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Physical activity and cognitive function in young people: key moderating variables and a spotlight on The Daily Mile

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Abstract

Although there is growing evidence that physical activity has a beneficial effect on cognitive function in young people, evidence is lacking regarding the extent to which the duration of a physical activity influences the acute physical activity-cognition relationship. Moreover, few studies have utilised high-intensity intermittent physical activity, despite evidence that this modality is ecologically valid and enjoyed by young people. Furthermore, there is a paucity of research on The Daily Mile, which is a practically viable school-based physical activity intervention that is currently being implemented in >9,000 schools in the UK. Despite this widespread uptake, there is a lack of research on the activity patterns of children during participation in The Daily Mile, as well as the subsequent effects on cognitive function, body composition and cardiorespiratory fitness. Therefore, this thesis examines how physical activity duration moderates the subsequent effects on cognition, the activity patterns of children participating in The Daily Mile, the acute and chronic effects of participation in The Daily Mile on cognition, alongside the chronic effects of participation in The Daily Mile on body composition and cardiorespiratory fitness in young people.

In the present thesis (Chapters IV, VI & VII), cognitive function was measured using three computerised cognitive function tests, which were administered via a laptop. Specifically, the Stroop test (which assesses attention and inhibitory control), the Sternberg paradigm (which assesses visual working memory), and the Flanker task (which assessed attention and inhibitory control), were utilised to provide a holistic view of cognitive function.

The first experimental chapter (Chapter IV) examined the acute effect of differing durations of high-intensity intermittent running on cognitive function in young people (n = 38, 23 girls, 12.4 ± 0.4 y). Participants completed three trials separated by 7 d: 30 min physical activity, 60 min physical activity, and rest; in a randomised crossover design. The physical activity was a modified version of the Loughborough Intermittent Shuttle Test (LIST), which elicited high-intensity intermittent running and enabled other physical activity characteristics (e.g. intensity and modality) to be controlled. Cognitive function was measured 30 min pre, immediately post, and 45 min post-physical activity. The main findings were that response times on an inhibitory control task improved to a greater extent 45 min following the 30 min LIST, compared to rest (p = 0.009). Moreover, response times on the one-item working memory task tended to improve to a greater extent 45 min following the 60 min LIST, compared to rest (p = 0.069, d = 0.069). However, response times improved to a greater extent on the three-item working memory task 45 min following the 30 min LIST, compared to the 60 min LIST (p = 0.002, d = 0.41) and rest (p = 0.013, d = 0.29). In conclusion, acute exercise enhanced subsequent cognition in adolescents. Overall, 30 min of high-intensity intermittent running is more favourable to adolescents' cognition, when compared to 60 min. This was the first dose-response within-subjects study to directly compare the effects of differing durations of physical activity on cognitive function in young people.

The second experimental chapter (Chapter V) examined the activity patterns (e.g., total distance covered and distance covered in age-specific speed zones) and physiological responses (average and peak heart rate) of children (n = 72, 38 girls, 10.4 ± 0.7 y) during participation in The Daily Mile. Moreover, cardiorespiratory fitness was assessed using the Multi-Stage Fitness Test and differences in both activity patterns and physiological responses between cardiorespiratory fitness quartiles and sexes were examined. The main findings were that participants covered an average distance of 2511 ± 550 m during The Daily Mile, and heart rate was 163 ± 27 beats·min^{-1}. Moreover, participants travelled the furthest distance, and were most intermittent, during the first 5 min (both p < 0.001, d > 0.83). Boys ran further and their activity was more intermittent

compared to girls (both $p < 0.001$, d > 0.80). Moreover, the highest fit children ran further than less fit children ($p < 0.001$, d > 0.25), however there was no difference in relative exercise intensity (average or peak heart rate) between children of varying fitness levels ($p = 0.41$). This study provided novel evidence that children covered, on average, 1.5 miles and exercised at a moderate-to-vigorous intensity during The Daily Mile. Furthermore, whilst boys and higher-fit children covered a greater distance than girls and lower-fit children, children of all fitness levels exercised at a similar relative intensity. The Daily Mile is thus an inclusive physical activity which makes a valuable contribution to in-school physical activity targets for all children.

The third experimental chapter (Chapter VI) examined the acute effects of The Daily Mile on cognitive function. It was also the first study to explore children's enjoyment of participation in the initiative. Participants ($n = 104$, 48 girls, 10.4 ± 0.7 years) completed a Daily Mile trial and a resting control trial in a randomised, counterbalanced order. Cognitive function was measured prior to, immediately following and 45 min following The Daily Mile and resting. Additionally, a sub-sample of children ($n = 87$) took part in focus groups to explore factors affecting their enjoyment of The Daily Mile. The main findings were that, whilst there was no statistically significant effects of The Daily Mile on cognition (all $p > 0.05$), accuracy in the working memory ($p = 0.073$) and inhibitory control ($p = 0.057$) tasks tended to improve immediately following The Daily Mile, compared to resting. Moreover, children enjoyed participating in The Daily Mile, particularly due to its outdoor location, social context, and self-paced nature. However, some children found The Daily Mile boring due to its repetitive nature.

The final experimental chapter (Chapter VII) examined the effect of chronic (5.5 weeks) participation in The Daily Mile on children's ($n = 35$, 18 girls, 11.1 ± 0.5 y) activity patterns during The Daily Mile, cognitive function, body composition and cardiorespiratory fitness. The main findings were that the intervention group, compared to the control group, tended to present both faster response times ($p = 0.063$) and higher accuracy ($p = 0.068$) on the attention task at follow-up. Moreover, whilst there was no statistically significant difference between the intervention and control group at follow-up in body mass, BMI z-score, waist circumference, waist-to-hip ratio or sum of skinfolds (all $p > 0.05$), BMI was lower ($p = 0.016$, d = 0.10) in the intervention group compared to the control group at follow-up. Furthermore, whilst there was no statistically significant difference between the intervention and control group at follow-up in cardiorespiratory fitness ($p = 0.249$), average heart rate ($p = 0.037$, d = 1.19) and peak heart rate ($p = 0.015$, d = 1.05) during The Daily Mile at follow-up were higher in the intervention compared to the control group. This is the first study to examine the chronic effects of The Daily Mile on attention, which tended to improve following participation for five and a half weeks. This is also the first study to demonstrate that improvements to body composition can be gained from five and a half weeks of participation in The Daily Mile.

In summary, the present thesis provides novel contributions to the literature with the following key findings: i) Duration is a significant moderator in the acute physical activity-cognition relationship, with 30 min compared to 60 min of high-intensity intermittent running – which is an ecologically valid form of activity in young people – leading to greater post-activity enhancements in cognitive function; ii) The Daily Mile is an enjoyable and inclusive physical-activity intervention that contributes to in-school physical activity targets; iii) Acute and chronic (5.5 weeks) participation in The Daily Mile tends to enhance cognitive function; iv) BMI scores are improved from five and a half weeks of participation in The Daily Mile, however other aspects of body composition (waist-to-hip ratio, skinfolds) and cardiorespiratory fitness are not. In summary, the findings of this thesis show that a shorter duration (30 min vs 60 min) of high intensity intermittent running leads to

immediate and prolonged (45 min post activity) enhancements in cognitive function in young people; this information is valuable to school staff and policy makers who are keen to implement physical activity in school, but frequently highlight time constraints as a barrier to implementation. The present thesis also demonstrates that The Daily Mile is a worthwhile addition to a comprehensive whole-school approach to physical activity; however additional research is needed to examine whether further enhancements to cognition can be gained from longer duration implementation of the initiative (e.g., across a school year).

Keywords: Physical Activity, Duration, The Daily Mile, Activity Patterns, Children, Adolescents, Cognitive Function, Enjoyment, Body Composition, Cardiorespiratory Fitness

List of Abbreviations

ACSM: American College of Sports Medicine

ANOVA: Analysis of variance

ANCOVA: Analysis of covariance

BMI: Body mass index

CI: Confidence interval

GPS: Global positioning systems

MSFT: Multi-stage fitness test

MVPA: moderate-to-vigorous physical activity

HR_{max}: Maximum heart rate

HRR: Heart rate reserve

RPE: Rating of perceived exertion

SEM: Standard error of the mean

SD: Standard deviation

SPSS: Statistical Package for the Social Sciences

$\dot{V}O_2peak$: peak oxygen uptake

$\dot{V}O_{2max}$: Maximum oxygen uptake

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Preface

Unless otherwise indicated by reference to published resources, the work presented in the present thesis is that of the author and has not been previously submitted for another degree to this or any other University.

Some of the work in this thesis has been published.

Published Papers

Hatch, L. M., Dring, K. J., Williams, R. A., Sunderland, C., Nevill, M. E., & Cooper, S. B. (2021). Effect of differing durations of high-intensity intermittent activity on cognitive function in adolescents. *International journal of environmental research and public health*, *18*(21), 11594. https://doi.org/10.3390/ijerph182111594

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Chapter I

Introduction

The World Health Organization recommend that young people (5–17 y) engage in an average of 60 min per day of moderate-to-vigorous physical activity (MVPA; Bull et al., 2020). However, it is estimated that only 45% of young people in the UK meet these guidelines (Public Health England, 2021). Evidence suggests that physical activity levels begin to decline in early childhood (Cooper et al., 2015; Farooq et al., 2018; Jago et al., 2017) and continue to decrease throughout childhood and adolescence at an estimated rate of 4% each year from five to ten years of age (Cooper et al., 2015), and 7% each year between 10 and 19 years of age (Dumith et al., 2011). In concurrence with the rising levels of physical inactivity in young people, rates of overweight and obesity are also increasing, with 50% of 10–11 year olds now classified as overweight or obese (Public Health England, 2022). These statistics are worrying as physical activity levels during childhood are predictive of physical activity levels during adulthood (Telama et al., 2005), and both physical inactivity and obesity are major risk factors for several chronic diseases including type 2 diabetes mellitus, cardiovascular disease and cancer (Hills et al., 2015; Miles, 2007), as well as all-cause mortality (World Health Organization, 2010). In contrast, physical activity is positively associated with physical, psychological and social indicators of health, with regular participation in physical activity during childhood linked to reduced adiposity, enhanced cardiorespiratory fitness and bone health, favourable cardiovascular and metabolic disease risk profiles, improved psychological wellbeing and reduced symptoms of anxiety and depression (Department of Health, 2011; Hills et al., 2015; Poitras et al., 2016; World Health Organization, 2010).

Physical activity has also been linked to areas of the brain, such as the prefrontal cortex, that support complex cognitive processes during cognitive tasks (e.g., Chu et al., 2017; Donnelly et al., 2016; Hillman et al., 2009), and there is evidence of a positive association between physical activity and cognitive function in young people (Bidzan-Bluma & Lipowska, 2018; de Greeff et al., 2018). Moreover, participation in an acute bout of physical activity has been shown to enhance post-activity cognitive function across cognitive domains such as attention, inhibitory control, working memory and cognitive flexibility (for reviews see Chang et al., 2012; Donnelly et al., 2016; Hillman et al., 2019; Verburgh et al., 2014). Pontifex et al. (2019), for example, recently reported that acute physical activity enhances both lower-order cognitive functions (e.g., information processing, attention) and higher-order cognitive functions (e.g., inhibitory control, working memory, cognitive flexibility), but with different sized effects. Specifically, Pontifex et al. (2019) suggested that acute physical activity enhances lower-order domains with a small-to-medium sized effect (d = 0.2–0.5 motor speed/learning and information processing, d = 0.1–0.7 attention) and high-order domains such as inhibitory control with a small-to-large sized effect (d = 0.2–1.2). Similar findings are reported across the literature, highlighting that the acute enhancements to cognition following physical activity are cognitive domain specific (Chang et al., 2012; Verburgh et al., 2014). However, evidence suggests that the variations in effect size within and between studies in the literature may also be due to the characteristics of the physical activity utilised (e.g., modality, intensity, duration), the characteristics of the participants involved (e.g., sex, cardiorespiratory fitness), and the timing of the cognitive testing following the cessation of the physical activity (Chang et al., 2012; Pontifex et al., 2019; Williams et al., 2019).

Whilst there is an abundance of literature which has examined the moderating role of physical activity modality and intensity by comparing the effects of various modalities (from aerobic to resistance) and intensities (from light to maximal) of activity on subsequent cognition, there is a paucity of evidence regarding the nature and extent to which physical activity duration moderates the acute physical activity-cognition relationship in young people. Additional research is therefore imperative to determine whether there is a minimum or optimum duration required to activate the mechanisms responsible for the physical activity-induced changes to cognitive function. This information will enable the development of much-needed evidence-based recommendations for the implementation of physical activity interventions for cognitive enhancements in young people.

Furthermore, the influence of participant characteristics, such as sex and cardiorespiratory fitness, on the acute physical activity-cognition relationship needs further investigation, as discrepancies exist within the literature. For example, whilst several studies report that young people with higher cardiorespiratory fitness exhibit greater post-activity enhancement in cognition (e.g., Cooper et al., 2018; Hogan et al., 2013; 2015; Jäger et al., 2015; Williams et al., 2020), other studies report no moderating influence of cardiorespiratory fitness (Booth et al., 2020; Crova et al., 2014; Ludyga et al., 2016). A greater understanding of the physical activity-cognition relationship in young people, and the moderating variables in this relationship, is imperative, as childhood and adolescence represents an important period of cognitive development (Diamond, 2013; Chen et al., 2014a) and cognitive functioning during this time will influence decision making, goal-directed behaviour, learning, and academic performance (Borella et al., 2010; Gathercole et al., 2004; McPherson et al., 2018; Tomporowski et al., 2008).

Schools represent a key setting to promote physical activity, as young people spend a significant amount of their time there (World Health Organization, 2018). Moreover, schools are an inclusive setting which provide access to large cohorts of young people of varying sex, cardiorespiratory fitness and socioeconomic background (Anderssen, 2013; Public Health England, 2020a). However, in recent years, due to budget cuts and increased pressure for academic success, schools are restricting time for physical activity in school to prioritise 'core' subjects such as Maths, English and Science (Centre on Education Policy, 2011; Sallis et al., 2012). This has been reflected through a reduction in time allocated to physical education (Youth Sport Trust, 2015), with current provision now falling below the national requirements of 120 min per week (Naylor et al., 2015). Additionally, only 28% of young people are meeting the UK in school recommendation of at least 30 min MVPA per day (Department of Health and Social Care, 2020; Public Health England, 2020a). Consequently, physical activity promotion is high on the UK policy agenda (Department of Health and Social Care, 2018) and whole-school approaches are a fundamental aspect of the latest School Sport and Activity Action Plan (Department of Health and Social Care, 2019).

There are three main physical activity intervention models which have been gaining traction within schools, namely classroom movement breaks, active learning and run-walk (or active mile) initiatives. One of most popular and widely implemented run-walk interventions is The Daily Mile, which involves children engaging in 15 min (around one mile) of self-paced physical activity outside each school day, during curriculum time (The Daily Mile, 2022a). The Daily Mile is now advocated by the UK government (Department of Health and Social Care, 2019), and is receiving substantial funding, both from the government and external bodies such as Sport England.

Despite this support, surprisingly little is known regarding the efficacy of The Daily Mile as a physical activity intervention. Specifically, there is a paucity of evidence on the type of activity children engage in when they participate in The Daily Mile and how this contributes to physical activity targets. Additionally, the effects of acute participation in The Daily Mile on young people's cognitive function is unknown, due to a heterogeneity in the findings of the two studies to explore this to date (Booth et al., 2020; Morris et al., 2019). Moreover, the effects of chronic participation on cognition have not yet been examined and whilst there has been some initial investigation into the chronic effects of The Daily Mile on body composition and cardiorespiratory fitness, the studies thus far have been diverse in their experimental design (including intervention duration), participant population, and findings. Given the widespread implementation of The Daily Mile, and the associated loss of academic classroom time (approximately 75 min per week), it is necessary to understand whether the physical activity characteristics (i.e., modality, intensity, duration) of The Daily Mile are sufficient for enhancements to physical activity, cognition, body composition and cardiorespiratory fitness, or whether an alternative school-based physical activity intervention would be more advantageous. Furthermore, despite enjoyment of a physical activity intervention being a key determinant of engagement in and adherence to the intervention (Nasuti & Rhodes, 2013;

Sebire et al., 2013), no studies have investigated whether young people enjoy participating in The Daily Mile, or factors influencing their enjoyment.

Therefore, the present thesis will examine some of the moderating variables in the physical activity-cognition relationship in young people, with a focus on duration and The Daily Mile as an ecologically valid form of school-based physical activity. The following research questions and hypotheses will be examined:

1. Does physical activity duration moderate the acute effect of high-intensity intermittent running on cognitive function in young people? *Hypotheses:* high-intensity intermittent running will enhance subsequent cognition regardless of activity duration. However, while comparison of different durations of activity is explanatory, a longer duration of activity will elicit a greater 'dose' and thus it is hypothesised that a longer duration will enhance subsequent cognition to a greater extent, compared to a shorter duration.
2. What are the activity patterns and physiological responses of children during participation in The Daily Mile? Additionally, are these influenced by participant sex and/or cardiorespiratory fitness? *Hypotheses:* The Daily Mile will elicit moderate-to-vigorous intensity intermittent activity; and both boys and high-fit individuals will engage in a greater quantity of activity (e.g., greater distance covered), due to the self-paced nature of The Daily Mile.
3. How does an acute bout of The Daily Mile affect cognitive function? Are these responses moderated by sex and/or cardiorespiratory fitness? Do children enjoy participating in The Daily Mile, and what factors influence their enjoyment? *Hypotheses:* The Daily Mile will transiently improve cognitive function, and the improvement in cognition will be of a greater magnitude in those considered high-fit. The Daily Mile will be considered an enjoyable activity as it is completed outside, and is an informal, social activity centered around having fun.

