeh et al., 2022; Kim et al., 2011; Tandon et al., 2019). Furthermore, the prevalence of obesity is very high (Faraone et al., 2021), with some studies reporting an increased prevalence of 40% compared to children without ADHD (Cortese et al., 2016). There is therefore a need to support increases in MVPA for children with ADHD (Taylor et al., 2023).

Research has shown that PA has a positive impact on ADHD symptoms (Gapin et al., 2011). Welsch et al. (2021) reviewed chronic PA interventions and reported the differential impact of PA on EF in young people with ADHD, with a moderating impact of the cognitive load associated with the activity (e.g. treadmill walking vs. rule-based sports). However, Liang et al. (2021) did not find an impact of intervention type in their review of young people with ADHD, but they did find greater effect sizes for moderate PA compared to light or vigorous PA. It can therefore be concluded from this literature that there may be differential benefits depending on the nature of the PA and that increasing MVPA along with a cognitive load may produce maximal benefit.

In terms of reading difficulties, longitudinal research has demonstrated a positive impact of a PA programme on dyslexia (Reynolds & Nicolson, 2007) however the methodology of this work has been criticised (Rack et al., 2007) suggesting strong conclusions are premature. Additional work has found moderate relationships between PA levels and reading ability (Darracott et al., 2019). However, caution should be taken in reviews about evidence which does not consider co-occurring difficulties given the substantial overlap between reading difficulties and ADHD (Pope & Whiteley, 2003).

Given the benefits of PA and lack of evidence which takes into account co-occurring difficulties, there is a need to consider further intervention work involving PA which may be beneficial for children with these specific developmental difficulties. Following the UK Medical Research Council (MRC) Framework for developing complex interventions (Skivington et al., 2021), this study implemented a preliminary evaluation of a PA programme which was successfully used in the US as an afterschool programme for children with obesity (Davis et al., 2011), but with children with ADHD symptoms and reading difficulties in the UK. The specific programme aimed to increase MVPA while also supporting cognitive skills (Tomporowski, McCullick, & Pesce, 2015). We aimed to ascertain whether participants could be recruited and retained to such a programme in the UK context, whether it was more or less feasible if conducted in-school or after-school hours, the intensity of the PA undertaken, as well as to determine sample size recommendations and effect sizes for the outcomes of the intervention for future power calculations. The key outcomes evaluated were EF, academic attainment and social and emotional behaviour.

METHOD

Recruitment and participants

To detect a medium effect with 0.8 power and an alpha level of 0.05, it is recommended that a sample size of 20 per group is adequate for a pilot study (Hertzog, 2008). Ethical approval was granted by the university ethics committee (UREC 13197). Following ethical approval, approval was gained from local education authorities to contact schools. Three schools agreed to take part and a delayed control design was employed. All pupils from primary six classes received information about the study (n=304). Information sheets and consent forms were given to carers and pupils. Inclusion criteria stated that pupils should be aged between 9 and 12 years old, and attending mainstream school in the UK, and free from neurological conditions such as cerebral palsy. Fully informed written consent was required from both carers and pupils to be able to participate (Figure 1). Details of participant recruitment and retention are illustrated in Figure 1. Sixty-nine children (35 males; 34 females) aged 7–13 years took part: 15 children with Reading Difficulties (RD), 15 with high levels of ADHD symptoms, 15 who had co-occurring RD and ADHD symptoms and 24 Typically Developing Children (TDC). Demographic information is displayed in Table 1.

Symptomatology

The Connors 3ADHD Index teacher version (Conners, 2008) indicated high levels of ADHD symptoms; scores >70 indicated a very elevated risk of diagnosis. Parents completed the Strengths and Weaknesses of ADHD symptoms and Normal-behaviours (SWAN) rating scale (Swanson et al., 2012) which assesses symptoms according to Diagnostic and Statistical Manual of Mental Disorders (DSM) criteria for ADHD, with scores of 1.65 standard deviations above the mean identifying those with high levels of ADHD symptoms. In addition, if participants' scores were high (>7) on the inattention/hyperactivity scale of the SDQ (Goodman, 2001) as reported by teachers or parents, scores across other sources were inspected and also used to identify participants.

Participants completed the word reading task from the WIAT-II^{UK} (Wechsler, 2005) and participants with a standard score of 84 or less (<15th percentile) were classified as having a reading difficulty (Lewis et al., 1994). In addition, participants who had both a reading difficulty and high levels of ADHD symptoms were classified as having co-occurring difficulties. All other participants were classified as being typically developing for the purposes of this study.

Instrumentation

Physical activity

Objective measurement of PA using Actigraph accelerometer GT3X was performed for all participants. Participants wore the accelerometer during waking hours for seven consecutive days. Movement is measured in Counts Per Minute (CPM). Valid measurement required at least 10 h wear for 3 days, with non-wear time defined as strings of consecutive zeros lasting 60 min or more and 60 s epoch applied (Mattocks et al., 2008). Evenson cut points (2008) were employed to define time being sedentary (<100 CPM), time in light-intensity activity (101 to 2295 CPM) and MVPA (>2296 CPM).

Cardiorespiratory fitness

Participants completed the PACER test from the multistage fitness test. Participants run between two cones spaced 20 m apart and keep time with an auditory signal until they can no longer keep pace. This test has good reliability and validity for youth population and is recommended for the assessment of fitness (Tomkinson et al., 2019).

