

# Northumbria Research Link

Citation: Daly-Smith, Andy, McKenna, Jim, Defeyter, Margaret Anne (Greta) and Manley, Andrew (2017) A review of school-based studies on the effect of acute physical activity on cognitive function in children and young people. In: Physical Activity and Educational Achievement : Insights from Exercise Neuroscience. Taylor & Francis, London, pp. 277-392. ISBN 9781138234970

Published by: Taylor & Francis

URL:

This version was downloaded from Northumbria Research Link:  
<http://nrl.northumbria.ac.uk/id/eprint/32233/>

Northumbria University has developed Northumbria Research Link (NRL) to enable users to access the University's research output. Copyright © and moral rights for items on NRL are retained by the individual author(s) and/or other copyright owners. Single copies of full items can be reproduced, displayed or performed, and given to third parties in any format or medium for personal research or study, educational, or not-for-profit purposes without prior permission or charge, provided the authors, title and full bibliographic details are given, as well as a hyperlink and/or URL to the original metadata page. The content must not be changed in any way. Full items must not be sold commercially in any format or medium without formal permission of the copyright holder. The full policy is available online: <http://nrl.northumbria.ac.uk/policies.html>

This document may differ from the final, published version of the research and has been made available online in accordance with publisher policies. To read and/or cite from the published version of the research, please visit the publisher's website (a subscription may be required.)

## **A review of school-based studies on the effect of acute physical activity on cognitive function in children and young people.**

### **Introduction**

Since the 1990s, a body of literature has emerged investigating the impact of single - acute - bouts of physical activity on cognitive function. To establish the underlying mechanisms, studies were first conducted on mice before progressing to humans in laboratory-based studies (Hillman et al., 2009). Recently, work has focused on settings with potential for establishing translational merit; testing the impact of acute bouts of physical activity delivered in schools. This research has focused on classroom exercise breaks and aerobic exercise or cognitively-engaging physical activity outside of the classroom environment.

This chapter reviews literature regarding the impact of different physical activity modes on cognition within the school environment. First, a definition of cognition will be provided along with an outline of the underlying cognitive processes. Next, current issues in physical activity will be discussed with specific reference to quantifying the participant experience. Each of the three acute intervention types will be discussed in turn; *classroom exercise breaks*, *aerobic exercise outside of the classroom*, and *cognitively-engaging physical activity outside of the classroom*. The chapter concludes with a summary, drawing conclusions based on existing evidence, followed by recommendations for practice and future research.

### **Cognition in the 21st century school**

Cognition refers to “a series of mental processes that contribute to perception, memory, intellect and action” (Donnelly et al., 2016, p. 1198). Within school, these processes are essential to processing new information, manipulating information in the mind and goal directed behaviours. It is assumed that acute exercise improves cognition through metabolic changes which occur both during and post exercise (Tomporowski, McCullick, Pendleton, & Pesce, 2015). While these effects are unlikely to endure, enhanced learning may occur through increased processing speed and/ or accuracy. Demonstrating these effects very precisely will be important to galvanise the energy of teachers to promote physical activity throughout the school day. Given the scale of need in many schools today to engage 21st century children these issues are given even greater prominence. Prior to reviewing the current literature, it is important to understand which tasks provide a measure of each cognitive process.

Confusingly, many studies assess one aspect of cognition and will wrongly assert that exercise “does/ does not improve cognitive function”. While the majority of cognitive tasks use multiple concurrent processes rather than a single one, more precise reporting is required than within some of the individual studies summarised in the following review; this enhanced precision will aid the understanding of practitioners and researchers alike. A further limitation is that measures such as speed and accuracy only provide indirect evidence about internal cognitive processes. While they clearly demonstrate children’s response to an imposed task, they do not explain how internal processes occur to facilitate learning. Despite these limitations, cognitive psychologists have developed strategies to discover the cognitive processes involved in a number of commonly-used cognitive tasks.

For the teachers and practitioners to fully understand the role of physical activity in cognition, it is important to express what we grasp about cognition and how physical activity might make a difference. We begin by focusing on human memory, the distinction between short-term and long-term memory, working memory and the central executive. Many prominent psychologists have argued that the central executive is the most important component of working memory. Establishing how physical activity plays a role in extending working memory will refine understanding of its relevance to 21st century learning.

Baddeley and Hitch (1974) argued that short-term memory is essential to performance on a number of complex tasks that are not explicitly memory tasks. A good example is that of mental mathematics. Mentally adding a string of numbers together requires that each addition results in a new total that must be remembered to generate the next number. This process continues to establish the final answer. Based on this thinking, Baddeley and Hitch (1974) replaced the concept of short-term memory with that of working memory. This is essential for any young person to thrive in contemporary learning environments.

As an example of the complexity in this area, their latest memory model has four components: a central executive; a phonological loop; a visuo-spatial sketchpad; and an episodic buffer (Baddeley, 2012). With four distinctive areas this gives an indication of the many ways in which physical activity might play a role in enhancing cognition in young people. The central executive itself does not store information, but acts as an “attentional system” and is a vital component in nearly all complex cognitive activities commonly faced by children in the classroom including multi-tasking and problem-solving. The phonological loop processes and temporarily stores information in a phonological form which may be a challenge for schools with high linguistic diversity. The visuo-spatial sketchpad processes and temporarily stores spatial and visual

information, which may have relevance for children who lack spatial awareness. Finally information from the phonological loop and the visuo-spatial sketchpad is stored in the episodic buffer. Clearly anything that expands the episodic buffer will benefit learning.

Even though the central executive has been claimed by many to be the most important, it does not store information; rather it resembles an attentional system. Baddeley (2012) acknowledged that the central executive is associated with a number of executive processes; focusing attention, dividing attention, switching attention, and interfacing with long-term memory are examples. To-date there is no overall consensus amongst scientists on the number of executive processes. While there is no agreement, it is important to understand the processes that play a role in completing the tasks that are used to indicate cognitive performance.