4. Does chronic participation in The Daily Mile affect the activity patterns and physiological responses of children during The Daily Mile? Additionally, how does chronic participation in The Daily Mile affect cognitive function, body composition and cardiorespiratory fitness? *Hypotheses:* Chronic participation in The Daily Mile will result in a greater quantity of activity completed (e.g., greater distance covered) at a lower relative exercise intensity (% HR_{max}). Chronic participation in The Daily Mile will also improve cognitive function, body composition and cardiorespiratory fitness.

Organisation of the thesis

This thesis is subsequently split into eight chapters. Chapter II provides a critical evaluation of the literature examining the acute effect of physical activity on cognitive function, and the variables which moderate this relationship. An evaluation of the available evidence on The Daily Mile is also provided. Chapter III, the general methods, describes the common methods which have been utilised throughout the studies presented within this thesis. Chapter IV examines the influence of physical activity duration on the acute effects of high-intensity intermittent running on cognitive function. Chapter V examines the activity patterns and physiological responses during an acute bout of The Daily Mile and Chapter VI examines the effect of an acute bout of The Daily Mile on cognitive function, alongside qualitatively examining the factors that influence enjoyment of the intervention. Chapter VII then investigates the effect of chronic participation in The Daily Mile on physical activity during The Daily Mile, cognitive function, body composition and cardiorespiratory fitness. Finally, in Chapter VIII, the key findings from the experimental chapters are discussed, overall conclusions are drawn, and practical applications are identified with regards to the moderating role of activity duration on the acute physical activity-cognition relationship, and the efficacy of The Daily Mile intervention.

Chapter II

Review of the Literature

2.1. Overview of the Review of the Literature

The review begins with definitions and explanations of the key concepts within the thesis, including ‘children’, ‘adolescents’, ‘physical activity’, ‘cardiorespiratory fitness’ and ‘cognitive function’ (section 2.2). Following this, section 2.3 consists of a brief evaluation of research on the acute effects of physical activity on cognitive function in adults; this has been included to provide the reader with contextual information regarding the historical development of acute physical activity-cognition literature. Section 2.4 then provides an extensive critical review of the literature regarding the acute effect of physical activity on cognitive function in young people and the moderating variables which may influence the relationship. Finally, in section 2.5 school-based physical activity interventions are discussed, with particular focus on The Daily Mile, which is currently receiving substantial funding and being implemented worldwide.

2.2. Definitions and Key Concepts

2.2.1. Children and Adolescents

The studies within this thesis focus on children and adolescents, thus it is important to define these terms. Childhood is a period of life typically commencing at the chronological age of three and finishing at the chronological age of 11 (Balasundaram & Avulakunta, 2021); the term children refers to individuals within this age range and thus typically those attending primary school in the UK. The period of adolescence begins at the chronological age of 12 and lasts until the age of 18 (Balasundaram & Avulakunta, 2021); the term adolescents refers to individuals within this age range and typically those attending secondary school in the UK. Adolescence is characterised by a transition towards the adult state involving many different maturational changes (Beunen et al., 2006). While adolescence is often considered to coincide with puberty, which is “*an event of short duration at the end of the juvenile stage, characterised* *by dramatic increases in sex hormones*" (Bogin, 1999), there is significant variation in the onset of puberty and rate of maturation changes between individuals (Beunen et al., 2006).

Due to its inherent variability, maturation is not always synonymous with chronological age. It is thus important to examine maturity when investigating child and adolescent populations. While methods such as skeletal wrist X-rays (Beunen et al., 2006) and the assessment of secondary sex characteristics (Tanner, 1962) can produce a reliable indicator of biological maturity, these methods are invasive in nature, raising both ethical and practical issues. Furthermore, invasive measures are not practical in school-based studies. However, estimates of somatic maturity can be calculated using more easily obtainable, non-invasive anthropometric measures (Mirwald et al., 2002; Moore et al., 2015). For example, the somatic prediction models produced by Moore et al. (2015) provide an estimate of maturity offset, which identifies the time (in years [y]) before or after peak height velocity, using measures of height and chronological age.

Within each of the studies in this thesis, participants will be referred to as children or adolescents based on their chronological age. Specifically, participants <11 years will be referred to as children and participants 12–18 years will be referred to as adolescents. Moreover, the term 'young people' will refer to children and adolescents collectively. Furthermore, the method of Moore et al. (2015) will be used to provide an estimate of maturity.

2.2.2. Physical Activity

Physical Activity is defined as "*any bodily movement produced by skeletal muscles that results in energy expenditure*" (Caspersen et al. 1985). Physical activity thus includes all activities that require energy expenditure above resting levels (Pontifex et al., 2019) and consequently increase the metabolic rate (Miles, 2007). Physical activity is a broad term which encompasses activities ranging from daily living (e.g., active transport, hoovering) and recreational pursuits, to organised sport and exercise (Lubans et al., 2021).

Physical activity is commonly characterised by its modality (e.g., aerobic, resistance), intensity (e.g. low, moderate, moderate-to-vigorous, vigorous), duration, and frequency (Miles, 2007). Although there is some variability between national and international physical activity guidelines (Parrish et al. 2020), the most recent World Health Organization guidelines state that children and adolescents (5–18 y) should achieve an average of 60 min per day of MVPA (consisting mostly of aerobic activities) (Bull et al. 2020). Moreover, vigorous aerobic activity, as well as bone and muscle strengthening activities, should be completed at least three times per week (Bull et al. 2020).

The term 'acute physical activity' refers to a single bout of physical activity, while 'chronic physical activity' is defined as repeated bouts over a short- or long-term period (Lubans et al., 2021).

2.2.3. Exercise

Exercise is defined as "*physical activity that is implemented in a planned, structured manner with the intent of the activity improving or maintaining one or more components of physical fitness*" (American College of Sports Medicine [ACSM], 2018). Therefore, exercise is a physical activity completed with a purpose to enhance physical fitness.

2.2.4. Cardiorespiratory Fitness

Physical fitness is defined as "*a set of attributes that are either health- or skill-related that relate to the ability to perform physical activity*' (Caspersen et al., 1985). Components of physical fitness include cardiorespiratory fitness, muscular endurance, muscular strength, power, speed, agility, flexibility and balance (Caspersen et al., 1985; Lubans et al., 2021). Specifically, cardiorespiratory fitness refers to "*the capacity of the circulatory and respiratory systems to supply oxygen to skeletal muscle mitochondria for energy production needed during physical activity*" (Raghuveer et al., 2020).

Physical activity is considered the principle, modifiable determinant of cardiorespiratory fitness (Blair et al., 2001; Morrow et al., 2013). Moreover, participation in physical activity which requires the involvement of large muscle groups, such as running and team sports, has been found to improve cardiorespiratory fitness (Lubans et al., 2021; Sun et al., 2013).

Laboratory measured peak oxygen uptake, also known as $\dot{V}O_{2peak}$, is typically considered the gold standard assessment of cardiorespiratory fitness in young people. However, the multi-stage fitness test (MSFT) is recognised as a valid and reliable field-based alternative for measuring cardiorespiratory fitness in young people, and also accounts for individual training status, which is a reliable indicator of habitual physical activity (Dring et al., 2019; Ramsbottom et al., 1988, Ruiz et al., 2011; Tomkinson et al., 2019a). Therefore, in the present thesis the distance covered during the MSFT will be used as the criterion outcome for cardiorespiratory fitness.

2.2.5. Cognitive Function

Cognitive function has been defined as a *"set of mental processes that contribute to perception, memory, intellect, and action"* (Donnelly et al. 2016; Lubans et al., 2021) and has been categorised into six distinct domains: memory (short- and long-term), psychomotor, attention, perception, executive functions and language skills (Figure 2.1; Schmitt et al., 2005). However, cognitive processes are thought to exist on a continuum, with basic information processing at one end and executive functions at the other (Colcombe & Kramer 2003).

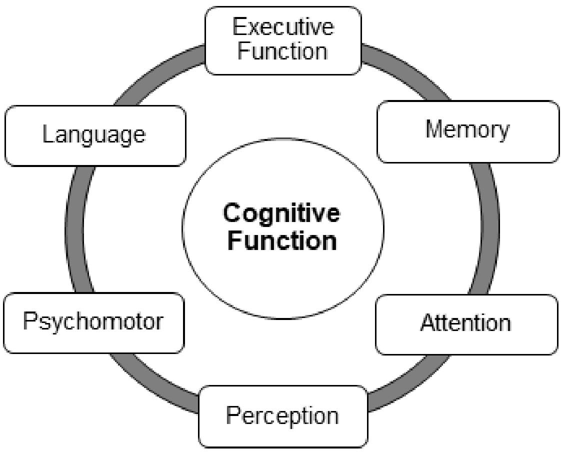

Figure 2.1. A schematic representation of the six distinct but interconnected domains of cognitive function, adapted from Schmitt et al. (2005).

Executive function, also termed cognitive control, refers to "*higher-order, self-regulatory cognitive processes that aid in the monitoring and control of thought and action*" (Carlson, 2005). Executive function facilitates goal-directed behaviour and is fundamental for planning, reasoning, problem solving and learning; it enables periods of intense concentration and focus (Diamond 2013; Pontifex et al., 2019). Executive function is split into three sub-domains: inhibition, working memory, and cognitive flexibility (Figure 2.2; Diamond, 2013; Lehto et al., 2003; Miyake et al. 2000). Inhibition relates to the ability to control attention, behaviour and thoughts, specifically the ability to override strong internal predispositions and instead enabling more appropriate, needed or beneficial actions; simply, the ability to act on the basis of choice rather than impulse (Diamond, 2013). Inhibition can be further categorised into inhibitory control and interference control which enable us to selectively attend to necessary stimuli and to supress unwanted thoughts, respectively (Anderson & Levy 2009; Diamond, 2013). Working memory refers to holding information in mind and mentally working with it (Diamond, 2013). According to Baddeley and Hitch's (1974) model, working memory is comprised of the visuo-spatial sketchpad, which processes visual/spatial information, and the phonological loop, which processes auditory/verbal information. Working memory is then further delineated, classified by stimuli content, including visual, spatial, visuo-spatial, verbal and auditory working memory. Furthermore, cognitive flexibility refers to the ability to change perspectives and be flexible to changing demands and priorities; it enables one to shift their behaviour to meet changing instruction and rules (Diamond, 2013).

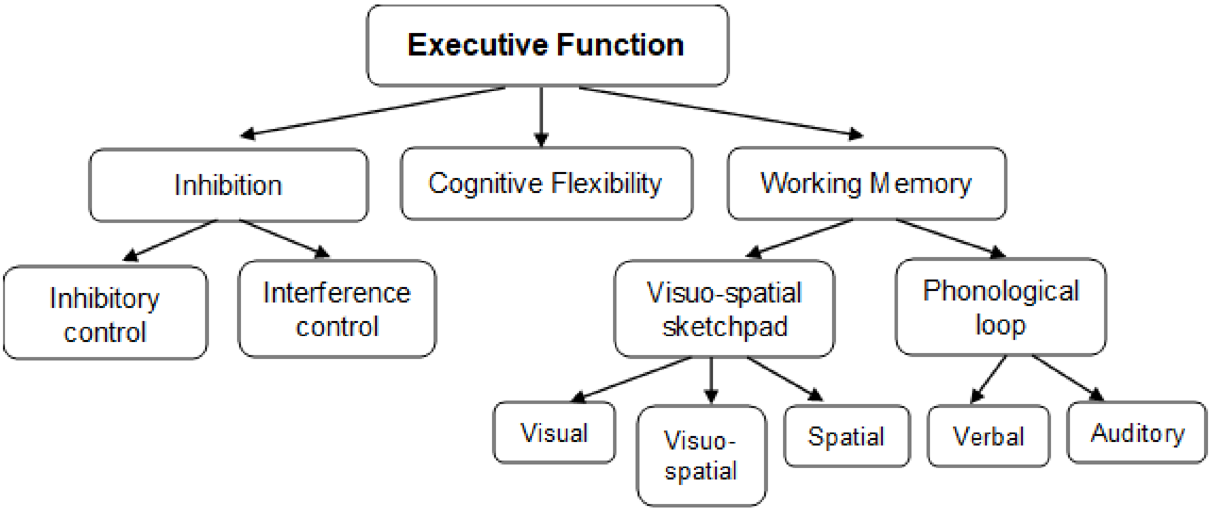

Figure 2.2. A schematical representation of the executive function sub-domains.

It is important to note that while cognitive function is categorised into separate domains and sub-domains, they are not mutually exclusive and in fact are reliant on one another (Miyake et al., 2000). They are interrelated and work together, with the efficiency of one domain being dependent on the others (Schmitt et al., 2005). For example, to learn in school a child needs to observe the information provided (perception), focus on this information (attention) while ignoring distractions (inhibitory control), and process the information (working memory).

Executive functions are thus instrumental in everyday learning situations, such as those in a school setting as well as daily life activities, and the period of childhood and adolescence is crucial for their development (Diamond, 2013). Moreover, young people with better executive function are reported to have an easier transition to formal schooling (Blair & Diamond, 2008) and are able to adapt their behaviour in the classroom more appropriately (Riggs et al., 2003). Therefore, executive functions are critical for school success and academic achievement (Borella et al., 2010; Gathercole et al., 2004).

Improving executive functions early in life is important because problems with executive function in early childhood predict problems with executive functions years later (Moffitt et al., 2011). Moreover, early executive function deficits often do not disappear but can become exacerbated over time (O'Shaughnessy et al., 2003; Riggs et al., 2003). For example, in a longitudinal study in which 1,000 children born in the same city in the same year were followed for 32 years, children whose inhibitory control was worse (i.e., they had less persistence, more impulsivity, and poorer attention regulation) between the ages of three and 11 grew up to have worse health, be less happy, earn less money, and commit more crimes than those who had better inhibitory control as children, controlling for gender, IQ, social class, and home and family circumstances during childhood (Moffitt et al., 2011).

Literature has repeatedly demonstrated that cognitive function is malleable and that it can be improved given adequate regimens or suitable environments, such as through participation in physical activity (Diamond & Lee, 2011; Drollette et al., 2012; Kamijo et al., 2011). Moreover, in line with the executive function hypothesis (Churchill et al., 2002; Hall, Smith & Keele, 2001; Kramer et al., 1999), evidence suggests that the beneficial effects of physical activity may be larger and more evident for executive functions than for other aspects of cognition (Kramer & Erickson, 2007; Chaddock et al., 2011a).

An important consideration when measuring executive functions is task impurity; executive functions are believed to operate on other cognitive processes and thus an executive task may involve both executive functions and other cognitive processes not relevant to the target executive function (Burgess, 1997). Nevertheless, neuropsychological tests, often computer-based to facilitate response capture, have been designed to assess each cognitive function domain with a degree of specificity and can be adapted to suit the population of interest, i.e., children and adolescents (Schmitt et al., 2005). A variety of assessments have been used to measure inhibitory control (e.g., Flanker task, Stroop task, go/no-go task), working memory (e.g., Sternberg paradigm, serial n-back task, Corsi block task), and cognitive flexibility (e.g., trail making test, Wisconsin card sorting test, switch task) in child and adolescent populations (Wade et al. 2020). Test performance is ideally assessed via both the speed and accuracy of responses; an important consideration to check for is the potential for a speed-accuracy trade-off (Schmitt et al., 2005).

Therefore, in the present thesis the effects of physical activity on higher-order executive functions including inhibitory control, working memory, and cognitive flexibility and lower-order cognitive processes, such as information processing and attention, will be examined using tests that assess both response times (speed) and accuracy of responses.

2.2.6. Moderate & Mediate

There are a number of variables which may moderate or mediate the effect of acute physical activity on cognitive function. A moderator is any factor which influences the strength of the relationship between the independent (physical activity) and dependent (cognitive function) variables (Baron & Kenny, 1986). In the physical activity-cognitive function context, this may include characteristics of the physical activity (e.g., modality, intensity, duration), the timing of post-activity cognitive testing, and the participant characteristics (e.g., sex, cardiorespiratory fitness). A mediator refers to any factor which represents a mechanism through which the independent variable (physical activity) may influence the dependent variable (cognitive function; Baron & Kenny, 1986). In the physical activity-cognitive function context, this may include neurobiological mechanisms such as an increase in brain-derived neurotrophic factor, which influences neurogenesis (Pontifex et al., 2019).