Executive function

For all tasks, administration followed standard testing procedures and instructions as per the relevant test manual. Inhibition was assessed using the Stop-Signal task from the Cambridge Neuropsychological test battery (CANTAB; Robbins et al., 1994) and the expressive attention task from the Cognitive Assessment System (CAS; Naglieri & Das, 1997). For the Stop-Signal task, participants press a button in response to the direction of an arrow displayed on a laptop. When an auditory beep sounded, participants withheld their response. A stop-signal reaction time (SSRT) was provided by CANTAB software and used as the outcome of interest. This task has good test–retest reliability (0.72) when used with an ADHD population (Soreni et al., 2009). The Expressive Attention subtest has good test–retest reliability of 0.80 (Naglieri & Das, 1997). Participants are presented with a page with rows of colour names printed in black and white and name the colour word. Participants are then presented with rows of blocks of colours and name the colour of each block. The final trial consists of rows of colour names printed in different colours. Participants name the colour of the ink in which a colour name is printed, for example,

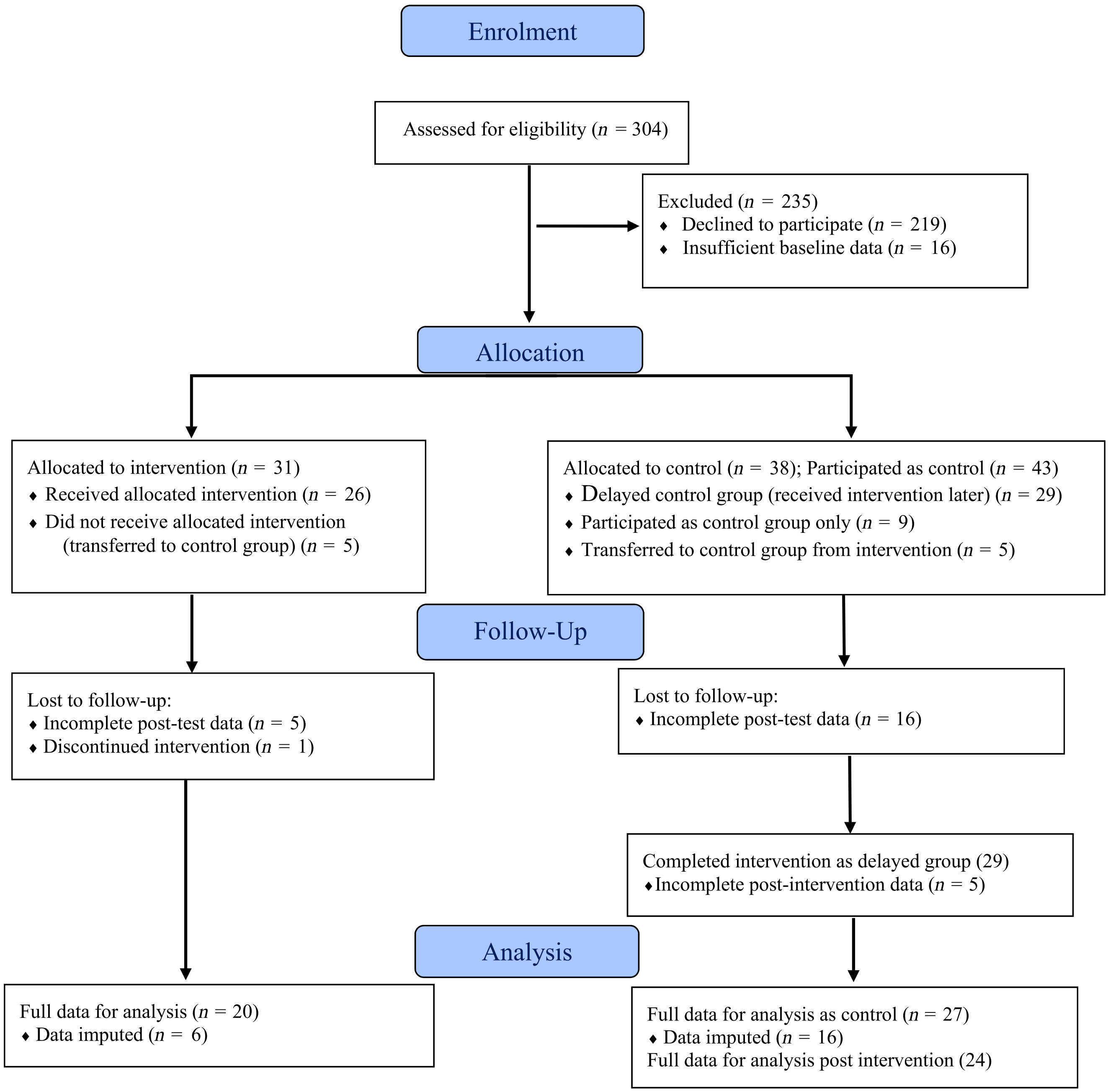

FIGURE 1 CONSORT diagram detailing participant recruitment and retention.

for the word 'yellow' written in red ink, participants should respond with 'red'. Standard instructions were followed with emphasis placed on speed and accuracy. The number of errors made and time taken to complete each item was used to compute an overall raw score as per the instruction manual.

To assess working memory, the Listening Recall and Spatial Recall subtests from the Automated Working Memory Assessment (AWMA) were employed (Alloway, 2007). These tasks were presented on a laptop PC and age-corrected standardised scores were employed (mean = 100, standard deviation = 15). The Listening Recall task assesses verbal working memory (test–retest reliability = 0.88). Participants listen to a series of sentences and judge the veracity of each sentence, for example, 'sheep have hair'. The final word from each sentence is recalled in serial order. The number of sentences presented in each block increases until three errors of recall are made within a block.