Expanding one framework from among many provides an insight into learning in humans. Within the framework of Miyake et al. (2000), the term 'executive function' (EF) is used to account for what is common to the three functions they identified; inhibition, shifting, and updating. Typically, inhibition is used to resist distraction, a familiar problem for many pupils. An excellent example of use of this function is in the well-known Stroop task in which rather than name a colour word people have to name the colour in which it is printed. This is easy when the colour name and the colour of the ink are congruent (e.g., RED printed in red) as no inhibition is required. However, in cases where the dominant response needs to be inhibited (e.g., the word RED printed in yellow) it is far more difficult. The shifting function is used to switch attention between tasks often seen within classroom lessons. Common assessment of shifting include the more-odd task or modified flanker test (Chen, Yan, Yin, Pan, & Chang, 2014; Jäger, Schmidt, Conzelmann, & Roebers, 2015). Updating, as usually measured by N-back tests, monitors rapid addition or deletion of working memory contents (Jäger, Schmidt, Conzelmann, & Roebers, 2014; 2015)

While working memory is important, the role of long-term memory in storing information is equally important. This schematic knowledge is extensively used during language comprehension for example when a pupil attempts to follow instructions provided by PE teachers. Although there are some similarities between episodic and semantic memory, it is generally accepted that they form separate memory systems, giving rise to speculation about specific physical activity effects. Recognition and recall are commonly used to assess episodic memory. Recognition memory is often tested by presenting a list of words or pictures and then later presenting the same stimuli alongside distractor items and simply asking participants if they have seen the item before. Typically, pictures are remembered better than words; the so called

‘picture superiority effect’ (Defeyter, Russo, & McPartlin, 2009). There are three forms of recall memory test: serial recall, free recall, and cued recall. Better understanding of the nuances of working and long term and memory and how physical activity plays a role in affecting these processes will be important for teachers preparing pupils for assessment and exams.

Another example of a title that has many facets is attention. This is a well-researched area due to its importance in everyday life and prediction of school achievement (Steinmayr, Ziegler, & Träuble, 2010). Although attention is cross modal, the majority of researchers have examined the effects of physical activity on visual attention. Posner (1980) proposes visual attention acts as a spotlight, while others have suggested a more flexible approach using the analogy of a zoom lens (Eriksen & St James, 1986). A third, and less well supported, approach uses the analogy of multiple spotlights, where attention can be split between two or more regions of space not adjacent to each other (Awh & Pashler, 2000). Essential to learning, visual attention enables an individual to process information while resisting distractors within a single task or across multiple tasks.

In the cognitive psychology literature, it is important to distinguish between selective - or focused - attention, divided attention, sustained attention, and mental shifting. Selective attention, as measured by the d2 Test of Attention (Schmidt, Egger, & Conzelmann, 2015), is the most assessed cognitive process within studies investigating the impact of acute physical activity on cognition. Within the test, participants are required to highlight correct letters presented among a string of distractors. In divided attention tasks, participants are also presented two or more stimuli at the same time, responding to all of the stimuli; rather like multitasking in everyday life. The distinction between selective and divided attention tasks is important as the former provides information on the nature of the selection process and the role of distractors, while the later provides information about processing capacity and limitations. Sustained attention refers to the ability to maintain attention and respond consistently to a stimulus during a repetitive or continuous activity. Finally, altering attention or mental shifting is the process of shifting attention from one task to another as required.

In addition to being able to attend to stimuli in the external world, it is also important for humans be able to plan efficiently. Planning, a higher order executive function, refers to the formation and management of goal directed behaviour (Diamond, 2013). An essential facet of educational achievement, planning supports organising a study timetable or the management and completion of school projects. Currently, only a limited number of studies have investigated the impact of acute physical activity on planning within the school environment providing opportunity for

further investigation. Common tests to assess planning function include the trail making test and the dot task (Kubesch et al., 2009; Pirrie & Lodewyk, 2012).

## **Conclusions**

The core thread of this chapter is while it is inappropriate to use a single label for cognitive processes that have multiple dimensions, it is equally inappropriate to use single tests to represent whole systems as complex as cognition. Researchers need to be cautious of attributing performance on cognitive tasks to one specific cognitive process and carefully consider the effect of cognitive load. Furthermore, researchers also need to ensure that cognitive tasks use age-appropriate stimuli and instructions, and that chronological age groups are theoretically underpinned in the cognitive developmental literature, rather than being based purely on opportunistic sampling. Further research is required to examine the effects of MVPA on a wider range of cognitive processes. While the above chapter has focussed on linking cognition to the school environment and the role of teachers may play in supporting this, parents and sports coaches also need to be aware of the role of cognition in the development of children and young people, enabling them to reach their potential.

## **Acute study physical activity considerations**

A recent systematic review (Donnelly et al., 2016) found that single bouts of physical activity positively impact children's cognitive performance. Closer inspection of the contributing studies and subsequent literature makes our interpretation more cautious. Prior to reviewing the contribution of each study, it is essential to present a physical activity framework within which the school-based literature can be analysed and more clearly understood. When designing a single bout of physical activity, many authors refer to the quantitative and qualitative aspects of exercise (Pesce, 2012).

Distinctive from the incidental activity associated with 'physical activity', "quantitative exercise" is the subset of activity that is planned, structured and repetitive (Shephard & Balady, 1999). Using the American College of Sports Medicine (ACSM) FITT-VP principle (frequency, intensity, time and type - volume and progression), this focuses on the intensity and time (duration of bout). Exercise mode requires minimal skill, focusing on rhythmic movement such as walking, jogging, running or aerobic circuits. As the activity requires minimal skill, participants are able to focus on maintaining the prescribed intensity, often moderate to vigorous in nature (ACSM, 2014). Examples of this approach within the research include; steady state

jogging (Chen et al., 2014), dance videos (Altenburg, Chinapaw, & Singh, 2015), and aerobic circuits (Gallotta et al., 2015).