2.3. The Acute Effects of Physical Activity on Cognitive Function in Adults

Much of the early work on the effects of acute physical activity in adults focused on 'low level' cognitive processes, such as simple motor speed/learning, information processing and attention (e.g., Allard et al., 1989; Fleury et al., 1981; Travlos & Marisi, 1995). It was hypothesised that these lower-level processes would be more susceptible to changes from acute physical activity compared to more complex 'higher-order' cognitive processes such as executive functions (e.g., inhibitory control, working memory, cognitive flexibility), which were considered more stable and unresponsive to external factors (Easterbrook, 1959; Pontifex et al., 2019). More recently, however, there has been a shift in focus within the acute physical activity-cognition literature to all aspects of cognition, including higher-order functions, since it has been recognised that these are also dynamic and able to be regulated (Botvinick et al., 2001). A recent review by Pontifex et al. (2019) reported that acute physical activity enhances both lower- and higher-order cognitive functions, with small-to-medium sized effect on lower-order domains (d = 0.2–0.5 motor speed/learning and information processing, d = 0.1–0.7 attention) and a small-to-large sized effect on high-order domains such as inhibitory control (d = 0.2–1.2). Moreover, meta-analyses in the adult population report that acute physical activity, across a range of modalities and intensities, can lead to improvements in cognition with small- (g = 0.11, Chang et al., 2012) to medium- (d = 0.52, Verburgh et al., 2014) sized effects. Variations in effect size are thought to be due to variations in the cognitive domains assessed and the cognitive tests utilised, and also dependent on the characteristics of the physical activity (e.g. modality, intensity, duration).

Continuous, moderate intensity physical activity is the modality and intensity most commonly assessed within the adult literature (Chang et al., 2012; Pontifex et al., 2019), however physical activity >93% HR_{max} has been suggested to elicit the largest effect sizes (d = 0.5) when cognition is measured after a delay (> 1 min) following the cessation of physical activity (Chang et al., 2012). Interestingly, in their meta-analytic review, Chang et al. (2012) also reported that post-physical activity improvement in cognition was the greatest in those with higher physical fitness, but only when cognition was measured immediately following the cessation of physical activity, and not when assessed after a delay; this suggest that physical fitness may moderate the effect of physical activity on cognition only during the immediate recovery period following physical activity.

Overall, the majority of the physical activity-cognition literature to date has employed young adults (18-34 y) as participants. This is reflected in meta-analyses and reviews, which although report on effects across the lifespan, predominantly include studies in young adults (e.g. 53% in Chang et al., 2012; 63% in Pontifex et al., 2019; 63% Verburgh et al., 2014). Surprisingly, there have been fewer studies in children and adolescents (11% in Chang et al., 2012; 37% in Verbugh et al., 2014), despite a strong theoretical capacity for improvement in cognitive function in this population (Pontifex et al., 2019). Childhood and adolescence mark important stages of cognitive development (Best et al., 2009; Brocki & Bohlin, 2004; Chen et al., 2014a), where there is an opportunity for shaping (Davidson et al., 2006) and during this time cognitive functioning will impact both learning and academic achievement (Diamond, 2013). Furthermore, cognition in early life is linked to cognition and health in later life; for example, Moffitt et al. (2011) found that children (3–11 y) with better inhibitory control had better physical and mental health as adults (30 y later). Therefore, the effects of physical activity on cognition in young people is an important and distinct area for research.

2.4. The Acute Effects of Physical Activity on Cognitive Function in Young People

The following two sections (section 2.4.1 and 2.4.2) review the evidence on the acute effects of physical activity on cognitive function in young people. A scoping electronic literature review was conducted by searching on three databases (Scopus, ProQuest, & PubMed), for all peer-reviewed primary research to date on the acute effects of physical activity on cognitive function in children or adolescents. The primary search terms were as follows: (1) “physical activity” (or “exercise” or “acute exercise” or “sport”), (2) “cognitive function” (or “cognition” or “attention” or “executive function” or “inhibitory control” or “working memory” or “cognitive flexibility”) and (3) “young people” (or “children” or “adolescents” or “juvenile” or “pubescent” or “prepubescent”). Additionally, the reference lists of selected research papers were examined for identification of any additional relevant research which were not found during the initial search. Literature was included in the following review if participants were aged between 7 and 16 years, it utilised a physical activity that was administered in a single bout, and it measured at least one aspect of post-activity cognitive function.

2.4.1. Adolescents

Table 2.1 provides an overview of studies examining the effects of an acute bout of physical activity on cognitive function in adolescents. As evidenced within the table, research on adolescents began in the 1990s and gained traction by the 2000s, with many early studies utilising pen and paper cognitive tests and primarily examining the effects of physical activity on attention or concentration (e.g., Budde et al., 2008; Raviv & Low, 1990). There was also an early emphasis on examining the effects of physical education in school on cognition (Budde et al., 2008; Kubesh et al., 2009a; Raviv & Low, 1990), compared to either a normal academic lesson (Raviv & Low, 1990), coordinative exercises (Budde et al., 2008) or seated rest (Kubesh et al., 2009a). By the mid-2000s, however, research designs expanded, with diverse physical activity protocols and cognitive tests utilised. Running (Browne et al., 2016; Cooper et al., 2012, 2016; Etnier et al., 2014) and cycling (Berse et al., 2015; Park & Etnier, 2019; Samuel et al., 2017; Stroth et al., 2009) modalities of physical activity have been utilised most frequently within the literature, but the effects of walking (Soga et al., 2015a, 2015b), team games (Cooper et al., 2018; Williams et al., 2020) and coordinative physical activity (Budde et al., 2008) have also been examined.

In terms of the cognitive domains assessed in the studies to date, the majority of studies examined the effects to inhibitory control (10 of 16 studies, 63%) and/or an aspect of working memory (9 of 16 studies, 56%; Table 2.1.). There has been much less focus on other cognitive domains such as attention (2 studies, 13%) and cognitive flexibility (1 study, 6%). Of the 16 studies reviewed, nine (56%) found an improvement in some aspect of cognitive function, whereas seven (44%) found no improvement. In most studies, both accuracy and response time of correct responses were measured on a cognitive test. Of the 29 instances that accuracy on a cognitive test was measured, it was improved on 11 (38%). Similarly, response time of correct responses was measured on 23 occasions within the studies, with eight of these demonstrating an improvement in response times following acute physical activity (35%).

Overall, the adolescent literature suggests that acute physical activity can enhance post-physical activity cognition. However, discrepancies between the findings of adolescent studies highlight the impact of moderating factors (e.g., physical activity characteristics, participant characteristics) in the physical activity-cognition relationship; these will be explored further in section 2.3.3. Overall, there is preliminary evidence that the greatest effects to cognition are observed on tasks that require greater allocation of cognitive resources (i.e.

complex or incongruent trials/tasks; e.g. Browne et al., 2016; Cooper et al., 2018; Kubesh et al., 2019a); this insightful finding highlights the importance of utilising cognitive tests which have both simple and complex levels, to ensure post-physical activity enhancements in cognition are not being overlooked due to adoption of only simple tasks which elicit less cognitive demand. It is also necessary for future research to provide detailed and transparent reporting of study design including physical activity modality, intensity and duration, as this will enable a better understanding of which physical activity types are most effective in enhancing cognition in adolescents. Moreover, additional research is needed to explore the effects of acute physical activity on attention and cognitive flexibility, as these domains are currently underrepresented in the literature.

Table 2.1. An overview of the studies examining the effects of acute bouts of physical activity on cognitive function and related outcomes in adolescents.

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
Berse et al. (2015)	n = 227 (boys) 14.8 ± 0.9 y	Within-subjects, randomised, control	Physical activity: Incremental cycling to exhaustion 25 W every 10 s Control: Watched a cartoon, seated	Modified number-letter task	Cognitive flexibility	RT Accuracy	Post-condition	Faster post physical activity vs. control No difference between conditions
Browne et al. (2016)	n = 20 (11 boys, 9 girls) 13.0 ± 1.8 y	Within-subjects, randomised, crossover, control	Physical activity: Running 20 min 65-75% HRR Control: Watched a cartoon, seated	Stroop Test	Inhibitory control	RT No. of errors	Pre- & 10 min post-condition	Improved on congruent & incongruent level post physical activity vs. rest Fewer errors on incongruent level post physical activity vs. rest
Budde et al. (2008)	n = 99 (80 boys, 19 girls) 15.0 ± 0.8 y	Between-subjects, randomised, control	Physical activity: Coordinative physical activity (ball bouncing & passing) 10 min HR: 122 ± 22 beats·min^{-1} Control: Normal PE lesson 10 min	d2 Test of Attention	Selective, sustained attention	No. of correct responses E%	Pre- & post-condition	Increased pre to post both conditions Greater increase in coordinative physical activity group Decreased pre to post both conditions Greater decrease in coordinative

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
			HR: 122 ± 27 beats·min^{-1}					physical activity group
Cooper et al. (2012)	n = 45 (15 boys, 30 girls) 13.3 ± 0.3 y	Within-subjects, randomised, crossover, control	Physical activity: Running 10 bouts of 7 x 20 m shuttles at 8.0km·h^{-1} with 30 s rest between bouts ~ 10 min HR: 172 ± 11 beats·min^{-1}	Visual Search Test	Visual processing	RT	Pre- & 50 min post-condition	Greater improvement post physical activity vs. rest
						Accuracy		Greater decrease post physical activity vs. rest
				Stroop Test	Inhibitory control	RT		No difference between conditions in RT or accuracy
						Accuracy		
			Control: Seated rest 10 min	Sternberg Paradigm	Visual working memory	RT		Improved post physical activity vs. rest
						Accuracy		No difference between conditions
Cooper et al. (2016)	n = 44 (11 boys, 23 girls) 12.6 ± 0.6 y	Within-subjects, randomised, crossover, control	Physical activity: Running 10 x 10 s sprints 50 s active recovery (walking) between sprints 10 min HR: 181 ± 13 beats·min^{-1}	Stroop Test	Inhibitory control	RT	Pre-, immediately post- & 45 min post condition	Faster immediately post physical activity on complex level and 45 min post on simple level vs. rest
						Accuracy		No difference between conditions
				Digit Symbol Substitution Test	Psychomotor speed	Accuracy		No difference between conditions
			Control: Seated rest 10 min	Corsi Blocks Test	Visuo-spatial working memory	Mean memory span		No difference between conditions

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
Cooper et al. (2018)	n = 39 (20 boys, 19 girls) 12.3 ± 0.7 y	Within-subjects, randomised, crossover, control	Physical activity: Basketball Skill drills & games 60 min HR: 158 ± 11 beats·min^{-1} Control: Seated rest 60 min	Stroop Test	Inhibitory control	RT	Pre-, immediately post- & 45 min post-condition	Slower 45 min post physical activity on simple level but faster immediately & 45 min post physical activity on complex level vs. rest
						Accuracy		Maintained 45 min post physical activity on simple level, declined post rest
				Sternberg Paradigm	Visual working memory	RT		Faster immediately post physical activity on 5-item level vs. rest
						Accuracy		No difference between groups conditions
				Trial Making Test	Information processing speed	Time to complete		No difference between conditions
				d2 Test of Attention	Selective, sustained attention	CP PT E%		No difference between conditions
Etnier et al. (2014)	n = 43 (15 boys, 28 girls) 11–13 y	Between-subjects, randomised, control	Physical activity: PACER test-Progressive intensity running until exhaustion	AB version of the RAVLT	Auditory working memory	Word recall	Immediately post	Better in physical activity vs. control group
					Verbal learning	Gains in word recall		Faster in physical activity vs. control group

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
			Control: Cognitive tests followed by normal PE lesson		Long-term memory	Word recall	Brief delay post	Better in physical activity vs. control group
				Recognition Task	Long-term memory	Word recall	24-h post	No difference between groups
Kubesh et al. (2009)[a]	n = 45 (26 boys, 19 girls) 13–14 y	Within-subjects, randomised, crossover, control	Physical activity: PE class of aerobic, endurance-based physical activity (running, jumping) 30 min	Flanker Task	Inhibitory control	RT	Pre-, post- & ~60 min post-condition	Faster immediately post physical activity vs. rest on the incongruent level No difference between conditions at ~60min post
			Control: Seated rest (listening to audio book) 30 min	Dots Task	Inhibitory control	RT		No difference between conditions
					Cognitive flexibility	RT		No difference between conditions
Kubesh et al. (2009)[b]	n = 36 (21 boys, 15 girls) 13–14 y	Within-subjects, randomised, crossover, control	Physical activity: Aerobic physical activity (running while boxing, waving) 5 min	Flanker Task	Inhibitory control	RT	Pre-, post- & ~60 min post-condition	No difference between conditions in Flanker or Dots task
				Dots Task	Inhibitory control	RT		
			Control: Seated rest 5 min		Cognitive flexibility	RT		
Park & Etnier. (2019)	n = 22 (10 boys, 11 girls) 15.9 ± 0.3 y	Within-subjects, randomised, counterbalanced, control	Physical activity: Cycling 20 min 64-76% HRmax	Symbol Digit Test	Psychomotor speed, attention	No. of correct answers	Immediately post-control	Higher post physical activity vs. rest

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
			Control: Seated school work 20 min	Stroop Test	Inhibitory control	No. of correct answers	10 min post-physical activity	Higher post physical activity vs. rest on the colour & colour-word levels
				Tower of London	Executive Function	Total moves		Lower post physical activity vs. rest
						Excess moves		Lower post physical activity vs. rest
Raviv & Low. (1990)	n = 96 (boys) 11–13 y	Between-subjects, control	Physical activity: Normal PE lesson Control: Normal science lesson	d2 Concentration Test	Concentration	No. of correct responses E%	Pre- & post-condition	No difference between groups
Samuel et al. (2017)	n = 20 (12 boys, 8 girls) 13.1 ± 2.4 y	Repeated measures	Physical activity: Incremental cycling to exhaustion 10 - 20 watts·min^{-1}	Forward Digit Span	Verbal working memory	No. of correct answers	Pre-, immediately post- & 1 h post-condition	Increased 1 h post vs. pre-physical activity
				Backward Digit Span	Verbal working memory	No. of correct answers		Increased 1 h post vs. pre- & post-physical activity
				Modified RAVLT	Auditory working memory	Word recall		Decreased post- vs. pre-physical activity but increased 1 h post vs. post physical activity
				Digit Symbol Substitution Test		No. of correct matches		

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
					Psychomotor speed, attention			Increased 1 h post- vs. post- physical activity
Soga et al. (2015)[a]	n = 28 (24 boys, 4 girls) 15.6 ± 0.5 y	Within-subjects, randomised, crossover, control	Physical activity: Treadmill walking 13 ± 2 min 60% HRmax	Flanker Task	Inhibitory control	RT	Pre-, during- & (approx. 5 min) post*-condition	No difference between conditions
						Accuracy		Lower during vs. post physical activity
			Control: Seated rest 13 ± 2 min	Spatial n-back	Visuo-spatial working memory	RT		Slower during physical activity vs. rest Faster post vs. during physical activity
						Accuracy		Lower during vs. post physical activity
Soga et al. (2015)[b]	n = 27 (18 boys, 9 girls) 15.8 ± 0.4 y	Within-subjects, randomised, crossover, control	Physical activity: Treadmill walking 13 ± 2 min 70% HRmax	Flanker Task	Inhibitory control	RT	Pre-, during- & (approx. 5 min) post*-condition	Faster post vs. pre & during physical activity
						Accuracy		No difference between conditions
			Control: Seated rest 13 ± 2 min	Spatial n-back	Visuo-spatial working memory	RT		Slower during physical activity vs. rest Faster post vs. pre & during physical activity
						Accuracy		Lower during physical activity vs. rest Higher post vs. during physical activity

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
Stroth et al. (2009)	n = 33 (boys) 14.2 ± 0.5 y	Within-subjects, randomised, crossover, control	Physical activity: Cycling, 10 min 60% HR_{max}	Modified (Go/NoGo) Flanker Task	Executive Function	RT Accuracy	Post-condition	No difference between conditions
			Control: Seated rest 10 min	EEG	Task preparation	CNV		No difference between conditions
					Action Monitoring	N2		
					Stimulus evaluation	P3		
Williams et al. (2020)	n = 36 (boys) 12.6 ± 0.5 y	Within-subjects, randomised, crossover, counterbalanced, control	Physical activity: Football drills & games 60 min 75 ± 8 %HRmax	Stroop Test	Inhibitory control	RT Accuracy	30 min pre-, 45 min post- & 90 min post-condition	No difference between conditions
			Control: Seated rest 60 min	Sternberg Paradigm	Visual working memory	RT Accuracy		No difference between conditions

Abbreviations [Listed Alphabetically]: CNV: contingent negative variation. CP: concentration performance. EEG: electroencephalogram. ERP: event-related potentials. E%: error rate. HIIE: high-intensity intermittent physical activity. HR: heart rate. $HR_{max:}$ maximum heart rate. HRR: heart rate reserve. MIE: moderate intensity physical activity. n: number. PACER test: progressive aerobic cardiovascular endurance test. PE: physical education. PT: number of processed targets. RAVLT: Rey auditory-verbal learning test. RT: response time. [a,b]: two separate experiments reported in the same paper.* cognitive tests administered post physical activity/rest once participant heart rate returned to within 10% of its pre-activity value. NB cognitive tasks are classified based on the classifications provided within the original paper and may not align with the classifications provided within this thesis or the wider literature.