The Spatial Recall test from the AWMA (Alloway, 2007) assesses visuospatial working memory (test–retest reliability = 0.79). Participants were presented with a series of diagrams showing two shapes facing either the same or opposite direction, some of which are rotated (e.g. upside down). Participants report whether the shapes are pointing in the same or

TABLE 1 Demographic information.

Characteristic	Symptomatology		Experimental			Control		
			n	**%**		***n***	**%**	
Sex	ADHD symptoms	Male	5	19		1	2	
		Female	5	19		4	9	
	RD	Male	1	4		7	16	
		Female	2	8		5	12	
	Co-occurring	Male	3	12		6	14	
		Female	2	8		4	9	
	TDC	Male	3	12		9	21	
		Female	5	19		7	16	
Ethnicity – white	ADHD symptoms		10	100		5	100	
	RD		12	100		3	100	
	Co-occurring		5	100		9	90	
	TDC		8	100		15	93.8	
Weight status: healthy weight	ADHD symptoms		9	90		3	60.0	
	RD		2	67		8	67	
	Co-occurring		4	80		8	80	
	TDC		4	50		11	69	
		n	**Mean**	**SD**	***n***	**Mean**	**SD**	
Age in months	ADHD symptoms	10	129	10	5	117	18	
	RD	3	128	10	12	125	14	
	Co-occurring	5	118	17	10	127	18	
	TDC	8	121	10	16	124	8	
BMI z score	ADHD symptoms	10	−0.24	0.98	5	0.51	1.21	
	RD	3	0.05	1.30	12	0.30	1.46	
	Co-occurring	5	0.24	1.46	10	−0.19	1.55	
	TDC	8	0.95	1.01	16	0.61	0.99	
Average daily minutes of MVPA at time 1	ADHD symptoms	8	57	23	3	78	30	
	RD	3	57	28	6	64	25	
	Co-occurring	4	74	9	8	62	19	
	TDC	5	47	11	13	69	14	
Conners hyperactivity/impulsivity	ADHD symptoms	8	66.25	15.02	4	75.25	15.17	
	RD	2	46.00	2.83	2	52.00	1.41	
	Co-occurring	5	65.40	14.76	8	66.38	15.34	
	TDC	3	47.00	4.58	10	48.90	5.49	

Abbreviations: *n*, number; SD, standard deviation.

opposite direction. One of the shapes in each pairing has a red dot and participants are asked to recall the position of these dots after the presentation of an increasing number of shape pairs. Accuracy is related to correctly recalling the position of the dots. The number of shape pairings increases in each block until three errors are made in a block.

The Spatial Working Memory task from the CANTAB (Robbins et al., 1994) was employed which has acceptable reliability and validity (Luciana, 2003). Participants were presented with a spatial array of boxes on a computer screen and searched by touching the screen to find blue tokens hidden inside the boxes. Trials start with four boxes relating to four tokens and increase incrementally to eight boxes. There is only one token hidden at a time. In each trial, once a token has been found in a location there will not be another one in the same location. To maximise performance, participants must hold in mind the location of previously found tokens and a 'Between Search Error' (BSE) is made when participants return to a box where a token was previously found.

The intra-extra-dimensional set shift (IED) task from the CANTAB (Robbins et al., 1994) was used to assess shifting ability (Robbins et al., 1994). Participants were presented withf visual stimuli made up of solid shapes and lines. Participants choose the stimuli they think are correct and receive feedback in order to learn the rule focussing either on the shape or the lines. After six trials, the rule changes and participants respond to the previously irrelevant dimension. The intra-dimensional stage involves shifting between solid shapes and the extra-dimensional stage requires shifting from one stimulus to another, for example, a shape to a line. The stage reached indicated the participant's ability to shift attention.

To assess planning ability, the Stockings of Cambridge task from the CANTAB (Robbins et al., 1994) was administered. Participants were presented with a visual display of balls to move to match a specified pattern. Each problem required a minimum number of moves (two, three, four or five moves). Problems solved in the minimum number of moves indicate planning ability independent of motor speed.

Academic attainment

The word reading subtest (split-half reliability = 0.97) and the reading comprehension subtest (split-half reliability = 0.95) of the WIAT-II[UK] (Wechsler, 2005) were administered to participants. In the word reading task participants read single unrelated words, and in the reading comprehension task participants read passages of text and answered questions concerning each passage. Scoring and interpretation followed the standard procedure as per the test manual and were performed by research staff holding appropriate post-graduate qualifications (author IM).

Intelligence quotient (IQ)

IQ was assessed using the Kaufman Brief Intelligence Test which consisted of two subtests indicating verbal IQ (verbal knowledge and riddles) and a matrices test indicating non-verbal IQ. High reliability and validity are reported (*r*-values 0.78 to 0.96; Kaufman & Kaufman, 2004).

Social and emotional behaviour

Class teachers and parents of all participants completed the Strengths and Difficulties Questionnaire (SDQ; Goodman, 2001). The SDQ included questions concerning peer relations, conduct problems, inattention and hyperactivity, emotional problems and pro-social behaviour and has acceptable reliability (Cronbach's alpha 0.57–0.85) and validity (Goodman, 2001).

Physical activity intervention

The PA intervention focussed on engaging pupils in MVPA and utilised a unique instructional methodology designed to mentally engage students in problem-solving tasks based on theories of children's learning and fully described by Tomporowski, McCullick, and Pesce (2015). The programme involves games in three areas: contextual interference; mental control; principle of discovery. There are 15 games each with three versions with an increasing cognitive load (45 games in total). For example, in Opposite Tag, the first version (Tagger ball) is a traditional tagging game but with the inclusion of a number of balls which the taggers must be holding in order to tag (number of balls increases depending on the size of the group). The second version adds a cognitive load by switching the use of the ball so that fleers have to hold a ball in order to be safe. The fleers must work as a team to pass the balls between them. Subsequent versions add complexity and additional cognitive load. Instructors also pose questions to pupils in order to add further mental engagement. Adjustments were made to the games for the UK context (e.g. changes to wording of instructions).