In recent years, researchers have developed interventions to assess the impact of cognitively-enhanced physical activity on cognition ((Budde, Voelcker-Rehage, Pietrabyk-Kendziorra, Ribeiro, & Tidow, 2008; Jäger et al., 2015; Schmidt et al., 2015). Termed “qualitative exercise” (Pesce, 2012), this involves physical activities that also impose cognitive demands on the individuals. Cognitive load is achieved through a range of modes. Recent studies by Jager and colleagues (2014, 2015) used cognitively enhanced games focused on activating one or more executive processes. Alternatively, Gallotta et al. (2015) used activities which combined gross-motor, manipulative control and perceptual-motor adaptation abilities. Such varied approaches produce two challenges in interpreting study outcomes. First, the cognitive demands of such activities may not be clear (Furley & Wood, 2016). Currently with no body of literature that details how activities link to different cognitive processes, it is difficult to interpret the specific cognitive impact. Second, while the focus of qualitative exercise sessions may be to engage young people in cognitively demanding physical activity, there are still quantitative outcomes such as duration and intensity to address. To confirm the “qualitative effects” a comparator “quantitative experience”, equal in duration and intensity, might be included within studies. To-date, few investigations have deployed this design (Budde et al., 2008; Jäger et al., 2015).

Comparing the different studies gives rise to a final challenge. In laboratory studies, researchers using steady-state exercise assess treatment fidelity through heart rate, often presented as group means (Hillman et al., 2009). This approach has been transferred, seemingly unquestioningly, to studies within school environments. Due to the intermittent nature of young people’s physical activity experiences, this poses challenges for interpreting the quantitative demands of the session (Bailey et al., 1995). First, heart rate has a delayed response to changes in the mechanical demands of exercise (Rowlands & Eston, 2007). Second, during game-based sessions, exercise is often intermittent in nature with a high degree of inter-individual variation. The result is that two individuals may engage very differently within the same acute bout. Within translational physical activity research with children and young people, accelerometers are increasingly regarded as the gold standard assessment tool, providing accurate interpretation of activity patterns, intensity and duration (Corder, Ekelund, Steele, Wareham, & Brage, 2008).

*INSERT FIGURE ONE HERE*

Figure one shows physical activity profiles, collected through accelerometry, of two different children taking part in the same game-based physical education session. On average, the two individuals accumulated 11 minutes of moderate to vigorous physical activity. Closer inspection of the physical activity traces shows a high degree of variability between the two individuals regarding total time engaged in moderate intensity or above. A recent meta-analysis found that a minimum engagement of 11 minutes at moderate intensity resulted in significant improvements in cognitive engagement (Chang, Labban, Gapin, & Etnier, 2012). In figure one, child A achieved five minutes of MVPA, while child B achieved 17 mins. Monitoring this individual variability and then factoring this into the statistical analyses is fundamental to developing a precise understanding of how acute physically activity bouts impact on cognition.

It is also important to consider the type of activity, as indicated along the x-axis within figure one, when analysing and interpreting such statistical data. During the first activity that focused on steady state walking, jogging and running, the intensity and duration profiles are similar. Within the second activity, a team game, there is high individual variability in both the duration and the intensity of the exercise. In the final activity, an active story, a large degree of variability in activity duration and intensity is again observed. Within the review which follows, identification of the physical activity profiles and corresponding modes of activity will provide an opportunity to evaluate the trustworthiness of study outcomes.

## **Conclusions**

In summary, the current literature can divide studies into quantitative and qualitative exercise. Quantitative exercise focuses on pre-determined intensity and duration and is often moderate to vigorous in nature. Qualitative physical activity has a direct or indirect cognitive requirement; often this arises from the activity being specifically designed to include cognitive challenges, and may include playing sport or learning new skills. Following sections will review current literature on acute bouts of physical activity within the school environment discussing the potential consequences of the issues raised on the cognitive outcomes.

## **Review of the literature**

To identify relevant articles, a two-step search strategy was used. First, a search of relevant databases (SPORTDiscus and PubMed) was undertaken. Second, a manual search of the reference lists of all included papers was completed. Studies were included if they met the following criteria; (i) the study was conducted within the school environment with children or

young people (<17 years of age), (ii) an acute bout of physical activity was compared to a control condition, (iii) one or more cognitive assessments were performed. The temporal threshold for including papers in this review was 2006, producing 20 studies over a particularly important decade of new work. This was justified by finding the first important study in 2008 followed by a mushrooming of work to the present day. These 20 studies were then divided into three sub-categories; (i) Classroom-based exercise breaks (CEB), (ii) Aerobic exercise outside of the classroom (AE-OC), (iii) Cognitively-enhanced physical activity outside of the classroom (CEPA-OC). A number of studies appeared in more than one sub-category due to multiple treatment interventions.

In the following subsections, for the physical activity and cognitive tests, we refer readers to the original source for the description and validity of the respective methods.

*INSERT TABLE ONE HERE*

### **Classroom-based exercise break (CEB)**

#### *Summarising table one*

Four peer-reviewed papers were identified that examined the impact of an acute classroom exercise break on cognition (Table 1, studies 1-4). Across the four papers, sample size varied from 88 (Ma, Le Mare, & Gurd, 2015) to 1224 (Hill et al., 2010), with a mean of 368 participants (girls=52%) per study. All studies focused on children aged 8-13 years old. Two studies were conducted in Europe (the Netherlands and UK), one in the US and one in Canada. This highlights a lack of replication of studies within the same school systems.