2.4.2. Children

Table 2.2 provides an overview of studies examining the effects of an acute bout of physical activity on cognitive function in children. Research interest in children began in the 1990s but has been increasing exponentially since the 2000s. Walking is the modality of physical activity most commonly utilised within the child literature (5 of 15 studies, 33%; Caterino & Polak, 1999; Drollette et al., 2012, 2014; Hillman et al., 2009; Tomporowski et al., 2008). Less commonly utilised modalities include running (3 studies, 20%; Chen et al., 2014a; Niemann et al., 2013; Tine & Butler, 2012), cycling (2 studies, 13%; Chen et al., 2016; Ellemberg & St-Louis-Deshênes, 2010), cognitively engaging physical activity (2 studies, 13%; Jäger et al., 2014; Schmidt et al., 2015), and dancing (1 study, 7%; Altenburg et al., 2016). Several studies examined the effect of acute physical activity on inhibitory control (7 of 15 studies, 47%), with the majority of these (6 of 7, 86%) reporting benefits. The next most commonly assessed cognitive domain was attention (5 of 15 studies, 33%), with all studies (5 of 5, 100%) reporting post-physical activity enhancements. There has been less focus on other domains of cognition such as cognitive flexibility (3 studies) and working memory (3 studies). Of the 15 studies reviewed, 14 (93%) found an improvement in some aspect of cognitive function (Table 2.2) and only one study (7%) found no improvement (Tomporowski et al., 2008).

In most studies, both accuracy and response time of correct responses on a cognitive test was examined; accuracy was enhanced in seven of 13 cases (54%) and response times were enhanced in nine of 16 cases (56%), demonstrating that both areas are susceptible to the acute effects of physical activity. Overall, there is strong evidence that acute physical activity has a positive effect on post-physical activity cognitive function in children. However, many adopted a between-subjects design (8 of 15 studies, 53%); the results may have thus been confounded by individual differences between the groups (e.g., in sex or baseline cognitive ability/performance; Chang et al., 2012; Williams et al., 2019). Moreover, a cognitively engaging control condition was utilised in several studies (8 of 15 studies, 53%). Control conditions included classroom activity (Altenburg et al., 2016; Caterino & Polak, 1999;

Pirrie & Lodewyk, 2012; Schmidt er al., 2015), an educational lecture (Ma et al., 2014), reading an educational book (Chen et al., 2014a), and watching educational videos (Tine & Butler, 2012; Tomporowki et al., 2008). Although it could be argued that these control conditions have higher ecological validity than seated (physical and cognitive) rest, evidence suggests that cognition decays over time in response to repetitive cognitive challenge under seated conditions (Drollette et al., 2012). Moreover, a study by Janssen et al. (2014a) demonstrated that selective attention improved when children (10–11 y) were given a 15 min cognitive (and physical) rest following a 60 min school lesson, whereas selective attention declined when the 15 min was used for continued cognitive activity. Thus, any cognitive benefits observed following physical activity compared to control in these studies may be due to participants experiencing cognitive rest during the physical activity condition, as opposed to the effects being due to the physical activity itself. There is thus a need within child literature for research which adopts a within-subjects design and a control condition involving both physical and cognitive rest. Only then will it be possible to gain understanding of the complex physical activity-cognition relationship.

Forthcoming literature should also address the factors which may influence the efficacy of acute physical activity in enhancing cognition in children, such as physical activity characteristics (e.g., modality, intensity, duration), as well as participant characteristics (e.g., cardiorespiratory fitness, sex; Pontifex et al., 2019; Williams et al., 2019). Furthermore, research is needed to examine the effects of acute physical activity on less well studied cognitive domains such as working memory and cognitive flexibility, as these domains are linked to learning (Diamond, 2013) and academic performance (Gathercole et al., 2003; St. Clair-Thompson & Gathercole, 2006), yet have been under-represented in the literature to date.

Table 2.2. An overview of the studies examining the effects of acute bouts of physical activity on cognitive function and related outcomes in children.

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
Altenburg et al (2016)	n = 56 (30 boys, 26 girls) 10–12 y	Between-subjects, randomised, control	Physical activity A: 1 x dancing Mid-morning 40-60% HRR 20 min Physical activity B: 2 x dancing Early & mid-morning 40-60% HRR 20 min Control: Simulated school lesson	Sky Search^{+}	Selective attention	RT	Pre-, immediately post- & 90 min post- each physical activity bout	Physical activity early morning (B), enhanced attention 90 min post vs. no early morning physical activity (A & control) Physical activity early- & mid- morning (B) maintained enhanced attention 90 min post vs. control
Caterino & Polak (1999)	n = 177 (***) 7–10 y Grade 2–4, split by age	Between-subjects, randomised, control	Physical activity: Walking 15 min Control: Classroom activity	Woodcock-Johnson Test of Concentration	Concentration	Accuracy	Immediately post-condition	Concentration higher post physical activity in grade 4 (9–10 y) but not grade 2 or 3

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
Chen et al. (2014)	n = 83 (50 boys, 33 girls) 8–11 y	Between-subjects, randomised, control	Physical activity: Running 60–70% HR_{max} 30 min Control: Seated educational reading 30 min	Modified Flanker Task	Inhibitory control	RT	Pre- & ~25 min post-condition	Improved post physical activity vs. rest
				Modified *n*-back Task	Visual working memory	RT		Improved post physical activity vs. rest
				More-odd Task	Cognitive flexibility	RT		Improved post physical activity vs. rest
Chen et al. (2016)	n = 9 (5 boys, 4 girls) 10 y	Within-subject, counterbalanced, control	Physical activity: Cycling 65% HR_{max} 30 min Control: Seated rest 30 min	*n*-back Task	Working memory	RT	Post-condition*	Faster post physical activity vs. rest
						Accuracy		No difference between conditions
					fMRI scanning			Greater activation of SPL, IPL, LHIP & bilateral Cerebellum post physical activity vs. rest
Drollette et al (2012)	n = 36 (16 boys, 20 girls) 9.9 ± 0.7 y	Within-subject, randomised, counterbalanced, control	Physical activity: Walking 60% HRmax ~20 min Control: Seated rest	Flanker Task	Inhibitory control	RT	Pre-, during-, & ~5 min post-condition	No difference between conditions
						Accuracy		Higher post physical activity vs. rest
				Spatial *n*-back	Visuo-spatial working memory	RT Accuracy		No difference in RT or accuracy between conditions
Drollette et al. (2014)	n = 40 (13 boys, 27 girls)	Within-subjects, randomised,	Physical activity: Walking 60–70% HR_{max} 20 min	Modified Flanker Task	Inhibitory control	RT	Pre- & 22.5 ± 3.4 min post-condition	No difference between conditions

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
	9.7 ± 0.7 y Higher- & lower-performers (IC)	counterbalanced, control	Control: Seated rest 20 min			Accuracy		Higher post physical activity vs. rest only in lower performers
				EEG	Action monitoring	N2 amplitude		Lower (better) post physical activity vs. rest
					Allocation of attentional resources	P3 amplitude		Higher post physical activity vs. rest only in lower performers
					Stimulus evaluation	P3 latency		Shorter (better) post physical activity vs. rest
Ellemberg & St-Louis-Deschênes (2010)	n = 36 7 y n = 36 10 y (boys)	Between-subjects, randomised, control	Physical activity: Cycling 63% HRmax 30 min (+5 min warm up & cool-down) Control: Seated rest 40 min	Simple reaction time task	Information processing	RT	Pre- & immediately post-condition	Faster post physical activity vs. rest in children 7 & 10 y
				Choice reaction time task	Inhibitory control	RT		Faster post physical activity vs. rest in children 7 & 10 y
						Accuracy		No difference between groups
Jäger et al. (2014)	n = 104 (47 boys, 57 girls) 7.9 ± 0.4 y	Between-subjects, randomised, control	Physical activity: Cognitively engaging, coordinative 20 min Control: Listened to audiobook, seated	Adapted Pictorial Updating Task	Updating	Accuracy	Pre-, immediately post- & 40 min post-condition	No difference between groups
				Modified Flanker Task	Inhibitory control	Conflict score		Improved immediately post physical activity vs. rest
					Cognitive flexibility	Switch costs		No difference between groups

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
Hillman et al. (2009)	n = 20 (12 boys, 8 girls) 9.5 ± 0.5 y	Within-subjects, counterbalanced, control	Physical activity: Walking 60% HR_{max} 20 min	Modified Flanker Task	Inhibitory control	RT	Post- (approx. 25 min)* condition	No difference between conditions
						Accuracy		Higher post physical activity vs. rest on incongruent level
			Control: Seated rest 20 min	EEG	Allocation of attentional resources	P3 amplitude		Greater in fronto-central, central, centroparietal & parietal regions post physical activity vs. rest
					Stimulus evaluation	P3 latency		No difference between conditions
				WRAT3	Reading	Accuracy		Higher post physical activity vs. rest
					Spelling	Accuracy		No difference between conditions for spelling or arithmetic
					Arithmetic	Accuracy		
Ma et al (2015)	n = 88 (44 boys, 44 girls) 8–11 y	Within-subjects, randomised, counterbalanced, control	Physical activity: FUNtervals** 20 s high intensity activity, 10 s rest x 8 4 min	d2 Test of Attention	Selective, sustained attention	TN	Pre- & 10 min post-condition	Higher post rest vs. physical activity
						E_{Omis}		Fewer E, E_{Omis}, E_{Comm} & E% post physical activity vs. rest
						E_{Comm}		
			Control: Lecture on kinesiology 10 min			E%		
						TN-E		
						CP		

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
Niemann et al (2013)	n = 42 (20 boys) 9.8 ± 0.4 y	Between-subjects, randomised, control	Physical activity: Running 85–90% HR^{max} 12 min Control: Watch a film (seated)	d2 Test of Attention	Selective, sustained attention	Accuracy	Pre- & 5 min post-condition	Improved to a greater extent post physical activity vs. rest
Pirrie & Lodewyk (2012)	n = 39 (***) 9.8 ± 0.4 y	Within-subjects, counterbalanced, control	Physical activity: PE lesson > 20 min MVPA 60 min Control: Classroom activity (reading) 60 min	Trial-Making Test	Executive function	RT	Staggered; 10-60 min post-condition	Higher post physical activity vs. rest
				Adapted Stroop Test	Inhibitory control	RT		No difference in RT or accuracy between conditions
						Accuracy		No difference between conditions
				Non-verbal Matrices Test	Simultaneous processing	Accuracy		No difference in simultaneous or successive processing between conditions
				Sentence Repetition Test	Successive processing	Accuracy		
Schmidt et al. (2015)	n = 90 (41 boys, 49 girls) 10–11 y	Between-subjects, randomised, control	Physical activity: Cognitively engaging activities e.g., coordination, balancing 45 min Control: Normal school lesson (language)	Revised d2 Test of Attention	Attention	FA TN	Pre-, immediately post- & 90 min post condition	Greater improvement in FA & TN post- to 90 min post in physical activity vs. control group
						E %		No difference in E % between groups

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
Tine & Butler (2012)	n = 164 (83 boys, 81 girls) 10–13 y	Between-subjects, randomised, control	Physical activity: Running 70–80% HR^{max} 12 min Control: Educational video 12 min	d2 Test of Attention	Selective, sustained attention	TC	Pre- & 1 min-post condition	Improved post physical activity vs. rest
Tomporowski et al. (2008)	n = 69 (33 boys, 36 girls) 9.2 ± 1.2 y	Within-subjects, counterbalanced, control	Physical activity: Walking 23 min Control: Educational video 23 min	Visual Switching Task	Cognitive flexibility	Response time	Pre- & post-condition	No difference between conditions

Abbreviations [Listed Alphabetically]: concentration performance. EEG: electroencephalogram. E_{Comm}: errors of commission (the number of mistakes made by including irrelevant symbols) E_{Omis}: errors of omisson (the number of mistakes made by missing relevant symbols). E%: the proportion of E_{Comm} + E_{Omis} made within all of the processed items E: total error score (E_{Comm} + E_{Omis}). FA: number of correct responses – E_{Comm}. fMRI: functional magnetic resonance imaging. HR_{max}: maximum heart rate. IC: inhibitory control. IPL: inferior parietal lobule. LHIP: left hippocampus. MVPA: moderate-to-vigorous physical activity. RT: response time. SPL: superior parietal lobule. TC: total number of correctly processed items (TN – TE). TE: total number of errors (accuracy). TN: total number of processed items (processing speed). WRAT3: wide range achievement test 3rd edition. * cognitive tests administered post physical activity/rest once participant heart rate returned to within 10% of its pre-activity value. ** FuNtervals: high intensity interval activities that involve whole-body movement e.g. squats, jumping jacks, scissor kicks, jumping, running. *** number of each sex not reported. + subset of the test of every day attention for children (TEA-Ch; Manly et al., 2001). NB cognitive tasks are classified based on the classifications provided within the original paper and may not align with the classifications provided within this thesis or the wider literature.

2.4.3. Moderating Variables

Whilst acute physical activity appears beneficial for cognitive function in children and adolescents, there are many factors which may influence the acute physical activity-cognition relationship. This includes the characteristics of the physical activity (e.g., modality, intensity, duration), the timing of the post-physical activity cognitive testing, and the participant characteristics (e.g., sex, cardiorespiratory fitness). An overview of the potential moderating variables is shown in Figure 2.3. The following section of this literature review will examine the evidence regarding each of these moderating variables.

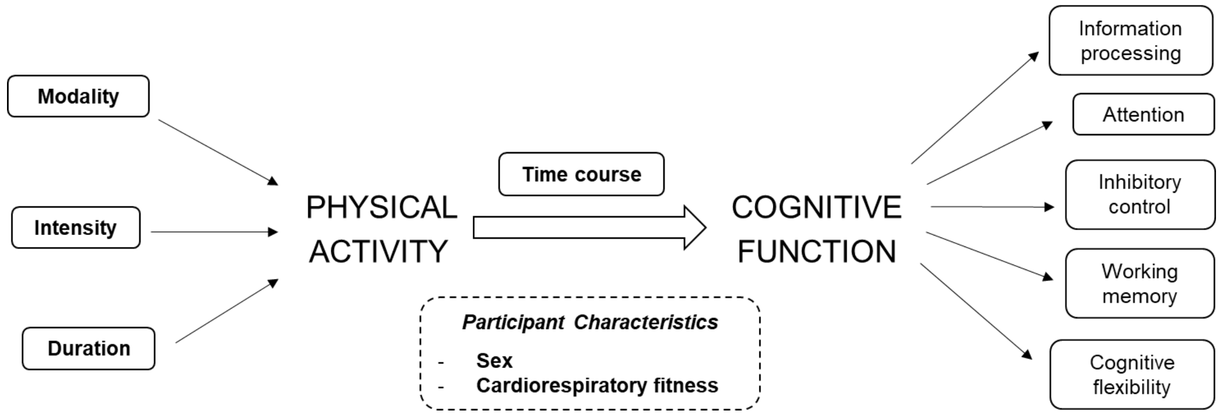

Figure 2.3. An overview of the physical activity-cognition relationship, including the key moderating variables: physical activity characteristics (left), timing of cognitive testing (top), and participant characteristics (bottom) shown in bold, and the cognitive domains (right). Schematic adapted from Williams et al. (2019).

2.4.3.1. Physical Activity Characteristics

While the characteristics of a physical activity (i.e., modality, intensity and duration) are inherently linked and will interact to influence the overall energetic impact (i.e., dose) of the physical activity, each characteristic is also considered to moderate the acute physical activity-cognition relationship independently, and thus will be reviewed separately in this section.

2.4.3.1.1. Modality

Physical activity modality refers to the type and/or form of physical activity completed. The main modalities of physical activity are categorised into aerobic activity (e.g., running, cycling), resistance activity (e.g., weightlifting), flexibility activities (e.g., yoga, stretching) and coordinate games (e.g., netball, football). Evidence suggests that physical activity-induced changes in cognition may differentially manifest based upon the modality of activity utilised (de Greeff et al., 2018; Pontifex et al., 2019). For example, a meta-analysis by Lambourne and Tomporowski (2010) reported that cognitive enhancements were larger following cycling modalities (g = 0.23), than for running modalities (g = 0.12).

Table 2.3 provides an overview of the studies which have directly compared the effect of different physical activity modalities on cognitive function in young people. Recently, there has been research interest in comparing non-cognitively engaging physical activity (e.g., running, cycling) to cognitively engaging physical activity (e.g., team games, coordinative physical activity), with findings in this area heterogeneous. Some evidence suggests that cognitively engaging physical activity, compared to non-cognitively engaging physical activity, may elicit greater benefits to attention (Budde et al., 2008), visual working memory (Pesce et al., 2009) and cognitive flexibility (Ishihara et al., 2017; Table 2.3), with this type of physical activity thought to pre-activate areas of the brain (frontal lobe, cerebellum) involved in these cognitive functions (Budde et al., 2008). However, other studies have reported no differences in cognitive outcomes comparing cognitively to non-cognitively engaging physical activity (Jäger et al., 2015, van den Berg et al., 2016). Furthermore, some studies have reported greater improvements (e.g., in attention) following aerobic physical activity (e.g., walking, running, skipping), compared to cognitively engaging, physical activity (Gallotta et al., 2012, 2015). Moreover, a recent study reported detrimental effects to cognitive flexibility following cognitively engaging physical activity, compared to aerobic (e.g., running, jumping) physical activity (Egger et al., 2018; Table 2.3). It has been postulated that the cognitive and attentional demands of more cognitively complex activities could mitigate the beneficial cognitive after-effects of physical activity, as neural resources are taxed to a greater extent in order to regulate the physical activity. It is also thought that there may be an 'optimal' level of cognitive engagement, whereby anything too high or low can result in nul or negative effects to cognition (Egger et al., 2018), and this 'optimal' level may be different between participants (e.g., depending on age, sex, baseline cognitive ability). Furthermore, the majority of studies that have compared cognitively engaging physical activity to other physical activity modalities have utilised between-subjects study designs (Table 2.3); existing findings may have thus been confounded by individual differences between physical activity groups.