Participants took part in one session lasting 50–60 min per week for 12 weeks in which games were completed. Schools indicated this was feasible considering curriculum demands. The order of games was counterbalanced so that there were an equal number of sessions focussing on contextual interference games, mental control games and principles of discovery games.

To ascertain the PA intensity of the intervention, a subgroup of participants wore Actigraph accelerometers GT3X during each intervention session. Participants also had their heart rate monitored using Solaris finger pulse oximeters at the beginning, middle and end of each session.

The control group undertook their usual school physical education (PE) programme (see here for curriculum information: https://education.gov.scot/curriculum-for-excellence/curriculum-areas/health-and-wellbeing/) which focussed on the development of specific sporting skills with no specific emphasis on cognitive engagement (Dalziell et al., 2019). Results from a meta-analysis demonstrated that pupils of this age group spend approx. 32.6% of school PE in MVPA (Hollis et al., 2016).

Intervention allocation and procedure

Head Teachers of schools were consulted to determine acceptability to the intervention administration. Based on these discussions, the first school was allocated to receive the intervention during school time (i.e. convenience sampling). All pupils typically received two lessons of PE a week following the national curriculum and the intervention was administered in place of one lesson of PE per week. The second school was allocated as the delayed control group where they first acted as the control group where they undertook the usual PE programme, and then received the intervention but at a later time period during school time. The third school was allocated to receive the intervention as an after-school programme in addition to their typical PE curriculum. The intervention followed the same format as the school-based version and was administered by the same instructor who had expertise in sports coaching and training in children. Half of the consenting participants from the third school were invited to attend this administration of the intervention with the other half serving as a control group with class teachers allocating pupils to either intervention or control. Local ADHD support groups were also contacted and members were invited to participate. Consenting participants were invited to join the after-school administration of the intervention. The after-school administration took place at one of the participating schools and participants' travel expenses were reimbursed.

Baseline measurements were taken from all participants individually in a quiet room at school during school time. Accelerometers were administered for 7-day activity monitoring and questionnaire completion by parents and teachers was also completed at Time 1. Participants were not asked to stop any medication. Participants from the intervention school and the after-school programme then took part in the PA programme for 12 weeks with one session per week for each group. Following this, the same measurements as at baseline were repeated for all participants (Time 2). The delayed control group then received the intervention in the same manner as the first intervention group. The same sequence and level of games were administered for a 12-week period in place of one of their normal PE lessons. Participants from the delayed intervention group then completed all tasks again at Time 3.

Statistical analysis

Due to the exploratory nature of this study and the number of participants with missing data (see Figure 1) which were not missing completely at random, data were treated using an intention-to-treat approach where missing data were imputed using the Last Observation Carried Forward (LOCF) method. This approach provides a conservative method to use all available data however may introduce bias based on the assumption of no change (Jakobsen et al., 2017).

Age-adjusted standard scores were computed for all standardised tasks using the relevant test manuals. In most cases, a higher score indicates better performance except for errors and reaction time scores where a lower score indicates better performance. For the SDQ, a higher score is indicative of more difficulties. Accelerometer output is in counts per minute (cpm). Cut points defined by Evenson et al. (2008) were used to calculate time spent at varying intensities of PA. To determine the intensity of the intervention, heart rate was measured as beats per minute (bpm) and the percentage of each session spent in MVPA was calculated.

In order to determine any differences between the intervention and control group following the initial administration of the intervention, an ANCOVA examining differences between the intervention and control group post-intervention scores while controlling for pre-intervention scores was undertaken. Given the pilot sample size, and in order to ascertain effect sizes for a future larger-scale RCT (Skivington et al., 2021), data from all those who took part in the intervention was combined (i.e. including delayed control group and after-school administration) to allow examination of associations before and after taking part in the intervention. This analysis was compared to the data from Time 1 and Time 2 for the control group. These observations were not independent, however, but allowed an examination of change for all those who received the intervention.

A mixed ANOVA was used to examine the difference between pre- and post-test scores (time: pre and post) for all outcome measures for all participants (symptomatology group: four conditions) who received the intervention (combination of intervention and delayed control data after receiving the intervention). Interactions between time and symptomatology group (ADHD, RD symptoms, ADHD/RD or control) were included in the analysis. The same analysis was also performed for the control group separately (time: pre and post; symptomatology: four conditions) and the results were compared as the same participants who were in the control group also received the intervention so separate analysis was appropriate due to a lack of independence of observations. Post hoc pairwise comparisons were used to identify group differences.

RESULTS

Recruitment and retention success

Thirty-one participants were initially allocated to receive the intervention. Recruitment to the after-school programme was challenging though. Five participants who were invited to attend the after-school administration of the intervention did not attend for various reasons (e.g. conflict of commitments) and instead transferred to the control group after completing baseline assessments. Only four participants received the intervention as an after-school programme; they completed all sessions and supplied complete data at pre- and post-test.

Recruitment and retention were more successful when the intervention was completed during school time. Of 22 participants who started the intervention in the first administration, only one discontinued. The attrition rate was therefore 19% (6 from 31) from initial allocation, but 5% from the start of the intervention. In the second administration (i.e. the delayed control group) all participants who began the intervention completed all sessions (attrition rate = 0%).