Across the four studies, of 10 cognitive assessment outcomes - compared to controls - there were two positive, five no-difference and three mixed outcomes. There were no negative outcomes. The two positive outcomes were observed when testing protocols did not control for day-to-day variation in cognition; this would be furnished by including pre-intervention measures (Hill et al., 2010; Ma et al., 2015). More recent studies using pre-post designs concluded no change in cognition. Treatment fidelity was difficult to ascertain; no studies accounted for variability of individual engagement within the session. Two studies reported group level engagement; one via heart rate (van den Berg et al., 2016) and the other through direct observation-using SOFIT (Howie, Schatz, & Pate, 2015; System for Observing Fitness Instruction Time). Two studies provided no assessment of the resulting duration and intensity of the exercise (Hill et al., 2010;

Ma et al., 2015). Superficially, the strength of evidence suggests CEBs do not lead to improvements in cognition, but there are important issues with treatment fidelity. Current CEB study designs may not elicit sufficient exposure to MVPA to generate improvements in cognition; papers often claim higher exposure than was confirmed by evidence of engagement.

### *Detail emerging from table one*

Exercise breaks within the classroom (CEB) have varied in duration from four (Ma et al., 2015) to 20 minutes (Howie et al., 2015). Activities focused on aerobic - on the spot - activity involving; marching with arm movements, jogging, running, jumping and hopping. The activities seem to be quantitative in nature, simple, and repetitive with a low cognitive load (Pesce, 2012). Only one study expanded beyond an aerobic focus to look at three different intervention types; aerobic, strength and coordination (van den Berg et al., 2016).

Selective attention was the most commonly assessed cognitive process, followed by information processing, working memory and planning. Assessed across three studies, selective attention showed positive change (Hill et al., 2010), no change (van den Berg et al., 2016) and mixed results (Ma et al., 2015). Following a 10-15 minute CEB, Hill et al. (2010) assessed selective attention using the digit symbol-coding task, finding improvements in the second week of testing. In contrast, van den Berg et al. (2016) found no change in overall selective attention (assessed by the d2-test) following three separate 12-minute bouts of exercise. In comparison, Ma et al. (2015) reported that four minutes of high-intensity interval exercise improved accuracy on the d2-test, although the total number of items processed by participants decreased. Unfortunately, no data was presented to account for the speed-accuracy trade off, which limits our ability to make direct comparisons. The two studies which assessed information processing found no change in speed or accuracy immediately post-physical activity (van den Berg et al., 2016) nor after a 60-minute delay (Hill et al., 2010), as measured by the letter digit substitution test and the paced serial addition task, respectively.

Working memory - assessed immediately after a five, 10- or 20-minute CEB - showed no change when assessed by the digit recall test (Howie et al., 2015). Further, in Hill et al (2010), after a 60-minute delay post-exercise, no improvements were observed in a size-ordering task. In the same study, positive improvements were observed in the listening span and digit span backwards tests. Only Howie et al. (2015) assessed planning ability using the trail making task; no change was observed in performance between conditions.

In summary, recent studies have demonstrated some improvements in cognition in association with CEB, principally in selective attention. Some of these effects have been observed immediately post-exercise and after extended delays. The majority of evidence shows no change, meaning we should currently be cautiously optimistic about the benefits of such active breaks. One reason for optimism stems from our understanding of CEB. While the prescribed duration and intensity of the breaks is *theoretically* sufficient to lead to changes in cognition, more evidence needs to be presented to confirm the treatment fidelity of the intervention, especially given that laboratory-based studies dominate this area. The only study to confirm engagement showed that children were active for 40% or less of the session duration (van den Berg et al., 2016). Future studies must confirm exposure to the active components of CEBs using more accurate methods. In addition, a wider array of cognitive domains should be examined. So far, no studies have assessed inhibition, updating, shifting, reaction time or recall.

*INSERT TABLE 2 HERE*

### **Aerobic exercise outside of the classroom (AE-OC)**

#### *Summarising table 2*

Thirteen peer-reviewed papers examined the impact of an acute bout of aerobic activity outside of the classroom on cognition (AE-OC; Table 2, studies 5-17). Across the 13 papers, sample size varied from 33 (Etnier, Labban, Piepmeier, Davis, & Henning, 2014) to 234 (Jäger et al., 2015), with a mean of 93 participants (girls=50%) per study. All studies focused on children aged 8-14 years. Ten studies were conducted in Europe; three in Italy ([Gallotta et al. 2012; 2015; Pesce et al. 2009](#)), two in the Netherlands (Altenburg et al., 2015; Janssen et al., 2014), two in Germany (Kubesch et al., 2009; Niemann et al., 2013), two in the UK (Cooper, Bandelow, Nute, Morris, & Nevill, 2012; Pirrie & Lodewyk, 2012) and one in Switzerland (Jäger et al., 2015). Of the remaining studies, two were conducted in the USA (Etnier et al., 2014; Tine & Butler, 2012) and one in China (Chen et al., 2014).

Across the studies, of 39 cognitive assessment outcomes there were seven positive, 23 no-difference, nine mixed, and zero negative when comparing the AE-OC to control conditions. Seven studies, the majority, assessed treatment fidelity at the group level presenting mean HR data and/or the percentage of time spent in activity thresholds ([Chen et al. 2014; Cooper et al. 2012; Gallotta et al. 2012, 2015; Jäger et al. 2015; Pesce et al. 2009; Pirrie and Lodewyk 2012](#)). Two studies did not record the intensity and/or duration of the physical activity bout (Etnier et

al., 2014; Kubesch et al., 2009). Three studies attempted to control for individual variation in engagement during the acute bout; one provided feedback through HR monitors to participants during the bout (Niemann et al., 2013) and two withdrew participants from their analysis who did not meet the required HR intensity (Altenburg et al., 2015; Tine & Butler, 2012). The final study assessed engagement through accelerometry. Participants who accumulated <12 minutes MVPA were withdrawn from the analysis, ensuring treatment fidelity at the individual level (Janssen et al., 2014). A range of activities were used to elicit a moderate-high intensity, examples included; running games (Jäger et al., 2015), steady state jogging (Chen et al., 2014), maximal tests (Etnier et al., 2014), dance videos (Altenburg et al., 2015) and aerobic circuits (Gallotta et al., 2015; Pesce et al., 2009).