Initial evidence suggests that intermittent physical activity may be more favourable than continuous physical activity in enhancing cognitive function in young people (Lambrick et al., 2016; Martins et al., 2021; Table 2.3). Specifically, Lambrick et al. (2016) reported faster response times on a Stroop task following 15 min of intermittent, compared to continuous, moderate intensity running (Lambrick et al., 2016). Similarly, Martins et al. (2021) found that response times on a Stroop task were faster 30 min following 15 min of intermittent, compared to continuous, cycling. Moreover, intermittent circuit training has been reported to improve response times on an inhibitory control task (Stroop test) up to 60 min following the cessation of the physical activity (Ludyga et al., 2019). Inhibitory control may thus be enhanced to a greater extent both immediately and following a delay from intermittent physical activity. These findings are pertinent, given that young people's activity patterns are typically intermittent in nature (Bailey et al., 1995; Howe et al., 2010) and that this type of activity is more enjoyable to youth than continuous physical activity (Malik et al., 2017), even when completed at high intensities (Malik et al., 2019). Intermittent physical activity is thus an ecologically valid, and potentially more efficacious, modality of physical activity that is currently underrepresented in the literature.

Table 2.3. An overview of the studies comparing the influence of physical activity modality on the acute physical activity-cognitive function relationship in young people.

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
Budde et al. (2008)	n = 99 (80 boys, 19 girls) 15.0 ± 0.8 y	Between-subjects, randomised	Physical activity: Coordinative (ball bouncing & passing) (CPE) 10 min HR: 122 ± 22 beats·min^{-1} vs. normal PE lesson (PE) 10 min HR: 122 ± 27 beats·min^{-1}	d2 Test of Attention	Selective, sustained attention	n of correct responses E%	Pre- & post-condition	Increased pre to post both conditions Greater increase in CPE group Decreased pre to post both conditions Greater decrease in CPE group
Egger et al. (2018)	n = 216 (110 boys, 106 girls) 7–9 y	Between-subjects, randomised, control	Physical activity: Aerobic (running & jumping) (PE) vs. instructional movements (CPE) MVPA 18 min Control: Sedentary cognitive games (CE) vs. rest (CON) 20 min	Backward Colour Recall Task Modified Flanker Task	Updating Inhibitory control Cognitive Flexibility	Accuracy Conflict score Switch costs	Pre- & immediately post-condition	No difference between conditions No difference between conditions Higher (lower performance) post CE & CPE vs. PE & CON
Gallotta et al. (2012)	n = 212 (boys) 8–11 y	Within-subjects, randomised,	Physical activity: Continuous aerobic (running,	d2 Test of Attention	Selective, sustained attention	TN CP	Pre- & post-condition	Smaller improvement in TN & CP post CPE vs. PE & CE

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
		counterbalanced, control	skipping) (PE) vs. coordinative (ball bouncing & passing) (CPE) MVPA 50 min Control: Normal lesson (CE) 50 min			E%		No difference between conditions
Gallotta et al. (2015)	n = 116 (boys) 8–11 y	Between-subjects, randomised, control	Physical activity: Continuous aerobic (running, skipping) (PE) vs. Coordinative (ball bouncing, passing) (CPE) MVPA 50 min Control : Normal lesson (CE) 50 min	d2 Test of Attention	Selective, sustained attention	TN	Pre-, 0 min & 50 min post-condition	No difference between groups
						CP		Improvement pre- to 0 min- & 50 min- post PE & CE Improvement pre- to 50 min- post CPE
						E%		No difference between conditions
Haverson et al. (2016)	n = 94 (48 boys, 46 girls) 16–17 y	Between-subjects, randomised, control	Aerobic exercise: Walking/ jogging (AE) vs. resistance exercise (RE) 50-60% HR_{max} 30 min Control: Seated rest (CON) 30 min	Adapted Stroop Test	Inhibitory control	RT	5-40 min pst condition	Faster post AE & RE vs. CON but no difference between AE & RE
				Trail-Making-Test	Attention & processing speed	RT		Faster post AE vs. RE and CON

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
Ishihara et al. (2017)	n = 81 (38 boys, 43 girls) 6–12 y	Between-subjects, control	Physical activity: Technique-based tennis (PA) vs. games-based tennis (CPA) 50 min Control: Watched TV (CON) 50 min	Stroop Colour & Word Test	Inhibitory control	RT Accuracy	Pre- & 15 min post-condition	Improved post PA & CPA vs. CON
				2-back Task	Visual working memory	RT Accuracy		Improved post CPA vs. PA & CON
				Local-Global Task	Cognitive flexibility	RT Accuracy		Improved post CPA vs. PA & CON No difference in accuracy between groups on any test
Jäger et al. (2015)	n = 217 (boys) 10–12 y	Between-subjects, randomised, control	Physical activity: Running (PE) vs. instructional games (CPE) 70% HR_{max} 20 min Control: Sedentary cognitive games (CE) vs. rest (CON) 20 min	Non-spatial n-Back	Updating	Accuracy	Pre- & immediately post-condition	No difference between conditions on any test
				Flanker Task	Inhibitory control	Accuracy		
				Adapted Flanker Task	Cognitive flexibility	Accuracy		
Lambrick et al. (2016)	n = 20 (9 boys, 11 girls) 8.8 ± 0.8 y	Within-subjects, randomised, counterbalanced	Intermittent (INT) vs. continuous (CONT) treadmill running Moderate intensity 15 min	Stroop Task	Inhibitory control	RT Accuracy	Pre-, 1-, 15- & 30-min post condition	Faster post INT vs. CONT No difference in accuracy between conditions

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
Martins et al. (2021)	n = 24 (14 boys, 10 girls) 10.3 ± 0.5 y	Within-subjects, randomised, control	Physical activity: Continuous cycling (CONT) 70% HR_{max} 15 min	Colour Stroop Task	Inhibitory control	RT	Pre-, 1 min- & 30 min-post condition	Faster post INT vs. CONT at 30 min
						Accuracy		No difference between conditions
			Intermittent cycling (INT) 12 x 30 s ≥85% HR_{max} 15 min	Digit Span Test	Verbal working memory	n of correct sequences		No difference between conditions
						Memory span		Better 1 min post CONT vs. REST
			Control: Watched a video (REST)	Corsi Block Test	Visuo-spatial working memory	Block span Memory span n of correct trials		No difference in block or memory span, or no. of correct trials between conditions
Pesce et al. (2009)	n = 52 (boys) 11–12 y	Within-subjects, randomised, counterbalanced, control	Physical activity: Team games (CPA), 42 min vs. circuit training (PA), 38 min Control: seated rest (CON)	Free-recall Memory Task	Visual working memory	Accuracy	5-8 min & 21-24 min post-condition	Higher for primary & regency items 5-8 min post CPA vs. CON Higher for regency items 21-24 min post CPA & PA vs. CON
Schmidt et al. (2016)	n = 92 (50 boys, 42 girls) 11.8 ± 0.4 y	Between-subjects, randomised, control	Physical activity: Running (PA) vs. instructional running (CPA) 73% HR_{max} 10 min	Modified d2 Test of Attention	Selective, sustained attention	CP	Pre- & immediately post-condition	Higher post CE & CPA vs. PA & CON
						TN E%		No difference between conditions in TN or E%

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
			Control: Sedentary cognitive engagement (CE) vs. rest (CON) 42% HR_{max} 10 min					
Van den Berg et al. (2016)	n = 195 (boys) 10–13 y	Within- (physical activity vs. control) & between- (physical activity type) subjects, randomised, counterbalanced, control	Physical activity: Aerobic physical activity (PA) vs. coordination (CPA) vs. strength (SPA) Moderate intensity 10 min Control: Lesson (CE) 10 min	d2 Test of Attention	Selective, sustained attention	CP	Pre- & immediately-post condition	No difference between conditions on any measure
				Letter Digit Substitution Test	Information Processing	Accuracy RT		No difference between conditions on any measure

Abbreviations [Listed Alphabetically]: CE: cognitive engagement. CON: control. CONT: continuous physical activity. CPA: cognitively engaging physical activity. CP: number of letters correctly marked minus errors of commission (concentration performance). E_{Comm}: errors of commission (the number of mistakes made by including irrelevant symbols) E_{Omis}: errors of omisson (the number of mistakes made by missing relevant symbols). E%: the proportion of E_{Comm} + $_{EOmis}$ made within all of the processed items. INT: intermittent. MVPA: moderate-to-vigorous physical activity. n: number. PA: Physical activity. PE: physical education. RT: response time. TN: total number of processed items (processing speed).

2.4.3.1.2. Intensity

Physical activity intensity is considered an important moderator in the physical activity-cognition relationship (Chang et al., Williams et al., 2019; Pontifex et al., 2019). An early supposition within the literature was the inverted-U hypothesis, which suggests that enhancements in cognition occur following moderate intensity physical activity, but are diminished following lighter and more vigorous intensity physical activity (Bender & McGlynn, 1976; Davey, 1973; Hillman et al., 2012; Weingarten & Alexander, 1970). In line with this hypothesis, the majority of the child and adolescent literature has utilised moderate intensity physical activity and reported positive effects to post-physical activity cognition (Altenburg et al., 2016; Chen et al., 2014a, 2016; Drollette et al., 2012, 2014; Ellemberg & St-Louis-Deschênes, 2010; Hillman et al., 2009; Park & Etnier, 2019; Soga et al., 2015b).

However, the timing of cognitive test administration post-physical activity is also considered an important moderator in this relationship, and is influenced by physical activity intensity (Chang et al., 2012; Pontifex et al., 2019). For example, evidence suggests that enhancements to cognition tend to occur immediately following moderate intensity physical activity, but after a delay following high intensity physical activity; meaning studies which examined the effects of high-intensity physical activity immediately post cessation of the physical activity may have missed possible delayed enhancements (Chang et al., 2012; Samuel et al., 2017). In the last decade, studies have begun to directly compare the effects of different physical activity intensities, of the same modality and duration, and have examined both the immediate and delayed effects to cognition (Table 2.4). While the findings of these studies are not homogenous, most likely due to methodological issues (e.g., adoption of between-subjects designs), the evidence overall suggests that moderate-to-vigorous and high-intensity physical activity may be the most effective at enhancing cognition in youth (Browne et al., 2016; Lind et al., 2019; Pastor et al., 2019).

In a study by Browne et al. (2016), for example, inhibitory control was measured 20 min following 10 min of running at 90% and 110% of lactate threshold (obtained through an incremental running test), and rest. Inhibitory control improved following running at 110%

lactate threshold, while no effects were observed from running at 90% lactate threshold or rest. Moreover, there is some initial evidence that intermittent moderate-to-vigorous and high-intensity physical activity may be particularly beneficial (Cooper et al., 2012, 2016, 2018; Ma et al., 2014). For example, 20 min of moderate-to-vigorous intensity, compared to low-to-moderate intensity, small-sided football games were reported to improve P3 amplitude (i.e., allocation of attentional resources) and inhibitory control 20 min following the cessation of physical activity (Lind et al., 2019). These findings are pertinent, as young people's activity patterns are typically sporadic, involving short bursts of high-intensity activity interspersed with rest (Bailey et al., 1995; Howe et al., 2010), and because this type of physical activity is more enjoyable than continuous physical activity for young people (Malik et al., 2017, 2019). High-intensity intermittent physical activity is thus an ecologically valid type of physical activity which will promote adherence (Howe et al., 2010). This intensity of physical activity thus warrants further investigation, including an investigation into its effects across cognitive domains and over time (e.g., 0–45 min post physical activity).

Table 2.4. An overview of the studies comparing the influence of physical activity intensity on the acute physical activity-cognitive function relationship in young people.

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
Browne et al. (2016)	n = 9 (4 boys, 5 girls) 10.3 ± 0.5 y	Within-subjects, randomised, control	Physical activity: Running 10 min 90% LT (MOD) 110% LT (HIGH) Control: Seated rest 10 min (CON)	Modified Flanker Task Free Recall Memory Test Trial Making Test	Inhibitory control Working memory Cognitive flexibility	Efficiency score (RT / accuracy) n of items correctly recalled Time to complete	20 min post-condition	Higher post HIGH vs. CON. No difference between conditions No difference between conditions
Budde et al. (2010)	n = 59 (33 boys, 26 girls) 14.4 ± 0.5 y	Between-subjects, randomised, control	Physical activity: Running 12 min 50-65% HR_{max} (LOW) vs. 70-85% HR_{max} (HIGH) Control: Seated rest 12 min	Letter Digit Span Task	Auditory working memory	n of correct responses	Pre- & post-condition	No difference between LOW & HIGH Improvements post physical activity vs. rest in low performers
Janssen et al. (2014)[a]	n = 123 (62 boys, 61 girls) 10.4 ± 0.6 y	Within-subjects, randomised, crossover, control	Physical activity: 15 min Moderate intensity (jogging, passing ball; MOD) vs. vigorous intensity (running, jumping; VIG) Control: Continued lesson (CE) vs. Listening to story (REST)	Sky Search [+]	Selective attention	RT	Pre- & post-condition	Improved post VIG vs. CE Improved post MOD vs. REST, CE & VIG

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
Lind et al. (2019)	n = 81 (48 boys, 33 girls) 11-12 y	Between-subjects, randomised, control	Physical activity: Small-sided football games 20 min (2 x 10 min with 5 min break) 60-100% HRR (MVPA) vs. 60-80% HRR (LMPA)	Modified Flanker Task	Inhibitory control	RT	5 weeks pre- & 20 min- post	No differences in RT, accuracy or interference accuracy between the groups
						Accuracy		
						Interference accuracy		
						Interference RT		Improved post MVPA vs. LMPA
			Control: Watched football seated (CON)	EEG	Allocation of attention resources	P3 amplitude		Improved post MV vs. LM & CON
					Stimulus evaluation	P3 latency		No difference between trials
Ludyga et al. (2019)	n = 94 (boys) 12-15 y	Between-subjects, randomised, control	Physical activity: Circuit training (jumping jacks, skipping), intermittent 16 min High-intensity (60 s on, 30 s off; HIGH) vs. moderate intensity (30 s on, 30 s off; MOD)	Flanker Task	Inhibitory control	RT	Pre-, immediately, 30- & 60-min post condition	Improved immediately and 60 min post MOD vs. HIGH & CON
						Accuracy		No difference in accuracy between groups
			Control: Watched a video of physical activity (CON)					
Pastor et al. (2019)	n = 35 (19 boys, 16 girls) 16.5 ± 0.8 y	Within-subjects, counterbalanced, control	Physical activity: Aerobics class 20 min light-to-moderate intensity	Stroop Test	Inhibitory control	Accuracy	5 min pre- & 15 min post condition	Improved post LMPA & MVPA vs. CE Improved to a greater extent post MVPA vs. LMPA

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
			(LMPA) vs. moderate-to-vigorous (MVPA) Control: Lesson (CE)					
Peruyero et al. (2017)	n = 44 (23 boys, 21 girls) 16.4 ± 0.7 y	Within-subjects, counterbalanced, control	Physical activity: Zumba 20 min Light-to-moderate intensity (LMPA) vs. moderate-to-vigorous (MVPA) Control: Lesson (CE)	Stroop Test	Inhibitory control	Accuracy	5 min pre- & post condition	Higher post MVPA vs. LMPA & CE

Abbreviations [Listed Alphabetically]: CE: cognitive engagement. G1: group 1. G2: group 2. HR: heart rate. HR_{max}: maximum heart rate. HRR: heart rate reserve. LMPA: light-to-moderate intensity physical activity. LT: lactate threshold. MVPA: moderate-to-vigorous intensity physical activity. n: number. RT: response time. + subset of the test of every day attention for children (TEA-Ch; Manly et al., 2001).

2.4.3.1.3. Duration

With regards to the duration of a physical activity, it is thought that there may be a minimum, or perhaps optimum, duration required to activate (or optimise) the mechanisms that underlie physical activity-induced changes to cognition (Pontifex et al., 2019). Certainly, different effects to cognition have been observed from different durations of physical activity, and literature reviews and meta-analyses in the area suggest that physical activity duration moderates the effect of acute physical activity on cognition in young people (e.g., Janssen et al., 2014b; Williams et al., 2019). However, the conclusions of these reviews and meta-analyses regarding the minimum and optimum duration of physical activity required for enhancements to cognition are heterogenous.