Descriptive statistics

Demographic information can be found in Table 1. Table 2 shows the mean test scores for all tasks before and after the intervention period. This is the data for the control group at Time 1 (pre) and Time 2 (post) and then all those who took part in the intervention (i.e. combined intervention and delayed control data after receiving the intervention).

Intensity of the intervention

On average, across all sessions of the intervention, participants spent 46% (SD = 14%) of the programme sessions in MVPA and 46% (SD = 12%) in light-intensity PA. Heart rate varied across the sessions. The average for the beginning of the session was 97 (SD = 21) beats per minute (bpm), 127 bpm (SD = 27) at the midpoint and 127 bpm (SD = 29) at the end.

Pilot analysis of the impact of the intervention

Results from an ANCOVA examining differences between the intervention and control group post-intervention scores while controlling for pre-intervention scores, revealed that there was a statistically significant difference for spatial working memory scores from the CANTAB ($F(1, 50) = 8.27$, $p = 0.006$, partial $\eta^2 = 0.14$) with the intervention group having fewer errors than the control group (Mean difference = 10.95, SE = 3.81, $p = 0.006$, 95% CI = 3.30 to 18.60). No other statistically significant differences were found.

As the sample size from the initial administration of the intervention was small ($n = 20$), we amalgamated data from all participants who undertook the intervention and undertook additional analysis. Results from a mixed ANOVA examining the difference in test scores before and after the intervention for all participants who took part in the intervention are presented in Table 3. A separate ANOVA was performed for the control group.

There was a significant effect of symptomatology for both the intervention group and the control group for word reading and reading comprehension scores. Inspection of means in Table 2 confirms this was due to lower scores for participants with RD and ADHD/RD thus confirming their group classification. A significant effect of symptomatology was also found for verbal IQ scores and inhibition as assessed by the expressive attention task.

A significant effect of time (pre- and post-intervention period) was found for teacher-completed SDQ scores and reading scores for both the intervention and control groups. This suggests improvements in scores which may be attributed to repeated administration of the tasks.

For the intervention group only, a statistically significant effect of time was found for inhibition, (assessed by the expressive attention task) and for visuospatial working memory (SWM task from the CANTAB). There was no significant interaction with symptomatology though and inspection of the means in Table 2 suggests participants in all groups had better scores after taking part in the intervention. The greatest improvement on these tasks was for the ADHD symptoms group, although this did not reach conventional levels of statistical significance. For both the inhibition and the working memory task, partial eta-squared indicates a medium to large effect of the intervention (see Table 3).

Cardiorespiratory fitness and physical activity levels

Inspection of scores from the multi-stage fitness test revealed that participants were of a good level of fitness prior to the intervention (mean level achieved = 5.6, Standard Error = 0.9) in line with normative data for the age group (Tomkinson et al., 2016). There was no significant change in participants fitness level after taking part in the intervention (post-intervention mean = 6.2, SE = 0.8), however, participants in the ADHD symptoms group improved the most (mean change = 1.9).

Repeated measures ANOVA indicated that there was no significant change in minutes spent in MVPA before and after the intervention, regardless of participant group or symptomatology. There was no significant correlation between average minutes spent in MVPA and scores on the executive function and attainment measures after taking part in the intervention (r-values ranging from 0.03 to 0.29).

DISCUSSION

The findings of this evaluation indicate it is possible to recruit and retain participants with ADHD symptoms, reading difficulties and co-occurring difficulties to take part in a PA programme in the UK and undertake a broad range of assessments pre- and post-intervention. Implementation of the programme was more successful during school time than after school, although after-school programmes may be more

TABLE 2 Mean (standard error) for tasks before and after the intervention period.