### *Detail emerging from table 2*

A range of cognitive domains were tested directly after the exercise bout, the most common being inhibitory control and selective attention. Beginning with inhibitory control, two studies reported conflicting results. After a 30-minute Physical Education (PE) session on aerobic exercise, Kubesch et al. (2009) revealed a significant improvement in immediate inhibitory control performance assessed by the flanker test, but not when assessed by the DOT test. In contrast, (Jäger et al., 2015) reported no change in immediate flanker test performance after 20 minutes of running games, regardless of fitness level or academic ability. Studies, which delayed the post-exercise test, found differing results. Ten minutes after the session, no change was found in inhibitory control assessed by the Stroop test after a heart smart aerobically focused PE lesson (Pirrie & Lodewyk, 2012). After 25 minutes, following 30 minutes of continual jogging, an improvement in inhibitory control processing speed was found on a flanker test (Chen et al., 2014). An extended delay of 45 minutes or more found no difference in scores between aerobic shuttle runs and an aerobic exercise group compared to sedentary control conditions (Cooper et al., 2012; Kubesch et al., 2009). In summary, improvements in inhibition following aerobic exercise are mixed, some suggesting increased performance and others no difference.

A similar pattern emerges for selective attention. Twelve minutes of high-intensity running (Niemann et al., 2013; Tine & Butler, 2012) and 15 minutes of moderate, but not vigorous, aerobic activity (Janssen et al., 2014) improved immediate selective attention on the d2-test and sky search tests respectively. Yet, contrary to these observed improvements, a 50-minute aerobic circuit elicited no change in immediate performance on the d2-test (Gallotta et al., 2015). Two studies assessed selective attention after an extended delay following the acute bout. Gallotta et al. (2015) assessed selective attention again following a 50-minute delay. Overall improvement

did not differ from that of control conditions, yet the percentage error rate increased slightly, suggesting a reduction in performance following this extended delay. In contrast, after two repeat 20-minute bouts of exercise conducted during a simulated school morning, sky search test performance was highest in the intervention group at 90 and 200 minutes post-exercise (Altenburg et al., 2015). This suggests that acute exercise repeated across a school morning can improve selective attention of children when placed between learning activities.

Further cognitive processes have been investigated in relation to acute aerobic exercise. Working memory assessed through the N-back test (Chen et al., 2014) and Sternberg test (Cooper et al., 2012) found improvements in processing speed after delays of 25 minutes and 45 minutes, respectively. The exercise mode, intensity and duration varied greatly from 30 minutes of continuous jogging (Chen et al., 2014) to 10 minutes of repeated shuttle running (Cooper et al., 2012), suggesting that exercise volume (duration x intensity) may play a role in promoting cognitive benefits. This same study also investigated the impact of exercise on shifting, assessed by a more-odd task, finding that processing speed improved with no differences in accuracy. The only other study to investigate changes to shifting found no significant changes on a modified flanker test (Jäger et al., 2015). Two studies have investigated the effects of acute aerobic exercise on the higher order executive function, planning. Both studies used an aerobically-focused PE lesson, where a 60-minute lesson led to increased performance on trail making test (Pirrie & Lodewyk, 2012), while a 30-minute lesson showed no change in performance either immediately after exercise or after the following maths lesson on the DOT task (Kubesch et al., 2009). In summary, there is emerging evidence to support positive impact of acute exercise on working memory. Currently, the findings for shifting and planning are equivocal, and warrant further investigation.

A small number of studies have investigated wider cognitive abilities, including information processing, reaction time, and immediate/delayed recall. For instance, Cooper et al. (2012) reported that information processing speed improved 45 minutes after completing a 10-minute bout of shuttle running, although a significant reduction in accuracy was observed, suggesting a speed accuracy trade-off. Kubesch et al., (2009) recorded no changes in reaction time, assessed by the DOT task, immediately after exercise and following an extended delay. For immediate recall, conflicting results have been found. Pirrie and Lodewyk (2012) observed no improvements in a sentence repetition test following aerobic exercises. In contrast, Pesce et al (2009) found improvements in primary and recency effects but not overall performance on an immediate free-recall memory test. Following a 12-minute discussion, delayed recall was then assessed. Significant improvements were observed in recency effects but not primary or overall

effects. Similarly, Etnier et al. (2014) reported a significant improvement in immediate RAVALT test performance following a PACER test. These improvements were maintained in delayed recall 12 minutes after the initial test, but not 24 hours later.

*INSERT TABLE 3 HERE*

### **Cognitively-enhanced physical activity outside of the classroom (CEPA-OC)**

#### *Summarising table 3*

Seven peer-reviewed papers examined the impact of an acute bout of cognitively enhanced physical activity outside of the classroom on cognition (CEPA-OC; Table 3, studies 5, 6,14,16,18-20). Sample size varied from 52 (Pesce et al., 2009) to 234 (Jäger et al., 2015), with a mean of 115 participants (girls=46%) per study. Participants within these studies were predominantly aged 8-12yrs ([Gallotta et al. 2012; 2015; Jäger et al. 2015; Pesce et al. 2009; Schmidt et al. 2015](#)), although one study included younger children aged 6-8 years (Jäger et al., 2014), and another young people aged 15 years (Budde et al., 2008). All studies were conducted in Europe; three in Switzerland (Jäger et al., 2014, 2015; Schmidt et al., 2015) , three in Italy ([Gallotta et al. 2012; 2015; Pesce et al. 2009](#)) and one in Germany (Budde et al., 2008).

Across the seven studies, of 17 cognitive assessment outcomes - compared to controls - two were positive, nine showed no difference, one was negative and five mixed. Treatment fidelity was difficult to ascertain; studies only reported mean group heart rates, meaning that full engagement of each participant could not be confirmed. Furthermore, the duration of the bouts varied widely, short sessions lasted <10 minutes (Budde et al., 2008) while other sessions lasted up to 50 minutes ([Gallotta et al. 2012, 2015](#)). In addition, the type of cognitively-engaging physical activity varied widely, with examples including; bilateral coordinate exercises (Budde et al., 2008), cooperative and competitive games requiring executive function (Jäger et al., 2014, 2015), team games (Pesce et al., 2009), cognitively-demanding exercise circuits (Schmidt et al., 2015) and movement-based problem solving and decision-making tasks ([Gallotta et al. 2012, 2015](#)). Given all these factors, all related interpretations and conclusions require due caution.