For example, in their systematic review in young people aged 4–18 years, Janssen et al. (2014b) reported that short physical activity bouts lasting < 20 min are favourable, as they result in the most consistent positive effects to attention. In contrast, Chang et al. (2012) suggested that physical activity of short durations ≤ 10 min have a negligible effect on the cognitive performance of youth and adults, but that physical activity lasting > 10 min has positive effects, with the largest benefits from physical activity ≥ 20 min in duration. Different still, a recent review of the child and adolescent literature concluded that physical activity of ~ 30 min duration enhances cognition across domains in children, while physical activity of 10–30 min duration is most beneficial for adolescents (Williams et al., 2019). The contrast in these conclusions reflect the contrast in the findings of the studies which have utilised the same durations of physical activity. For example, while some studies report beneficial effects to cognition following shorter durations (< 15 min) of physical activity, such as on attention (Budde et al., 2008), working memory (Cooper et al., 2012) and inhibitory control (Cooper et al., 2016), others report no effects on cognitive flexibility (Kubesh et al., 2009b), working memory (Stroth et al., 2009) or inhibitory control (Kubesh et al., 2009b) from short durations. Similarly, while some studies report 20 min of physical activity to improve attention (Altenburg et al., 2016; Park & Etneir, 2019) and inhibitory control (Browne et al., 2016; Drollette et al., 2012), other studies observed no effects to cognitive flexibility (Jäger et al., 2014;

Tomporowski et al., 2008) or visuo-spatial working memory (Drollette et al., 2012) from 20 min of physical activity.

Moreover, previous studies which have explored the effect of acute physical activity bouts with a duration of > 30 min on cognition are also inconclusive, with some evidence suggesting improvements to attention (Schmidt et al., 2015), inhibitory control (Chen et al., 2014a; Cooper et al., 2018; Kubesh et al., 2009a), visual working memory (Chen et al., 2014a; Cooper et al., 2018) and cognitive flexibility (Chen et al., 2014a), and others reporting no effects to attention (Cooper et al., 2018), cognitive flexibility (Kubesh et al., 2009a), inhibitory control (Pirrie & Lodewyk, 2012; Williams et al., 2020), or visual working memory (Williams et al., 2020). The problem is that these studies utilised different modalities and intensities of physical activity, and different cognitive outcome measures, all of which can impact the acute physical activity-cognition relationship in young people.

Reliable conclusions can only be made from studies which have explored the effects of multiple durations of physical activity within the same study, while holding other variables (e.g., modality and intensity) constant. However, there is a paucity of research within the literature which has done this (Table 2.5). Howie et al. (2015) examined the effect of 5-, 10- and 20-min of physical activity and found evidence of improved Math fluency following 10- and 20-min of physical activity, compared to rest. No difference in Math Fluency was observed from 5-min of physical activity, compared to rest. Moreover, compared to rest there was no difference in executive function or working memory performance from any duration of physical activity, suggesting that longer durations > 20 min may be necessary to elicit effects to these cognitive domains. However, Howie et al. (2015) did not directly compare the effects of each duration of physical activity within analysis and each duration was compared to the sedentary control.

To date, there are only two dose-response studies which have directly compared the effects of different physical activity durations on cognition; one in children and one in adolescents. McNaughten and Gabbard (1993) compared the effects of 20-, 30- and 40-min of moderate intensity walking on children's concentration performance. The authors observed improved concentration following 30- and 40-min of walking, compared to 20-min, with similar performance following 30- and 40-min. Van den Berg et al. (2018) compared the effects of 10-, 20- and 30- min of moderate intensity cycling on aspects of attention (e.g., alerting, orienting) and visual working memory in adolescents. No difference between any physical activity duration and rest, or between the physical activity durations, was observed; indicating that longer durations > 30 min may be required to affect these cognitive domains. The findings of these studies suggest that longer durations > 30 min of physical activity may be more favourable for enhancing cognition in young people. This is in line with research reporting that brain-derived neutrophic factor (BDNF), which is considered a potential mechanism responsible for physical activity-induced enhancements in cognition (Huang & Reichardt, 2001; Piepmeier & Etnier, 2015), was significantly increased after physical activity lasting > 30 min, compared to ≤ 30 min (Dinoff et al., 2017).

Furthermore, McNaughen and Gabbard (1993) and van den Berg and colleagues (2018) both compared the effects of physical activity duration using a between-subjects design, meaning individual differences among the participants in each group, such as in baseline cognitive ability, may have influenced the results. There is thus a substantial gap in the literature for dose-response, controlled studies, which directly compare the effects of multiple durations of physical activity on cognition utilising a within-subjects design. Future work on physical activity duration should also consider utilising a modality and intensity of physical activity that is more ecologically valid than that used in previous studies (e.g., high intensity intermittent physical activity) and should consider how physical activity duration may influence the time course of cognitive effects, as this is unknown.

The findings of these studies would be particularly valuable to school staff and policymakers, who are keen to support young people's engagement in physical activity in school, but cite time constraints as a major barrier to implementation (Cox et al., 2011; Howie et al., 2015; Naylor et al., 2015; McMullen et al., 2014; van den Berg et al., 2017). Therefore, information on the minimum and optimum duration of physical activity required for cognitive enhancements, and of the time course of these cognitive enhancements, will help to form evidence-based recommendations for school-based physical activity that put minimal pressure on staff and time, whilst promoting learning and academic performance throughout the school day.

Table 2.5. An overview of the studies comparing the influence of physical activity duration on the acute physical activity-cognitive function relationship in young people.

Study	Sample Details	Experimental Design	Physical activity Details	Cognitive Tests & Related Outcomes	Cognitive Domain	Cognitive Variable	Timing of Tests	Main Findings
Howie et al. (2015)	n = 96 (34 boys, 62 girls) 10.7 ± 0.6 y	Within-subjects, randomised, control	Physical activity: Stationary marching, jumping, running MVPA 5 vs. 10 vs. 20 min Control: Lesson on physical activity science 10 min	Trial Making Test	Executive Function	RT	Pre- & post-condition	No difference between conditions on TMT or DR
				Digit Recall	Auditory working memory	Accuracy		
				Timed Math Test	Math fluency	n of correct answers in 1 min		Higher post 10- & 20- min physical activity vs. rest
McNaughten & Gabbard (1993)	n = 120 (60 boys, 60 girls) 11-12 y	Between-subjects, control	Physical activity: Walking Moderate intensity (120-145 beats·min^{-1}) 20 vs. 30 vs. 40 min Control: Not specified	Mathematical computation test	Concentration	Not specified	Pre- & post-condition	Higher post 30 & 40 min vs. 20 min No difference between 30 & 40 min
Van den Berg et al. (2018)	n = 99 (47 boys, 52 girls) 12.3 ± 0.6 y	Within- & between-subjects, randomised, control	Physical activity: Cycling 40-60% HRR 10 vs. 20 vs. 30 min Control: Educational activities 10, 20, 30 min	Attention Network Test	Alerting	RT Accuracy	Pre- & post-condition	No difference between physical activity & control, or between physical activity durations on any test
					Orienting	RT Accuracy		
					Executive control	RT Accuracy		
				n-Back Task	Visual working memory	RT Accuracy		

Abbreviations [Listed Alphabetically]: DR: digit recall. HRR: heart rate reserve. MVPA: moderate-to-vigorous physical activity. n: number. RT: response time. TMT: trial making test.

2.4.3.2. Timing of Cognitive Testing

Meta-analyses and reviews within the physical activity-cognition literature suggest that the effects of physical activity on cognition are time sensitive and thus may differ depending on the time that cognitive function is measured following the cessation of physical activity (e.g., Chang et al., 2012; Hillman et al., 2019; Williams et al., 2019). Chang et al. (2012), for example, reported that positive effects to cognition were observed when cognition was measured between 11-20 min or > 20 min following the cessation of physical activity, but not when measured ≤ 10 min following physical activity. Moreover, the authors highlighted that a greater enhancement to cognition occurs between 11–20 min (effect size d = 0.26), compared to > 20 min (d = 0.17), following physical activity. It's important to note, however, that some of the studies included within the meta-analytic review were conducted on adults and thus the findings of those studies may not be transferable to young people.

Nevertheless, despite suggestions within the literature that the timing of cognitive testing moderates the physical activity-cognition relationship, very few studies in young people have systematically investigated how cognitive performance changes over time following the cessation of physical activity. Thus, the conclusions of reviews and meta-analyses have been formulated by comparing between research studies which have utilised different modalities, intensities and durations of physical activity, along with different cognitive tests and in different participants, all of which may influence the time course of effects following physical activity.

Furthermore, most studies in young people (21 of 31 studies, 68%) have measured cognition at only one time point following physical activity (Table 2.1 & Table 2.2). Fewer studies have measured cognition at two (9 of 31 studies, 29%) or three (1 of 31 studies, 1%) time points following physical activity (Table 2.1 & Table 2.2). Moreover, 26% of studies (8 of 31) in young people have failed to report the exact time that cognitive function was assessed following physical activity (Berse et al., 2015; Budde et al., 2008; Chen et al., 2016; Kubesh et al., 2009a; Kubesh et al., 2009b; Raviv & Low, 1990; Stroth et al., 2009; Tomporowski et al., 2008; Table 2.1 & Table 2.2), making it difficult establish the nature to which timing of cognitive testing moderates the effect of physical activity on cognition.

Of the 27 studies which did report the time of cognitive testing, cognitive function was measured immediately following the cessation of physical activity in seven studies (26%), between 1-10 min following the cessation of physical activity in eight studies (30%) and > 20 min following the cessation of physical activity in 12 studies (44%) (Table 2.1 & Table 2.2). No studies measured cognition between 11–20 min following the cessation of physical activity. Therefore, while Chang et al. (2012) highlighted in their meta-analysis that the greatest enhancement to cognition occurs between 11–20 min in adults, compared to ≤ 10 min and >20 min, no research has examined the post-physical activity effects to cognition during this time frame in young people. The conclusions from the meta-analysis by Chang et al. (2012) regarding the influence of cognitive test timing on the acute physical activity-cognition relationship were thus based off the results of adult studies, highlighting an important area for future research in young people.

Of the seven studies which assessed cognitive function immediately following physical activity, enhancements to cognition were observed in six (86%) studies (Caterino & Polak, 1999; Cooper et al., 2016, 2018; Ellemberg & St.-Louis-Deschênes, 2010; Etnier et al., 2014; Tine & Butler, 2012), while no effect to cognition was reported in one study (Samuel et al., 2017). However, Samuel et al. (2017) did not include a control trial and instead compared participants' cognition pre-physical activity to cognition post-physical activity.

Of the eight studies which measured cognition between 1–10 min following the cessation of physical activity, six (75%) found positive effects (Browne et al., 2016; Drollette et al., 2012; Etnier et al., 2014; Ma et al., 2015; Niemann et al., 2013; Park & Etnier, 2019), while two (25%) found no effects (Soga et al., 2015a, 2015b). It is important to note, however, that the physical activity and control condition within the studies by Soga and colleagues (2015a, 2015b) were conducted at different times of day. Time of day is suggested to influence both baseline (i.e., normal) cognitive performance (Drollette et al., 2012; van der Heijden et al., 2010), and the acute effect of physical activity on cognitive performance (Chang et al., 2012; Travlos, 2010), due to the underlying impact of circadian rhythms on cognition (Manly et al., 2002; Wright et al., 2002). For example, in their meta-analytic review on adults and young people, Chang et al. (2012) concluded that post-physical activity enhancements to cognition are only evident when the physical activity is performed during the morning, and that no effects to cognition are observed when physical activity is performed in the afternoon or evening. Similarly, Travlos (2010) found that mathematical computation performance was enhanced following an intense PE class (40 min interval running eliciting a heart rate of ~175 beats·min^{-1}) when performed after the first, third and fifth school periods, but not after the sixth period (i.e., at the end of the school day). The inconsistency between the time of the physical activity and control trials within the studies by Soga and colleagues (2015a, 2015b) is thus a major limitation and may, at least partly, explain the discrepancies in the conclusions of the wider literature.

With regard to the 12 studies that measured cognition > 20 min following the cessation of physical activity, three studies assessed cognition between 20–25 min following physical activity; these studies monitored participants' heart rate and measured cognition once heart rate returned to within 10% of its pre-activity (resting) value, as this is when the general arousal effects of physical activity participation are considered to have ceased (Chen et al., 2014a; Drollette et al., 2014; Hillman et al., 2009). All three of these studies (100%) found positive effects to cognition following physical activity. Moreover, four of the 12 studies assessed cognition between 45-50 min following physical activity; three of these (75%) reported enhancements to at least one cognitive domain (Cooper et al., 2012; 2016, 2018), while one (25%) study reported no effects (Williams et al., 2020). Three studies measured cognition 60 min following the cessation of physical activity; one of these studies (33%) reported improved cognition at this time (Samuel et al., 2017), while two (67%) reported no effects to cognition (Kubesh et al., 2009a, 2009b). Furthermore, three studies assessed cognition 90 min following physical activity; two of these studies (67%) reported enhanced cognition (Altenburg et al., 2016; Schmidt et al., 2015), while one study (33%) reported no effects to cognition (Williams et al., 2020).

Overall, the evidence suggests that positive effects to cognitive function are observed when cognition is measured immediately, and up to ~ 50 min, following physical activity. The evidence regarding the acute effects of physical activity on cognitive function measured > 50 min following physical activity is less consistent, however this may in part be because fewer studies have assessed cognition past this time. While measuring cognitive function at multiple (e.g., > 3) time points following the cessation of physical activity would be optimal for gaining a detailed picture of the time course of cognitive effects, this is not always feasible in field-based research. Assessing cognition at two or three time points following the cessation of physical activity is more achievable, yet only 30% of studies have done this (Table 2.1 & Table 2.2). Therefore, future research should aim to administer cognitive tests both immediately and after a delay following the cessation of physical activity. The cognitive tests utilised should measure various cognitive domains; this will enable a more comprehensive understanding of the time course and nature (e.g., stable, oscillatory) of effects to each cognitive domain following physical activity. Moreover, future research should be accurate and transparent in reporting the exact time that cognitive tests are administered following physical activity, and all participants should be completing cognitive testing at the same time. Future research should also report what participants do between the cessation of the physical activity and the onset of cognitive assessments, as the nature of any activity (e.g., physical or cognitive) during this time may influence the impact of the physical activity on cognitive function.

2.4.3.3. Participant Characteristics

Preliminary evidence suggests the characteristics of a participant, such as sex and cardiorespiratory fitness, may also moderate the acute effects of physical activity on cognitive function in young people (Chang et al., 2012; Pontifex et al., 2019; Williams et al., 2019).

2.4.3.3.1. Sex

Sex refers to the '*biological characteristics that define humans as female or male*' (World Health Organization, 2021). Over the past two decades, there has been an emergence of evidence demonstrating an association between sex and cognitive function (e.g., Lock & Berger, 1990; Schweinsburg et al., 2005; Ma et al., 2014). Literature in young people (4–12 y) suggests that boys, compared to girls, are faster on simple reaction time tasks (Dykiert et al., 2012; Ghisletta et al., 2018; Lock & Berger, 1990). Additionally, adolescent boys compared to girls (12–17 y) exhibited faster response times on a spatial working memory task (Schweinsburg et al., 2005). Interestingly, however, girls (9–11 y) are reported to present higher accuracy compared to boys on tests of both concentration (Caterino & Polak, 1994) and sustained attention (Ma et al., 2014).

One hypothesis is that sex differences in response times and accuracy on cognitive tests may be attributable to the effects of sex hormones within the brain (Deary & Der, 2005; Der & Deary, 2006). Estrogen, which is known to affect the brain of each sex differently, has receptors in several brain regions involved in information processing, motor performance and attention processing (Hampson, 1990; Hausmann et al., 2000). However, according to this theory, sex differences in reaction time should be present only after puberty, when estrogen production increases in girls (Alonso et al., 2002). However, sex differences in cognition are observed in children from four years old (Dykier et al., 2012), suggesting that other factors must also influence the sex differences in cognition.

In their cross-sectional study, Lynn and Ja-Song (1993) explored response time as a combination of two separate constructs, processing time and movement time. The results of the study revealed that boys presented faster movement time compared to girls, but that there was no difference in processing time between the sexes. Consequently, the authors attributed the sex difference in response times to differences in neurophysiological processes and muscle differences.

While additional research is needed to better understand the mechanism(s) responsible for the differences in cognition between the sexes, the findings in this area regarding the differences between boys and girls in cognitive functioning highlights the necessity to consider participant sex as an important variable when conducting research on physical activity and cognition. Future studies should ensure that the number of participants of each sex is reported, should adopt a within-subjects design and ideally, should control for this variable within the analysis.

Furthermore, only three studies to date have explored the moderating role of participant sex on the acute physical activity-cognition relationship in young people (Booth et al., 2020; Ma et al., 2014; Soga et al., 2015). While these studies found that sex did not moderate the acute effect of physical activity on cognitive function, additional research is necessary in order to draw reliable conclusions in this area.

2.4.3.3.2. Cardiorespiratory Fitness

Cardiorespiratory fitness is positively associated with habitual physical activity (Kristensen et al., 2010) and can be enhanced from participation in physical activity interventions (Sun et al., 2013). Moreover, several reviews contend that cardiorespiratory fitness is positively associated with cognitive function (Chaddock et al., 2011a; Hillman et al., 2011; Khan & Hillman, 2014; Van Waelvelde et al., 2019). The conclusions of these reviews are based off the findings of primary research in this area which is extensive and reports that higher cardiorespiratory fitness is associated with better cognition in young people (e.g., Kao et al., 2017; Hillman et al., 2005; van der Niet et al., 2014; Wu & Hillman, 2013; Westfall et al., 2018; Wu et al., 2011).