		Intervention		Control	
Outcome	**Symptoms**	**Pre-mean (SE)**	**Post-mean (SE)**	**Pre-mean (SE)**	**Post-mean (SE)**
SDQ – Teacher	ADHD symptoms	7.77 (1.76)	7.08 (1.75)	4.80 (2.92)	1.40 (3.00)
	RD	11.10 (2.01)	9.40 (2.0)	8.50 (2.07)	8.70 (2.12)
	Co-occurring	7.75 (2.24)	6.25 (2.23)	11.50 (2.07)	4.70 (2.12)
	TDC	4.70 (1.41)	4.10 (1.41)	4.00 (1.63)	2.81 (1.68)
SDQ – Parent	ADHD symptoms	7.11 (1.88)	7.78 (1.94)	14.00 (2.95)	11.75 (3.04)
	RD	10.25 (2.82)	10.75 (2.90)	10.67 (3.40)	10.67 (3.51)
	Co-occurring	9.43 (2.13)	9.43 (2.19)	10.25 (2.08)	10.25 (2.15)
	TDC	6.00 (1.88)	6.56 (1.94)	5.80 (1.86)	5.80 (1.92)
Non-verbal IQ	ADHD symptoms	97.75 (5.83)	101.25 (5.1)	107.40 (5.88)	109.00 (7.40)
	RD	90.20 (5.21)	96.60 (4.56)	95.08 (3.79)	93.83 (4.78)
	Co-occurring	86.89 (5.50)	90.78 (4.81)	101.20 (4.16)	100.80 (5.23)
	TDC	98.74 (3.78)	97.63 (3.31)	99.81 (3.29)	101.00 (4.14)
Verbal IQ	ADHD symptoms	105.00 (4.24)	105.13 (3.73)	102.60 (5.39)	110.40 (5.47)
	RD	81.00 (3.79)	84.20 (3.34)	89.08 (3.48)	87.83 (3.53)
	Co-occurring	86.22 (4.00)	85.22 (3.52)	87.60 (3.81)	91.60 (3.87)
	TDC	100.79 (2.75)	100.90 (2.42)	97.13 (3.01)	101.81 (3.06)
Word reading	ADHD symptoms	99.38 (4.73)	98.25 (4.22)	105.00 (5.32)	106.00 (5.20)
	RD	75.90 (4.23)	77.20 (3.78)	73.83 (3.43)	74.33 (3.36)
	Co-occurring	78.00 (4.46)	81.22 (3.98)	81.10 (3.76)	86.00 (3.68)
	TDC	102.74 (3.07)	100.74 (2.74)	103.50 (2.97)	107.06 (2.91)
Reading comprehension	ADHD symptoms	100.13 (4.26)	100.38 (4.69)	103.00 (5.11)	105.80 (4.73)
	RD	78.30 (3.81)	79.70 (4.19)	82.25 (3.30)	82.50 (3.06)
	Co-occurring	80.67 (4.01)	83.56 (4.42)	81.10 (3.62)	85.10 (3.35)
	TDC	100.84 (2.76)	105.42 (3.04)	99.25 (2.86)	102.25 (2.65)
Inhibition – EA	ADHD symptoms	10.88 (1.09)	13.38 (0.97)	10.67 (1.79)	11.33 (1.44)
	RD	8.00 (0.97)	8.60 (0.87)	7.73 (0.93)	7.91 (0.75)
	Co-occurring	10.50 (1.09)	10.63 (0.97)	8.29 (1.17)	11.29 (0.95)
	TDC	11.59 (0.75)	12.12 (0.67)	11.29 (0.83)	11.71 (0.67)
Inhibition – SST	ADHD symptoms	228.66 (24.39)	226.00 (22.17)	286.43 (75.62)	229.73 (60.51)
	RD	219.74 (23.14)	193.63 (21.04)	321.55 (37.81)	252.24 (30.26)
	Co-occurring	248.02 (25.87)	238.84 (23.52)	275.57 (41.40)	283.87 (33.15)
	TDC	215.83 (16.79)	201.89 (15.26)	242.99 (35.01)	215.61 (28.01)
Working memory – LR	ADHD symptoms	108.48 (5.00)	113.12 (4.49)	106.67 (9.84)	103.23 (9.22)
	RD	92.30 (4.75)	95.06 (4.26)	91.79 (4.90)	91.93 (4.61)
	Co-occurring	99.50 (5.00)	94.99 (4.49)	99.80 (5.39)	99.87 (5.05)
	TDC	104.45 (3.36)	110.24 (3.02)	104.47 (4.40)	108.38 (4.12)
Working memory – SR	ADHD symptoms	103.56 (5.22)	98.90 (6.59)	95.63 (7.93)	97.73 (7.17)
	RD	94.68 (4.95)	92.78 (6.25)	97.53 (3.96)	97.69 (3.58)
	Co-occurring	103.56 (5.22)	105.09 (6.59)	102.56 (4.34)	107.83 (3.93)
	TDC	101.46 (3.50)	102.89 (4.42)	105.79 (3.55)	106.27 (3.21)
Working memory – SWM	ADHD symptoms	44.11 (5.13)	32.22 (5.79)	46.00 (9.58)	50.67 (10.25)
	RD	45.60 (4.87)	40.10 (5.49)	45.00 (4.79)	45.92 (5.12)
	Co-occurring	34.88 (5.44)	37.38 (6.14)	42.30 (5.25)	41.80 (5.61)
	TDC	44.84 (3.53)	34.00 (3.98)	32.79 (4.44)	38.14 (4.74)

(Continues)

TABLE 2 (Continued)

Outcome	Symptoms	Intervention		Control	
		Pre-mean (SE)	Post-mean (SE)	Pre-mean (SE)	Post-mean (SE)
Shifting – IED	ADHD symptoms	7.78 (0.29)	8.11 (0.33)	9.00 (0.67)	8.33 (0.67)
	RD	7.80 (0.28)	8.00 (0.31)	7.83 (0.33)	7.67 (0.34)
	Co-occurring	8.25 (0.31)	7.75 (0.35)	8.30 (0.37)	8.40 (0.37)
	TDC	8.68 (0.20)	8.42 (0.23)	8.07 (0.31)	8.43 (0.31)
Planning – SOC	ADHD symptoms	7.44 (0.53)	8.44 (0.67)	7.00 (0.96)	8.00 (0.92)
	RD	7.50 (0.51)	7.10 (0.64)	6.42 (0.48)	7.08 (0.46)
	Co-occurring	6.00 (0.57)	6.00 (0.71)	7.20 (0.53)	7.20 (0.50)
	TDC	7.47 (0.37)	8.00 (0.46)	7.21 (0.45)	7.79 (0.43)

Abbreviations: EA, expressive attention task from CAS; IED, Intra/extra-dimensional shift from the CANTAB; LR, Listening recall from AWMA; SDQ, Strengths and Difficulties Questionnaire; SE, Standard Error; SOC, stockings of Cambridge from the CANTAB; SR, spatial recall from the AWMA; SST, Stop signal task from CANTAB; SWM, spatial working memory between search errors from the CANTAB (NB lower score is better).

successful in other geographic regions and at other times of the year (e.g. winter rather than summer). The lead-in time before administration of the intervention may impact on attendance at an after-school programme; as many after-school activities are booked at the beginning of the school year, advertising and recruiting prior to this may reduce conflict of activities and increase attendance.