#### *Detail emerging from table 3*

Selective attention, consistently assessed by the d2 test, was the most commonly examined cognitive process. The first study in the field assessed the impact of bilateral coordinate exercise

on selective attention (Budde et al., 2008). Findings showed that, compared to a moderately-active control, speed and accuracy significantly improved within CEPA-OC participants immediately after exercise. In contrast, more recent research found a 45-minute cognitively-demanding exercise circuit showed no immediate improvements in selective attention (Schmidt et al., 2015). Yet, after a delay of 90 minutes, the intervention group, compared to sedentary controls, improved their attention scores for speed only, as well as combined speed and accuracy scores. The first of two studies by Gallotta et al. (2012) found no change in selective attention immediately following movement-based problem-solving and decision-making tasks. In a follow-up study, focused on immediate and delayed cognition, mixed results were found. Immediately post-intervention, speed decreased, with accuracy and combined speed remaining consistent. After a 90-minute delay, the combined speed and accuracy remained consistent but accuracy decreased (Gallotta et al., 2015).

Conflicting results were reported within a series of studies investigating the impact of a cooperative and competitive games session requiring executive function on inhibition control, updating and shifting (Jäger et al., 2014, 2015). In the first study, compared to sedentary controls, CEPA-OC resulted in improved inhibitory control immediately post-exercise, with no change observed in updating or shifting (Jäger et al., 2014). To identify whether this improvement was due to the quantitative characteristics or the cognitively-engaging activity, a four-arm follow-up study was conducted. This study compared aerobic exercise, cognitively-challenging physically active games, a cognitively-challenging sedentary session, and a non-cognitively-engaging sedentary session (Jäger et al., 2015). Immediately post-exercise, inhibition and shifting improved across all conditions, although no differences were observed between groups. Refined analysis revealed that students with higher fitness and academic achievement levels improved their updating scores compared to less fit individuals or lower academic achievers. This suggests that exercise may have differing effects on cognition due to personal characteristics. Follow up studies are required to confirm that these effects truly exist.

Finally, Pesce et al., (2009) investigated the impact of team games on immediate and delayed recall. Immediately following team games, significantly higher rates of primacy and recency but not total number of recalled items were observed compared to the sedentary control condition, with no difference found for aerobically based exercise. For delayed recall (i.e., 12-minutes post-session), both team games and aerobic exercise elicited improvements in recency items but not primacy or overall effects.

In summary, while the positive effects of CEPA-OC appear limited, beneficial effects have been observed. The strongest positive outcomes are found within selective attention, mainly due to the volume of research being conducted within this cognitive domain (Budde et al., 2008; Schmidt et al., 2015). Inhibitory control has been seen to improve immediately post-exercise, although these benefits were not sustained 45 minutes later (Jäger et al., 2014), or confirmed in a follow-up study (Jäger et al., 2015).

## **Implications and future directions**

We are confident in making the following recommendations precisely because the studies pool the recent evidence established using powerful research designs. Given the translational nature of the data, the strengths and limitations are so tightly intertwined that they relate to both research and implementation. The key issues will now be addressed.

### ***What is common?***

*Task impurity affects both the assessment of cognition and of physical activity.* Within different cognitive assessments it is likely that more than one cognitive process is being measured. While researchers would be wise not to elevate an outcome from one measure (e.g. Inhibition control-Stroop Task) to claim ‘improved executive functioning’, a nod should be made to other cognitive domains that may have been challenged within the test. Within physical activity, there was high variability in the activity that was completed, despite authors’ claims for uniformity. Handling the variability inherent to each component of the FITT-VP framework illustrates the scale of the challenge here.

*Few studies are replicated within school systems.* Obviously, this field of research examining cognition, within the school environment, in children and young people is still in its infancy. At present, studies are spread across countries with little replication within country. For example, in table one, of only four studies, each was conducted in different countries and therefore, in widely differing school systems. Confirmatory studies are needed to establish outcomes. With proof of concept, international studies should be conducted.

### ***What is specific to the physical activity experience?***

*Confirming the dose establishes face validity of both the treatment and the control conditions.* Currently, due to measurement issues, studies over-report the duration and intensity of physical

activity within acute bouts. Therefore, confident conclusions cannot be drawn from *theoretically* doing 10-minutes of PA when only a proportion of children *actually* did this; most did far less. Assessment methods need to clearly report the number of minutes of physical activity performed at a moderate to vigorous intensity. Where necessary, non-compliance should be addressed in the outcome analysis.

*Address the inter-individual variability in the dose-response.* As outlined, not all individuals engage in equal measures within real world physical activity opportunities. Therefore, all individuals may not achieve advertised cognitive benefits because their involvement did not meet thresholds for duration and intensity. Practitioners need to create physical activity environments that maximise the engagement of all individuals within the session. Researchers need to accurately assess inter-individual variability using measurement tools appropriate to the activity context and pediatric population (Corder et al., 2008). To enable accurate assessment of cognitive outcomes, minimum thresholds for activity should be used to identify participants who qualify to be included in the analysis (Janssen et al., 2014).

*Classroom control conditions favour what the teachers are likely to consider the alternative to being physically active.* The majority of control conditions utilise seated or sedentary control conditions. First, it is inherently unhelpful to endorse to teachers, whether implicitly or explicitly, an activity-sedentary dichotomy. Where no cognitive improvements are attributable to exercise conditions, the research incidentally endorses sedentary learning. Studies should have multiple comparison groups to enable the identification of successful active ingredients (Jäger et al., 2015). Equally, designing studies with more physically active control conditions is justified. In addition, future studies should look to assess physically active learning that has been confirmed within laboratory-based experiments (Vazou & Smiley-Oyen, 2014).