Chaddock et al. (2010), for example, employed magnetic resonance imaging and a relational memory task to examine whether cardiorespiratory fitness (measured via a maximum oxygen uptake [$\dot{V}O_{2max}$] test) was related to hippocampal volume and relational memory performance, respectively. Relational memory is critical for forming connections between pieces of information and flexible expression of information (Eichenbaum & Cohen, 2001); it is thus integral to support learning in school and everyday life. In line with their hypotheses, Chaddock et al. (2010) found that higher fit ($\dot{V}O_{2max}$: 51.5 ± 4.3 ml.kg.min$^{-1;}$ ≥ 70th percentile), compared to lower-fit ($\dot{V}O_{2max}$: 36.4 ± 4.0 ml.kg.min^{-1}: ≤ 30th percentile) children (9–10 y) exhibited greater bilateral hippocampal volumes and performed with higher accuracy on the relational memory task; the findings thus represented a clear association between cardiorespiratory fitness and both cognitive structure and function in young people.

Moreover, Pontifex et al. (2011) found that children (9–10 y) with higher cardiorespiratory fitness ($\dot{V}O_{2max}$: 52.6 ± 4.3 ml.kg.min^{-1}) exhibited higher response accuracy on a modified Flanker task relative to those with lower cardiorespiratory fitness ($\dot{V}O_{2max}$: 35.7 ± 5.3 ml.kg.min^{-1}), thus demonstrating enhanced inhibitory control and cognitive flexibility in higher-fit children. Moreover, higher-fit participants also exhibited increased P3 amplitude and shorter latency relative to lower-fit participants, demonstrating a greater allocation of attentional resources and information processing speed, respectively. Furthermore, Williams et al. (2020) reported that adolescents (12.6 ± 0.5 y) with higher cardiorespiratory fitness (determined by performance [distance covered] in the MSFT) had overall quicker response times across all levels of a Stroop task and the Sternberg paradigm, demonstrating enhanced information processing, inhibitory control and working memory performance.

Similar findings are reported throughout the literature, where cross-sectional studies consistently find that higher cardiorespiratory fitness is associated with enhanced cognitive performance, across cognitive domains, in both children and adolescents (Crova et al., 2014; Huang et al., 2015; Páez-Maldonado et al., 2020; Scudder et al., 2014; Westfall et al., 2018). This association is also presented in longitudinal studies (Chaddock et al., 2012; Niederer et al., 2011). Chaddock et al. (2012), for example, found that children (9–10 y) with high ($\dot{V}O_{2max}$ >70th percentile), compared to low ($\dot{V}O_{2max}$ <30th percentile) cardiorespiratory fitness at baseline exhibited higher accuracy on a Flanker task both at baseline and when measured one year later. Additionally, while low-fit children's reaction time worsened from baseline to follow-up, high-fit children's reaction time improved over this same time period. These findings thus corroborate with the growing evidence that indicates the importance of cardiorespiratory fitness for cognitive function across cognitive domains in young people. Therefore, these findings highlight the necessity for future research to both measure and report participants' cardiorespiratory fitness.

Recent reviews suggest that cardiorespiratory fitness may also moderate the acute physical activity-cognition relationship (Chang et al., 2012; Pontifex et al., 2019). Specifically, there is initial evidence that young people with higher cardiorespiratory fitness may gain greater cognitive benefits from acute physical activity (Cooper et al., 2018; Hogan et al., 2013; 2015; Jäger et al., 2015; Williams et al., 2020). For example, Jäger et al. (2015) reported enhanced working memory performance following physical education (20 min, 70% HR_{max}), compared to rest, but only in children (11.4 ± 0.5 y) with higher cardiorespiratory fitness ($\dot{V}O_{2max}$ 52.4 ± 4.4 units) and not in children with lower cardiorespiratory fitness ($\dot{V}O_{2max}$ 42.9 ± 3.5 units). Similarly, it has been shown that adolescents with a higher level of cardiorespiratory fitness, assessed by a continuous-graded maximal exercise test until exhaustion, demonstrate improved response times on an inhibitory control task immediately after 20 min cycling at 60% HR_{max} (Hogan et al., 2013). Moreover, adolescents with a higher cardiorespiratory fitness, as measured by distance covered on the MSFT, present faster response times on an inhibitory control (Cooper et al., 2018) and a working memory task (Cooper et al., 2018; Williams et al., 2020) 45 min after basketball (Cooper et al., 2018) and football (Williams et al., 2020). In contrast, adolescents with lower cardiorespiratory fitness exhibit higher error rates (Hogan et al., 2013) and slower response times (Cooper et al., 2018; Williams et al., 2020) following physical activity.

In contrast to these findings, however, a meta-analysis concluded that cardiorespiratory fitness does not moderate the acute physical activity response with respect to aerobic physical activity and executive functions (inhibitory control, working memory, cognitive flexibility) (Ludyga et al., 2016). This is echoed by primary research; a six-month longitudinal study in children (9–10 y), for example, reported that the positive effect of physical activity (enhanced physical education programme) on inhibitory control was not moderated by participant cardiorespiratory fitness level (Crova et al., 2014). Interestingly, Booth et al. (2020) examined the potential mediating role of cardiorespiratory fitness on the acute physical activity-cognition relationship and found that, while 15 min of self-paced (walk/run) physical activity enhanced participants' (10.2 ± 0.7 y) post-activity inhibitory control and verbal working memory, this effect was not mediated by the participants' cardiorespiratory fitness level.

It is possible that cardiorespiratory fitness may have a greater or lesser impact on the physical activity-cognition relationship depending on the characteristics of the physical activity. As this type of fitness refers to an individual's tolerance for sustaining physical activities (Caspersen et al., 1985; Ross et al., 2016), it may have less of a moderating influence for shorter duration bouts of activity. However, it may be particularly important for sustaining longer durations of activity, and thus may play a greater moderating role in the after-effects of long-duration physical activity on cognition. The opposing findings in the literature may therefore be due to the different types of physical activity utilised; Booth et al. (2020) reported no moderating role of cardiorespiratory fitness when participants completed 15 min of self-paced (walk/run) activity, whereas Cooper et al. (2018) and Williams et al. (2020) both reported a moderating role of cardiorespiratory fitness on the effects of 60 min of high-intensity intermittent activity.

Furthermore, the timing of the cognitive testing following the cessation of physical activity may also play a role in the extent to which cardiorespiratory fitness moderates the acute physical activity-cognition relationship. In their meta-analytic review, Chang et al. (2012) noted that cardiorespiratory fitness was only a moderating variable when cognitive function was measured immediately following the cessation of a physical activity, and not when measured after a delay; this suggests that the influence of cardiorespiratory fitness on the after-effects of acute physical activity on cognition may be restricted to the recovery period. Most of the studies which contend that cardiorespiratory fitness moderates the effect of physical activity on cognition measured cognition immediately following the physical activity (e.g., Hogan et al., 2013, 2015; Jäger et al., 2015). Additionally, the study by Booth et al. (2020), which did not find a moderating role of cardiorespiratory fitness, measured cognition up to 20 min following the cessation of the physical activity. However, higher cardiorespiratory fitness has been linked to enhanced working memory performance 45 min following physical activity (Cooper et al., 2018; Williams et al., 2020), thus highlighting the complex nature of the relationship.

Overall, the available evidence suggests that higher cardiorespiratory fitness may enhance the post-activity improvements in cognition following certain types of physical activity (e.g., high intensity and/or long duration), and particularly when cognition is assessed immediately following physical activity. However, clearly, more rigorous investigations are necessary to better elucidate the nature of and degree to which cardiorespiratory fitness moderates the acute physical activity-cognition relationship.

2.4.3.4. Summary

As discussed, there are several variables that moderate the acute physical activity-cognition relationship including physical activity characteristics, participant characteristics, and the timing of cognitive testing. Moreover, such moderating variables may interact to influence the relationship. It is important to acknowledge that not all potential moderating variables can be manipulated in all studies. However, future studies should report the key moderating variables as this will enable comparisons between studies and thus support the development of understanding in this area. The physical activity modality and duration should be reported alongside the timing of cognitive testing. Furthermore, participant characteristics, such as sex and cardiorespiratory fitness, should be reported within each study.

2.5. Physical Activity Interventions in Young People

Literature consistently shows that many young people are not meeting the global physical activity guidelines (Aubert et al., 2021; Inchley et al., 2017; Konstabel et al., 2014; Sallis et al., 2016), which recommend an average of 60 min a day of MVPA (Bull et al., 2020). Specifically, Public Health England (2021) recently reported that only 45% of young people are meeting these guidelines, and that there has been a significant decrease in physical activity levels in recent years. Similarly, the Active Healthy Kids Global Alliance, which gathers data regarding the physical activity trends of young people worldwide, reported that in the UK participation in physical activity has decreased and time spent sedentary is continually increasing (Standage et al., 2018). The organisation grades countries based on common indicators of physical activity such as opportunities for school-based physical activity, organised sport and active play; highlighting country-specific priorities for action. One such UK priority identified within the most recent report was the necessity to provide comprehensive, non-traditional school-based physical activity programmes that support young people of all fitness, weight and skill levels (Standage et al., 2018).

School-based physical activity programmes are a pragmatic method of promoting physical activity as virtually all young people attend school and spend a large proportion of their time, over a continuous period, in school (World Health Organization, 2018). Schools thus present an inclusive setting with access to a captive audience, including young people of varying sex, cardiorespiratory fitness level and socioeconomic background (Anderssen, 2013). Currently, there are three types of physical activity programmes that have gained the most traction in schools: classroom movement breaks, active learning, and run-walk (or active mile) initiatives. Run-walk initiatives, such as Marathon Kids, The Golden Mile and The Daily Mile, are particularly popular with schools due to being low cost and easy to implement (Babey et al., 2014), and are advocated by the UK government as part of the School Sport and Physical Activity Action Plan (Department of Health and Social Care, 2019). The effects of classroom movement breaks and active learning programmes on cognitive function and academic performance are well documented (e.g., Daly-Smith et al., 2018; Fedewa et al., 2018; Ma et al., 2015; Watson et al., 2017). A full review of such interventions is beyond the scope of this thesis. However, there has been much less research examining run-walk and active mile programmes. Consequently, the efficacy of these programmes is yet to be confirmed. The next section of this thesis will review the available research on The Daily Mile, the most widely adopted run-walk/active mile programme.

2.5.1. The Daily Mile

The Daily Mile was developed in 2012 by Elaine Wylie, the headteacher of St Ninian's Primary School in Scotland, in response to the lack of physical activity involvement and cardiorespiratory fitness observed in children at the school. The initiative is teacher-led and involves children engaging in approximately one mile (15–20 min) of informal outdoor self-paced (e.g., walk, jog, run, sprint) activity each school day, during curriculum time (The Daily Mile, 2022a).

Since its development, there has been large uptake of The Daily Mile across the UK and worldwide. One in five primary schools in England have registered for The Daily Mile since its development (Venkatraman et al., 2021) and 9,074 schools currently implement the initiative in the UK (The Daily Mile, 2022b). Moreover, over three million young people across 86 countries now participate worldwide (The Daily Mile, 2022b). Uptake in the grass-roots initiative continues to grow, with support and funding from governments and external bodies. In the UK, The Daily Mile initiative is now recommended to all primary schools as part of the government's child obesity strategy (Department of Health and Social Care, 2018) and £1.5 million has been invested in the initiative (Sport England, 2018). Furthermore, the initiative is endorsed by several organisations (e.g., Athletic Ireland), charities (e.g., London Marathon Events), and public figures (e.g., Eliud Kipchoge, Mo Farah).

The Daily Mile has ten core principles or 'steps to success': implementation takes place flexibly during curriculum time, on a set route, outside in most weathers and in normal school clothing; it is inclusive, low risk, quick, simple, self-paced and fun (The Daily Mile, 2022c). The simple, inclusive and fun nature of The Daily Mile, and its cost-effectiveness (Breheny et al., 2020) are factors considered key to its global uptake and may explain why more complex and/or costly school-based interventions have failed (Daly-Smith et al., 2018; Love et al., 2019; Naylor et al., 2015). Only recently, however, has research began to investigate the effects of The Daily Mile on health and cognitive function, meaning this wide-spread initiative is being implemented without an understanding of its short- and long-term impact on young people. While physical activity is generally considered beneficial to health (Miles 2007; Poitras et al., 2016) and cognition (Chang et al., 2012; Pontifex et al, 2019), different modalities (section 2.4.3.1.1), intensities (section 2.4.3.1.2) and durations (section 2.4.3.1.3) of physical activity vary greatly in their acute and chronic effects on young people (Williams et al., 2019; Xue et al., 2018). Therefore, if school staff are willing to dedicate 15 min each day to additional physical activity such as The Daily Mile, it is vital that the type of physical activity adopted is the most beneficial in its effects on young people, as well as being easy to implement.

2.5.1.1. Research on the Effects of The Daily Mile on Young People's Physical Activity, Cardiorespiratory Fitness, Body Composition and Cognitive Function

2.5.1.1.1. Effects of The Daily Mile on Physical Activity

So far, there have been four studies which have examined the effects of participation in The Daily Mile on children's physical activity. Two of these studies assessed the impact on overall physical activity levels (Chesham et al., 2018; Venkatraman et al., 2021) and two investigated physical activity during the active mile initiative (Harris et al., 2019; Morris et al., 2019).

A recent cross-sectional study, which utilised self-reported data from 49,561 children, compared minutes of MVPA inside and outside of school hours between children in schools registered and not registered to participate in The Daily Mile (Venkatraman et al., 2021). Children attending The Daily Mile-registered schools reported an extra 36 min of MVPA per week overall; including 10 additional min of MVPA per week during school hours, and an additional 26 min of MVPA per week outside school hours. Additionally, children in The Daily Mile-registered schools were 6% more likely to meet physical activity guidelines (Venkatraman et al., 2021). Moreover, Chesham et al. (2018) conducted a quasi-experimental repeated measures study, whereby accelerometer-measured average daily MVPA and sedentary behaviour was assessed at baseline and following 28 weeks of participation in The Daily Mile initiative. Children in the intervention group, compared to the control group, reduced their average daily sedentary time by 18 min and increased average daily time in MVPA by nine min. Together the findings of these studies suggest that participation in The Daily Mile has a positive influence on children's overall engagement in physical activity, and thus will help to contribute towards daily physical activity targets.

The two studies to measure physical activity during The Daily Mile both examined time spent engaging in MVPA (Harris et al., 2019; Morris et al., 2019). Harris et al. (2019) utilised the System for Observing Fitness Instruction Time (SOFIT) to measure the percentage of time spent in MVPA during participation in The Daily Mile on week 12 of implementation of the initiative. Harris et al. (2019) reported that, during participation in The Daily Mile, children in key stage 1 (5–7 y) and key stage 2 (8–11 y) spent 100% and 88% of their time during The Daily Mile in MVPA, respectively. While the SOFIT is considered a reliable method for recording physical activity in young people (McKenzie & Smith, 2017), the study by Harris et al. (2019) utilised a single observer rather than the paired (or dual) observation method which is advised, meaning the results may have been prone to bias.

Only one study to date has quantitatively examined physical activity during The Daily Mile. Morris et al. (2019) utilised accelerometers to assess time in MVPA and light physical activity during participation in The Daily Mile. On average, children spent 3.5 ± 2.0 min in light physical activity and 10.7 ± 2.7 min in MVPA, equating to ~23% and ~71% of the 15 min activity, respectively. However, large variability in physical activity between participants, particularly in time spent in MVPA, was observed. While the most active child spent the total 15 min of The Daily Mile (100% of time) engaging in MVPA, the least active child spent only 5 min (33% of time) in MVPA and the remaining time in light physical activity.

The findings of these studies demonstrate that The Daily Mile provides an opportunity for engagement in MVPA, however it raises questions regarding what factors are responsible for the variability in activity observed between individuals. Therefore, future research is needed to examine how factors such as participant sex and cardiorespiratory fitness may influence the physical activity patterns of children during The Daily Mile. Moreover, further research is needed to provide a more comprehensive understanding of the activity patterns of children during The Daily Mile. This includes exploration of time spent in other intensities of physical activity, which should be assessed relative to individual maximal intensity (i.e., HR_{max}), alongside examination of the nature of the activity (e.g., intermittent/continuous) and factors such as speed and distance covered; these measures will provide an indicator of both absolute and relative physical activity dose. Furthermore, it would be beneficial for future research to explore how physical activity patterns may change over time during The Daily Mile. Together, this information will help to establish how The Daily Mile contributes to physical activity targets, will enable comparison of The Daily Mile with other school-based physical activity initiatives, and will help to inform implementation. Quantification of the physical activity undertaken during The Daily Mile will also enable a better understanding of the impact of The Daily Mile on children's health and cognitive function; given that the specific 'dose' of physical activity is key in determining the subsequent effects on health and cognition.