Preliminary estimates demonstrated that taking part in the intervention, which engaged pupils cognitively and in which almost half of the time was spent in MVPA, led to improvements in EF, specifically for inhibition and visuospatial working memory. These improvements were observed for all participant symptomatology groups; that is, irrespective of participants displaying high levels of ADHD symptoms or RD symptoms or being typically developing. Improvements were not found across all aspects of EF examined though, consistent with the findings from recent reviews of differential impact (Liang et al., 2021; Welsch et al., 2021). Indeed, the review from Welsch et al. (2021) reported a beneficial impact on working memory and shifting from all PA programmes for those with ADHD, but also that more cognitively demanding activity had a beneficial impact on inhibition while less cognitively demanding PA did not. Furthermore, Liang et al. (2021) also found a beneficial impact of PA on inhibition and shifting (aka cognitive flexibility) in their review and reported that PA of moderate intensity was more beneficial overall than light PA. Only three studies measured shifting in the Welsch et al. review and employed tasks with differing formats (e.g. Wisconsin Card Sorting Task) from that in the present study (CANTAB IED task). It is possible that an impact of the intervention might have been found for shifting in the present study with an alternative assessment method; future studies should consider the choice of assessment task carefully. Following the UK MRC Framework (Skivington et al., 2021), it is important to perform a definitive RCT to ascertain the true extent of the impact of this intervention (Craig et al., 2008) and consider as part of this, criteria for symptomology group membership. Based on the effect sizes observed in this study ($\eta^2=0.18$ for working memory), it is estimated that ~120 participants are required for an RCT with four groups of participants with the same outcome measures.

No changes were observed as a result of the intervention in habitual levels of MVPA though. This intervention was administered instead of standard PE due to logistical constraints within the participating school and did not explicitly aim to increase overall activity levels. This indicates that the improvements in EF observed were not due to changes in overall PA, although we do not know how much habitual PA pupils were accumulating during the course of the intervention. Instead, the findings suggest that improvements were linked to the nature of the school-based intervention (e.g. the cognitive load). Welsch et al. (2021) found that more cognitively demanding PA had a beneficial impact on inhibition, but that less cognitively demanding activity did not which aligns with the present findings. Indeed, it has been suggested that the cognitive demands of activity may be an important factor to consider and related to how long-lasting any beneficial impact on cognition is (Tomporowski, McCullick, Pendleton, & Pesce, 2015; Tomporowski & Pesce, 2019).

In addition, there were no changes in the overall fitness level of the participants. This is counter to previous research which has suggested that the relationship between PA and cognition is mediated by fitness level (Castelli et al., 2007; Visier-Alfonso et al., 2021) and instead suggests that the specific aspects of this intervention are sufficient to be beneficial. While participants took part in greater amounts of MVPA in the intervention sessions than might typically be experienced in usual school PE (Hollis et al., 2016), it will be important to measure habitual MVPA during the intervention period in further work to ensure an accurate picture of how much MVPA was being accumulated and understand any compensation

TABLE 3 Mixed ANOVA assessing difference in test scores before and after the intervention period for all who received intervention and separate ANOVA for the control group.

	Intervention						Control					
	Time		Symptomatology		Interaction		Time		Symptomatology		Interaction	
	***F* (*df*)**	η^2	***F* (*df*)**	η^2	***F* (*df*)**	η^2	***F* (*df*)**	η^2	***F* (*df*)**	η^2	***F* (*df*)**	η^2
SDQ Teacher	6.78 (1,47)*	0.13	2.10 (3,47)	0.12	0.45 (3, 47)	0.03	9.83 (1, 37)**	0.21	2.34 (3, 37)	0.09	3.50 (3, 37)*	0.22
SDQ Parent	2.10 (1, 25)	0.08	0.71 (3, 25)	0.08	0.28 (3, 25)	0.03	1.48 (1, 21)	0.07	1.75 (3, 21)	0.20	1.34 (3, 21)	0.16
Non-verbal IQ	2.21 (1, 42)	0.05	1.22 (3, 42)	0.08	0.75 (3, 42)	0.05	0.04 (1, 39)	0.00	1.17 (3, 39)	0.08	0.23 (3, 39)	0.02
Verbal IQ	0.29 (1, 42)	0.01	10.95 (3, 42)***	0.44	0.62 (3, 42)	0.04	12.06 (1, 39) **	0.24	4.36 (3, 39)*	0.25	2.97 (3, 39)*	0.19
Word reading	0.08 (1, 42)	0.00	13.69 (3, 42)***	0.49	0.98 (3, 42)	0.07	4.87 (1, 39)*	0.11	21.78 (3, 39)***	0.63	0.97 (3, 39)	0.07
Reading comprehension	4.30 (1, 42)*	0.09	12.16 (3, 42)***	0.47	0.88 (3, 42)	0.06	5.48 (1, 39)*	0.12	11.70 (3, 39)***	0.47	0.71 (3, 39)	0.05
Inhibition – EA	4.58 (1, 39)*	0.11	4.83 (3, 39)**	0.27	1.26 (3, 39)	0.09	4.12 (1, 31)	0.12	4.70 (3, 31)**	0.31	1.91 (3, 31)	0.16
Inhibition – SST	1.99 (1, 42)	0.05	0.73 (3, 42)	0.05	0.27 (3, 42)	0.02	4.10 (1, 35)	0.11	0.72 (3, 35)	0.06	1.34 (3, 35)	0.10
Working memory – LR	1.18 (1, 44)	0.03	4.33 (3, 44)**	0.23	1.34 (3, 44)	0.08	0.01 (1, 36)	0.00	2.12 (3, 36)	0.15	0.43 (3, 36)	0.04
Working memory – SR	0.18 (1, 44)	0.00	0.80 (3, 44)	0.05	0.50 (3, 44)	0.03	1.21 (1, 36)	0.03	1.45 (3, 36)	0.11	0.66 (3, 36)	0.05
Working memory – SWM	9.00 (1, 42)**	0.18	0.33 (3, 42)	0.02	2.16 (3, 42)	0.13	1.03 (1, 35)	0.03	1.12 (3, 35)	0.09	0.46 (3, 35)	0.04
Shifting – IED	0.17 (1, 42)	0.00	2.04 (3, 42)	0.13	1.84 (3, 42)	0.12	0.35 (1, 35)	0.01	0.93 (3, 35)	0.07	1.65 (3, 35)	0.12
Planning – SOC	0.71 (1, 42)	0.02	3.17 (3, 42)*	0.18	0.80 (3, 42)	0.05	4.51 (1, 35)*	0.11	0.61 (3, 35)	0.05	0.64 (3, 35)	0.05