#### ***Specific issues affecting cognitive assessment.***

*Assess a wider range of cognitive domains.* To develop the evidence base, studies should strive to assess a wider range of cognitive domains. Care must be taken to appropriately structure larger cognitive assessment batteries to control time-dependent effects of acute physical activity on cognition and minimise test-induced fatigue. Within the current review, fifty-percent of the studies assess a single cognitive outcome, limiting understanding of the potential impact of exercise on cognition. Further, within the current literature, there is a skewed distribution of cognitive domains assessed, with a dominant focus on selective attention, closely followed by inhibition. By extending the scope of experimental designs to incorporate a broader range of

cognitive domains, researchers and practitioners stand to benefit from evidence that offers a deeper comprehension of the complex relationship that exists between exercise and cognition. Due to time-dependent effects of acute physical activity on cognition, care should be taken to limit the range of cognitive tests included within testing batteries

*Cognitive tasks must use age-appropriate stimuli and instructions.* Studies and interventions need to detail the selection criteria for the testing battery, clearly outlining the validity of the test adopted for use with children and young people. Specifically, stimuli and instructions utilised within research and practice should be specific to the age of the participants, ensuring that cognitive maturation is accounted for as explicitly as physical capability.

*Chronological age groups should be underpinned by relevant theory, and not based solely on opportunistic sampling.* Building upon the above conclusion, it is crucial that sampling methods go beyond mere convenience. Future interventions and research studies should make greater efforts to develop and justify robust participant recruitment strategies to ensure effective alignment between population samples and the protocols deployed. To this end, it is important that appropriate theories, models and frameworks are utilised in the development of research questions and evaluation methods.

### ***Final Conclusions***

Based on our review, we suggest a cautious optimism regarding claims for the impact of acute bouts of physical activity on cognition within the school environment. To be more confident would require further studies that address the depth of the problem in confirming the benefits of physical activity - within the school context - on cognition. Many of the shortcomings affecting the current evidence base arise from the complexity inherent to all the possible combinations of FITT-VP, the cognitive processes and how they are observed. Within the current literature, the physical activity bout is generally defined as a common experience, whereas the observation data indicates a highly variable experience. To progress the field, researchers need to clearly define the physical activity provision and confirm levels of individual engagement.

Further, to progress more systematically, there is need for researchers to manipulate single components of the FITT-VP framework within each experimental study, assessing the alteration against each cognitive outcome. To aid these developments, multidisciplinary research teams together with context-relevant practitioners need to design interventions that optimise the

physical activity that can be achieved while assessing the impact on a range of cognitive outcomes.

## Reference List

- ACSM. (2014). *ACSM's Guidelines for Exercise Testing and Prescription* (9th revised North American ed edition). Lippincott Williams and Wilkins.
- Altenburg, T. M., Chinapaw, M. J. M., & Singh, A. S. (2015). Effects of one versus two bouts of moderate intensity physical activity on selective attention during a school morning in Dutch primary schoolchildren: A randomized controlled trial. *Journal of Science and Medicine in Sport / Sports Medicine Australia*. doi:10.1016/j.jsams.2015.12.003
- Awh, E., & Pashler, H. (2000). Evidence for split attentional foci. *Journal of Experimental Psychology. Human Perception and Performance*, 26, 834–846.
- Baddeley, A. (2012). Working memory: theories, models, and controversies. *Annual Review of Psychology*, 63, 1–29.
- Baddeley, A. D., & Hitch, G. (1974). Working Memory. In Gordon H. Bower (Ed.), *Psychology of Learning and Motivation* (Vol. Volume 8, pp. 47–89). Academic Press.
- Bailey, R. C., Olson, J., Pepper, S. L., Porszasz, J., Barstow, T. J., & Cooper, D. M. (1995). The level and tempo of children's physical activities: an observational study. *Medicine and Science in Sports and Exercise*, 27, 1033–1041.
- Budde, H., Voelcker-Rehage, C., Pietrabyk-Kendziorra, S., Ribeiro, P., & Tidow, G. (2008). Acute coordinative exercise improves attentional performance in adolescents. *Neuroscience Letters*, 441, 219–223.
- Chang, Y. K., Labban, J. D., Gapin, J. I., & Etnier, J. L. (2012). The effects of acute exercise on cognitive performance: a meta-analysis. *Brain Research*, 1453, 87–101.
- Chen, A.-G., Yan, J., Yin, H.-C., Pan, C.-Y., & Chang, Y.-K. (2014). Effects of acute aerobic

- exercise on multiple aspects of executive function in preadolescent children. *Psychology of Sport and Exercise*, 15, 627–636.
- Cooper, S. B., Bandelow, S., Nute, M. L., Morris, J. G., & Nevill, M. E. (2012). The effects of a mid-morning bout of exercise on adolescents' cognitive function. *Mental Health and Physical Activity*, 5, 183–190.
- Corder, K., Ekelund, U., Steele, R. M., Wareham, N. J., & Brage, S. (2008). Assessment of physical activity in youth. *Journal of Applied Physiology*, 105, 977–987.
- Defeyter, M. A., Russo, R., & McPartlin, P. L. (2009). The picture superiority effect in recognition memory: A developmental study using the response signal procedure. *Cognitive Development*, 24, 265–273.
- Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, 64, 135–168.
- Donnelly, J. E., Hillman, C. H., Castelli, D., Etnier, J. L., Lee, S., Tomporowski, P., Lambourne, K. & Szabo-Reed, A. N. (2016). Physical Activity, Fitness, Cognitive Function, and Academic Achievement in Children: A Systematic Review. *Medicine and Science in Sports and Exercise*, 48, 1223–1224.
- Eriksen, C. W., & St James, J. D. (1986). Visual attention within and around the field of focal attention: a zoom lens model. *Perception & Psychophysics*, 40, 225–240.
- Etnier, J., Labban, J. D., Piepmeier, A., Davis, M. E., & Henning, D. A. (2014). Effects of an acute bout of exercise on memory in 6th grade children. *Pediatric Exercise Science*, 26, 250–258.
- Furley, P., & Wood, G. (2016). Working Memory, Attentional Control, and Expertise in Sports: A Review of Current Literature and Directions for Future Research. *Journal of Applied*