Abbreviations: EA, expressive attention task from CAS; IED, Intra/extra-dimensional shift from the CANTAB; IQ, Intelligence Quotient; LR, Listening recall from AWMA; SDQ, Strengths and Difficulties Questionnaire; SOC, stockings of Cambridge from the CANTAB; SR, spatial recall from the AWMA; SST, Stop signal task from CANTAB; SWM, spatial working memory between search errors from the CANTAB (NB lower score is better).

$^*p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$.

which may have been occurring and to consider the role of fitness further.

This study extends work finding PA with a cognitive load to be beneficial for EF in children with ADHD (Welsch et al., 2021) and also suggests this may be useful in children with reading difficulties. No positive impact of the intervention was found on symptomatology though for either ADHD symptoms or reading ability which is counter to findings from (Gapin et al., 2011). Reading scores were found to improve with time which may be a product of the repeated administration of the task. It is possible that an alternative assessment task may have been more sensitive to group differences though. As this is a preliminary evaluation it is possible that the administration of a larger-scale RCT may find a wider range of benefits however careful consideration should be given when choosing instruments.

Study strengths, limitations and future directions

In this study we were successful in recruiting and retaining a reasonable sample of participants with varying symptomatology levels to complete a wide battery of tasks before and after a 12-week intervention programme. Our sample size is small, although typical of research in this area with neurodiverse populations (Bikic et al., 2018; Downs et al., 2016). Furthermore, missing data was a challenge, in some part due to the complexity of gathering information from multiple informants (pupils, parents and teachers). We employed an intention-to-treat approach and LOCF method for data imputation in order to provide a conservation estimate of the impact of the intervention though. However, our pilot analysis should be interpreted with caution and effect sizes used to determine the sample size for subsequent research, rather than over-interpreting these preliminary findings. While participants are representative of children in a typical mainstream classroom in the UK, only a small number ($n=2$) provided evidence of a confirmed specialist diagnosis of ADHD. These participants were not asked to stop medication and it may be that different effects of the intervention may have been found if participants had been recruited through an alternative setting and a clinical diagnosis required and/or medication paused. The age range of the sample could be considered a limitation as there may be a differential impact on younger children compared to older children, some of which may already have entered puberty. However, this study demonstrates that the intervention is suitable for participants found in a typical mainstream classroom in the UK across a wide age range, therefore demonstrating generalisability.

The administration of the intervention as an after-school activity may be a useful mechanism to support an addition to standard school PE. We identified several challenges in recruitment and discussion with parents identified time and location as key barriers to participation. Our findings suggest that administering the intervention within ADHD support groups or as additional support during school time may be more successful and may increase participation from young people with a confirmed ADHD diagnosis which should be explored in future research. Future research should also randomise participants to receive the intervention and include follow-up of participants after the end of the active intervention period. This was not possible in the present pilot work due to resource limitations and school term dates, however, this is important to build into future work in this area.

CONCLUSIONS

Taking part in a PA intervention involving an increasing cognitive load was beneficial for inhibition and visuospatial working memory in young people with high levels of ADHD symptoms, reading difficulties and those with co-occurring problems as well as typically developing participants. This study's findings suggest this programme should be explored more widely and a definitive RCT conducted, especially as it has been suggested that physical activity may have benefits similar to psychostimulant medication and potentially provide a viable alternative (Ng et al., 2017). Evidencing the broader beneficial impact of a promising PA intervention may also help to address the pandemic of inactivity.

AUTHOR CONTRIBUTIONS

JNB, PDT, BAM, JMEB and JJR were responsible for the study design and conceptualisation. IAM administered the intervention, collected the data and contributed to the analysis. JNB conducted the analysis and drafted the manuscript. All authors were involved in the interpretation of the data, critically reviewing the manuscript and approving the final version of the manuscript.

ACKNOWLEDGEMENTS

We would like to acknowledge the assistance of Mariel Symeonidou, Elaine Hutton and Gemma Gill with data collection. We would also like to thank Dundee & Angus ADHD Support Group for assistance with study recruitment. We extend sincere thanks to all the participants, their parents and schools for taking part and supporting this work.

FUNDING INFORMATION

This work was funded by a grant from the Waterloo Foundation to the authors (grant number: 1283-1982).

CONFLICT OF INTEREST STATEMENT

The author(s) declare that they have no competing interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ETHICS STATEMENT

This study followed ethical guidance from the British Psychological Society (BPS) code of ethics and conduct. Ethical approval was granted by the University of Dundee ethics committee. All participants and their parents gave fully informed written consent to participate.

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How to cite this article: Booth, J.N., Mitchell, I.A., Tomporowski, P.D., McCullick, B.A., Boyle, J.M.E. & Reilly, J.J. (2023) Evaluation of a pilot physical activity intervention for children with ADHD symptoms and reading difficulties. *Journal of Research in Special Educational Needs*, 00, 1–15. Available from: https://doi.org/10.1111/1471-3802.12628