- Gallotta, M. C., Emerenziani, G. P., Franciosi, E., Meucci, M., Guidetti, L., & Baldari, C. (2015). Acute physical activity and delayed attention in primary school students. *Scandinavian Journal of Medicine & Science in Sports*, *25*, e331–8.
- Gallotta, M. C., Guidetti, L., Franciosi, E., Emerenziani, G. P., Bonavolontà, V., & Baldari, C. (2012). Effects of Varying Type of Exertion on Children's Attention Capacity. *Medicine & Science in Sports & Exercise*, *44*, 550–555.
- Hill, L., Williams, J. H. G., Aucott, L., Milne, J., Thomson, J., Greig, J., Munro, V., & Mon-Williams, M. (2010). Exercising attention within the classroom. *Developmental Medicine and Child Neurology*, *52*, 929–934.
- Hillman, C. H., Pontifex, M. B., Raine, L. B., Castelli, D. M., Hall, E. E., & Kramer, A. F. (2009). The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. *Neuroscience*, *159*, 1044–1054.
- Howie, E. K., Schatz, J., & Pate, R. R. (2015). Acute Effects of Classroom Exercise Breaks on Executive Function and Math Performance: A Dose–Response Study. *Research Quarterly for Exercise and Sport*, *86*, 217–224.
- Jäger, K., Schmidt, M., Conzelmann, A., & Roebbers, C. M. (2014). Cognitive and physiological effects of an acute physical activity intervention in elementary school children. *Frontiers in Psychology*, *5*, 1473.
- Jäger, K., Schmidt, M., Conzelmann, A., & Roebbers, C. M. (2015). The effects of qualitatively different acute physical activity interventions in real-world settings on executive functions in preadolescent children. *Mental Health and Physical Activity*, *9*, 1–9.

- Janssen, M., Chinapaw, M. J. M., Rauh, S. P., Toussaint, H. M., van Mechelen, W., & Verhagen, E. A. L. M. (2014). A short physical activity break from cognitive tasks increases selective attention in primary school children aged 10–11. *Mental Health and Physical Activity, 7*, 129–134.
- Kubesch, S., Walk, L., Spitzer, M., Kammer, T., Lainburg, A., Heim, R., & Hille, K. (2009). A 30-Minute Physical Education Program Improves Students' Executive Attention. *Mind, Brain and Education: The Official Journal of the International Mind, Brain, and Education Society, 3*, 235–242.
- Ma, J. K., Le Mare, L., & Gurd, B. J. (2015). Four minutes of in-class high-intensity interval activity improves selective attention in 9- to 11-year olds. *Applied Physiology, Nutrition, and Metabolism = Physiologie Appliquee, Nutrition et Metabolisme, 40*, 238–244.
- Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The Unity and Diversity of Executive Functions and Their Contributions to Complex “Frontal Lobe” Tasks: A Latent Variable Analysis. *Cognitive Psychology, 41*, 49–100.
- Niemann, C., Wegner, M., Voelcker-Rehage, C., Holzweg, M., Arafat, A. M., & Budde, H. (2013). Influence of acute and chronic physical activity on cognitive performance and saliva testosterone in preadolescent school children. *Mental Health and Physical Activity, 6*, 197–204.
- Pesce, C. (2012). Shifting the focus from quantitative to qualitative exercise characteristics in exercise and cognition research. *Journal of Sport & Exercise Psychology, 34*, 766–786.
- Pesce, C., Crova, C., Cereatti, L., Casella, R., & Bellucci, M. (2009). Physical activity and mental performance in preadolescents: Effects of acute exercise on free-recall memory.

- Mental Health and Physical Activity*, 2, 16–22.
- Pirrie, A. M., & Lodewyk, K. R. (2012). Investigating links between moderate-to-vigorous physical activity and cognitive performance in elementary school students. *Mental Health and Physical Activity*, 5, 93–98.
- Posner, M. I. (1980). Orienting of attention. *The Quarterly Journal of Experimental Psychology*, 32, 3–25.
- Rowlands, A. V., & Eston, R. G. (2007). The Measurement and Interpretation of Children's Physical Activity. *Journal of Sports Science & Medicine*, 6, 270–276.
- Schmidt, M., Egger, F., & Conzelmann, A. (2015). Delayed positive effects of an acute bout of coordinative exercise on children's attention. *Perceptual and Motor Skills*, 121, 431–446.
- Shephard, R. J., & Balady, G. J. (1999). Exercise as cardiovascular therapy. *Circulation*, 99, 963–972.
- Steinmayr, R., Ziegler, M., & Träuble, B. (2010). Do intelligence and sustained attention interact in predicting academic achievement? *Learning and Individual Differences*, 20, 14–18.
- Tine, M. T., & Butler, A. G. (2012). Acute aerobic exercise impacts selective attention: an exceptional boost in lower-income children. *Educational Psychology Review*, 32, 821–834.
- Tomprowski, P. D., McCullick, B., Pendleton, D. M., & Pesce, C. (2015). Exercise and children's cognition: The role of exercise characteristics and a place for metacognition. *Journal of Sport and Health Science*, 4, 47–55.
- van den Berg, V., Saliasi, E., de Groot, R. H. M., Jolles, J., Chinapaw, M. J. M., & Singh, A. S. (2016). Physical Activity in the School Setting: Cognitive Performance Is Not Affected by Three Different Types of Acute Exercise. *Frontiers in Psychology*, 7, 723.

Vazou, S., & Smiley-Oyen, A. (2014). Moving and academic learning are not antagonists: acute effects on executive function and enjoyment. *Journal of Sport & Exercise Psychology*, 36, 474–485.