2.5.1.1.2. Effects of The Daily Mile on Cardiorespiratory Fitness

Of the six studies which have quantitatively examined the effect of The Daily Mile on children's cardiorespiratory fitness, five (83%) reported an improvement (Brustio et al., 2019, 2020; Chesham et al., 2018; de Jonge et al., 2019; Marchant et al., 2020). Specifically, Chesham et al. (2018) reported a ~40 m increase in distance covered in the 20-metre multistage fitness test following participation in The Daily Mile for 28 weeks. Moreover, Brustio et al. (2020) reported a 69.6 m increase in distance covered in the six-minute run test following participation in The Daily Mile three days per week for 24 weeks. Interestingly, shorter intervention durations have also been observed to lead to improvements in cardiorespiratory fitness. Participation in The Daily Mile for three days per week for 12 weeks, for example, has been shown to increase the distance covered in the six-minute run test by 25.2 m (Brustio et al., 2019) and level reached in the 18-metre shuttle run test by 1.1 levels (de Jonge et al., 2020).

In contrast to the findings of these studies, a recent randomised controlled trial showed no effect of The Daily Mile on cardiorespiratory fitness following four or 12 months of participation

(Breheny et al., 2020). However, as highlighted by the authors of the study, the fitness assessment (British athletics linear track test) was administered by school staff with minimal training in procedures, and there was a large amount of missing data; these factors may have thus impacted the reliability of the results.

Overall, the evidence suggests that chronic participation in The Daily Mile can have a positive effect on children's cardiorespiratory fitness. It would be valuable, however, for future research to explore when improvements in cardiorespiratory fitness occur from participation in The Daily Mile and whether they can be achieved from shorter durations of intervention (e.g., < 12 weeks), as this is currently unknown. Considering improvements have been observed from participation three days per week for 12 weeks (Brustio et al., 2019; Jonge et al., 2020), it's possible that improvements may occur from shorter durations if The Daily Mile is implemented daily, as recommended (The Daily Mile, 2022c).

2.5.1.1.3. Effects of The Daily Mile on Body Composition

So far, four studies have examined the effect of The Daily Mile on body composition, with mixed findings (Breheny et al., 2020; Brustio et al., 2019, 2020; Chesham et al., 2018). Breheny et al. (2020) compared change in BMI z-scores between an intervention and control group following four and 12 months of participation in The Daily Mile. An increase in BMI z-scores from baseline to follow up at four and 12 months was observed in both groups. However, the increase in BMI z-scores from baseline to follow up was lower in the intervention group compared to the control group, demonstrating a small but non-significant positive effect on weight status from participation in The Daily Mile. Furthermore, in their quasi-experimental pilot study Chesham et al. (2018) reported a 1.4 mm reduction in sum of four skinfolds (triceps, biceps, iliac crest and subscapular) from participation in The Daily Mile for 28 weeks. In contrast to these findings, Brustio and colleagues reported no change in children's body mass index (BMI) from 12 weeks (Brustio et al., 2019, 2020) or 24 weeks (Brustio et al., 2020) of participation in The Daily Mile. It's important to note, however, that The Daily Mile was implemented 2–3 days per week in these studies.

The heterogenous findings from limited research in this area make it difficult to draw conclusions regarding the effect of The Daily Mile on body composition in children. Future research is thus vital. Improvements in BMI and other body composition outcomes may occur from shorter durations (e.g., ≤ 12 weeks) of The Daily Mile, if the initiative is implemented daily, as intended (The Daily Mile, 2022c). However, no research to date has examined the effect of daily participation in The Daily Mile for less than 12 weeks on body composition.

2.5.1.1.4. Effects of The Daily Mile on Cognitive Function

Only two studies have examined the effects of participating in The Daily Mile on cognitive function, both of which focused on the acute effects (Booth et al., 2020; Morris et al., 2019). Specifically, in a citizen science study on 5,463 children from 332 schools, Booth et al. (2020) examined the acute effect of The Daily Mile on inhibitory control, verbal and visuospatial working memory. Compared to near exhaustive exercise (20 m bleep test) and seated rest, participation in The Daily Mile resulted in greater improvements in inhibitory control and verbal working memory. The Daily Mile also led to greater improvements in visuospatial memory compared to near exhaustive exercise. As highlighted by the authors, however, the study involved remote data collection whereby schoolteachers administered the project; this may have impacted the fidelity of, and adherence to, the tasks, as well as the order in which the physical activity and resting tasks were completed (Booth et al., 2020). Moreover, it is possible that the cognitive tests were administered at different time points following each activity, as teachers were instructed only to conduct the tests within 20 min following an activity. As discussed previously, the acute physical activity-induced effects to cognitive function are time sensitive, with improvements to some domains presenting immediately and others after a delay (Chang et al., 2012; Hillman et al., 2019; Williams et al., 2019). Therefore, a lack of control over experimental procedures may have impacted the results of this study. Nonetheless, the study of Booth et al. (2020) does provide evidence that children's cognitive function is enhanced following participation in The Daily Mile.

In contrast to the findings of the study by Booth et al. (2020), Morris et al.'s (2019) randomised controlled trial found no effect of participation in The Daily Mile on executive functions such as inhibitory control, working memory and cognitive flexibility, compared to continued classroom activity. However, this study utilised a between-subjects design. Moreover, while participant age, body composition and cardiorespiratory fitness were compared between the groups at baseline, cognitive function was not. There is some evidence which suggests that baseline cognition may influence the effect of acute physical activity on cognition (Williams et al., 2019). Therefore, the results of the study may have been confounded by inter-individual variability. Additionally, more demanding cognitive tasks are thought to be more sensitive to the beneficial effect of physical activity (Pontifex et al., 2019) and several studies have reported that the acute effects of physical activity were greater on tasks that required higher cognitive demands (Browne et al., 2016; Cooper et al., 2018; Hillman et al., 2009; Kubesh et al., 2019a). However, in the study by Morris et al. (2019), a relatively brief and simple version of the Stroop test was used; the test may have thus lacked sufficient cognitive demand to illuminate any enhancements to executive function that may have resulted from participation in The Daily Mile.

Overall, these two studies varied greatly in their study design, protocols and cognitive measures, as well as in their findings. Therefore, it is not yet possible to infer the acute effect of The Daily Mile on cognitive function and more research is needed. Future research should utilise a within-subjects design, adopt a high level of control over procedures and potential moderating variables (ensuring the aforementioned moderating variables in the physical activity-cognition relationship are held constant and/or reported, as appropriate), and should utilise cognitive tests which are sufficiently demanding for the participant sample. It would also be valuable for future research to examine whether participant characteristics, such as sex and cardiorespiratory fitness, moderate the acute effects of The Daily Mile on cognitive function in children. Furthermore, the chronic effect of The Daily Mile on cognitive function has not yet been explored. The long-term impact of participation in the initiative on children's cognition, learning and academic performance is thus currently unknown.

2.5.1.1.5. Summary

While the evidence base on The Daily Mile is evolving, it is still within its infancy and there is a lack of consistent evidence from high quality studies of the effects on children's physical activity, body composition, cardiorespiratory fitness and cognitive function. This has been echoed in a recent briefing published by Public Health England on the evidence and policy of active mile initiatives (Public Health England, 2020b). Additional research is required to draw firm conclusions and to validate many of the claims being made about The Daily Mile, which are not yet substantiated by research. In particular, future research should aim to quantify the type of physical activity engaged in during The Daily Mile, establish the effect of acute and chronic participation on cognitive function, and clarify the long-term effects of participation on cardiorespiratory fitness and body composition.

2.5.2. Enjoyment of Physical Activity Interventions

When considering the effectiveness of physical activity interventions, it is important that research also considers the social and psychological outcomes of participation, as well as looking at the more traditional physiological and cognitive outcomes. This will provide a more holistic understanding of the efficacy of the intervention, including the likelihood of its successful implementation and long-term adherence in schools (Daly-Smith et al., 2020).

A particularly important consideration is participant enjoyment of the physical activity. Literature consistently demonstrates a positive association between physical activity enjoyment and physical activity levels in young people across age groups (9–16 y) and sexes (Bai et al., 2018; Garcia et al., 2016; Wing et al., 2016). Furthermore, enjoyment of physical activity has been reported as a significant mediating variable in large intervention trials aimed at increasing physical activity in young people (Dishman et al., 2005, Prochaska et al., 2003).

The level of enjoyment in a physical activity also influences the level of effort invested in the activity (Diamond, 2012; McCullogh et al., 2019). This was reported in a qualitative study which involved focus groups and semi-structured interviews with primary school children to explore their views on school-based physical activity interventions; a key finding was that the enjoyment of a physical activity was central to a child's active engagement in the activity (McCullogh et al., 2019). Moreover, enjoyment plays a vital role in determining adherence to physical activity. For example, a qualitative study by Jago et al. (2009) found that enjoyment was the most important factor in maintaining activity participation in primary school children. Similarly, Jakauc et al. (2015) found that enjoyment during a physical activity intervention mediated the effects of the intervention on adherence, with increases in enjoyment linked to greater adherence. Young people's enjoyment of a physical activity intervention has also been shown to influence teachers' perceptions of the intervention, with high levels of enjoyment leading teachers to evaluate the intervention as worthwhile and promote its school-level adherence (McMullen et al., 2014). Staff buy-in to school-based physical activity interventions is reported to be one of the most important determinants of successful and continued implementation (Chalkley et al., 2018, 2020a); which is unsurprising given that it is school staff who drive the participation of young people in school-based physical activity interventions.

Therefore, it is vital that physical activity interventions are enjoyable to young people, as this will promote participation, effortful engagement and adherence, which in turn will support long-term benefits to physical, psychological and social health, as well as cognitive function (Doré et al., 2019; Miles, 2007; Poitras et al., 2016).

Despite the aforementioned evidence, there is a paucity of research which has examined young people's enjoyment of physical activity interventions. Moreover, the majority of studies which have measured enjoyment have focused on lunchtime activity (Hyndman et al., 2014) and active learning (Vazou & Smiley-Owen, 2014), and have utilised a questionnaire (physical activity children's enjoyment scale, PACES; Hyndman et al., 2014; Vazou & Smiley-Owen, 2014). However, semi-structured interviews and focus groups would provide a more comprehensive understanding, including on both the level of enjoyment in the physical activity and factors affecting enjoyment. Furthermore, while The Daily Mile is the most widely implemented and substantially funded school-based physical activity intervention in the UK, no research to date has examined whether young people enjoy participating in The Daily Mile or the factors affecting their enjoyment. While one study examined children's experiences of a running-based intervention (Marathon Kids) and suggested that the intervention was enjoyed by participants, this intervention varies greatly from The Daily Mile in its core principles (e.g., Marathon Kids is delivered during lunchtime and is underpinned by goal setting and rewards; Chalkley et al., 2020a). Moreover, data was collected retrospectively and in some cases four years later. By this time children's perspective on the intervention may have changed. Future research is thus needed to examine young people's enjoyment of The Daily Mile. These findings will help to determine the overall effectiveness and long-term viability of the intervention.

2.6. Summary of the Literature Review

This literature review has outlined the current evidence base examining the relationship between physical activity and cognitive function in young people, including the factors which may influence this relationship. Moreover, this review has highlighted the importance of school-based physical activity interventions and the necessity for research on their physical, cognitive and psychological effects on young people.

Overall, the available evidence suggests that participation in an acute bout of physical activity can enhance post-activity cognitive function in young people. However, there are several variables which can moderate the effect of physical activity on cognitive function, such as activity modality, intensity and duration, as well as timing of cognitive testing, participant sex and participant cardiorespiratory fitness. Therefore, additional research which examines the impact of these moderating variables is required to better understand the nature of the complex physical activity-cognition relationship. In particular, research which compares the effects of different durations of physical activity on cognition would be valuable as there is a paucity of research in this area and yet the findings of this research would have important implications for implementation of physical activity interventions in school, where time constraints are a frequently reported barrier to physical activity.

Furthermore, future research is needed to explore the effects of school-based physical activity interventions on young people's physical activity, health, cognitive function, and enjoyment. In particular, research on the acute and chronic effects of The Daily Mile is vital, as this wide-spread school-based intervention is currently receiving substantial government support and funding despite a lack of evidence of its efficacy. Therefore, the aims of the studies presented within this thesis are:

- To compare the acute effects of differing durations of physical activity on young people's cognitive function (Chapter IV).
- To examine the activity patterns of young people during participation in The Daily Mile (Chapter V).
- To investigate the acute effects of participation in The Daily Mile on young people's cognitive function, and factors affecting their enjoyment of the initiative (Chapter VI).
- To examine the chronic effects of participation in The Daily Mile on young people's cognitive function, body composition and cardiorespiratory fitness (Chapter VII).

Chapter III

General Methods

3.1 Introduction

This chapter summarises the general methodological procedures utilised within the studies presented in this thesis (Chapter IV–VII) and is separated into nine sections. The first section (section 3.2) describes the procedures for participant recruitment and gaining informed consent. The second section (section 3.3) explains the purpose and protocol of the familiarisation session within each study. The third section (section 3.4) outlines the pre-trial requirements that participants followed in advance of the experimental trials within each of the studies. Section 3.5 then provides a description of the standardised breakfast consumed by participants on the day of each experimental trial within each study. The following four sections (section 3.6–3.9) explain the procedures that were conducted during the main experimental trials, namely the physical activity performance (3.6), body composition (3.7) and cardiorespiratory fitness (3.8) measurements, as well as the cognitive function tests (3.9). The final section (section 3.10) outlines the statistical analyses that were conducted on the data collected.

3.2 Participant recruitment

The studies presented within this thesis (chapters IV–VII) were conducted in primary and secondary schools in the East Midlands, UK. Prior to participant recruitment for each study, approval was gained from Nottingham Trent University Ethical Advisory Committee. Moreover, all researchers who were involved in data collection underwent full Disclosure Barring System checks. Recruitment commenced with the head teacher at the schools being contacted. The head teachers were informed of the purpose of the study and what was involved, should they decide to participate. In line with the British Education Research Authority guidelines, once a school had agreed to participate, school level consent was obtained from the head teacher in writing prior to commending each study. An information pack was then taken home by potential participants from the school, to read along with their parent/guardian/caregiver. The pack contained a sheet which provided information about the study aims, requirements and experimental procedures (Appendix A), an informed consent form (Appendix B), an informed assent form (Appendix C) and a health screen questionnaire (Appendix D). The contact details of the researchers were also included in the pack and parents/guardians/caregivers were encouraged to get in contact, should they have any questions about the study. The consent form and health screen were completed by the parent/guardian/caregiver of the interested participant and the assent form was completed by the participant. The forms were checked by the lead investigator to ensure that they had been completed (i.e., signed with contact details) and that there were no health conditions present which could pose risk to the health of the participant, by taking part in the study, or potentially contribute bias to the study results. Furthermore, participants and their parents/guardians/caregivers were informed that they could withdraw from the study at any time without having to provide a reason.

3.3. Familiarisation

For all the studies presented within this thesis (chapters IV–VII), participants attended a familiarisation session, in advance of the main experimental trials. During the familiarisation sessions, the procedures involved in the study were explained to participants. Participants practiced each of the measures, including the cognitive function tests, to minimise any learning effects. The familiarisation sessions also served as an opportunity for participants to ask any questions about the procedures and/or measures, with researchers available to clarify any elements that were unclear.

3.4. Pre-trial requirements

Prior to each experimental trial, participants adhered to a number of pre-trial requirements. Participants were requested to record their dietary intake the evening prior to the first main experimental trial; dietary intake was then replicated prior to the subsequent experimental trial. Participants fasted from 9 pm the evening before each experimental trial until arrival at the school the following morning (12 h overnight fast), at which point they were provided with a standardised breakfast (described in section 3.5) prepared by the researchers. Water was allowed *ad libitum* during this time to maintain euhydration. Participants refrained from vigorous physical activity and the consumption of caffeine for 24 hr prior to each experimental trial. Information regarding these requirements were included within the information pack sent out during the recruitment process and parents/guardians/caregivers were reminded of these requirements via a telephone call or text message two days prior to each experimental trial.

3.5. Standardised Breakfast

For each of the studies presented in this thesis (chapters IV–VII), participants were provided with a standardised breakfast on morning of each experimental trial. The breakfast contained cornflakes with milk and white toast with margarine, and provided 1.5 $g \cdot kg^{-1}$ body mass of carbohydrate, as previously used in this population (Cooper et al., 2012). Breakfast was provided shortly after participants arrived at school; all participants consumed the breakfast at the same time, over a 15 min period. Participants were encouraged to consume all the food they were provided, however if any food remained at the end of the 15 min, the leftovers were weighed. Adjustments were then made for the breakfast on the subsequent trial so that the same quantity of food was consumed prior to each experimental trial. Dietary intake was controlled as both breakfast consumption (Cooper et al., 2011) and composition (Cooper et al., 2012, 2015) can affect cognitive function and the physical activity-cognition relationship. An example breakfast composition for a representative 50 kg participant is presented in Table 3.1.

Table 3.1. An example of the standardised breakfast quantities and carbohydrate provision based on a hypothetical 50 kg participant

Food Item	Mass (g)	Carbohydrate (g)
Cornflakes [a]	55	46.3
White bread [b]	42	18.8
1% fat milk [c]	216	9.9
Margarine [d]	6	0
Total quantity	319	75

[a] Cornflakes (Kelloggs Ltd., UK)
[b] Lightly toasted white bread (Kingsmill soft white thick slice, UK)
[c] 1% fat milk (Sainsbury's Ltd., UK)
[d] Margarine (Flora Original, UK)

3.6. Measurement of Heart Rate and Physical Activity Performance

3.6.1. Heart Rate

Participants' heart rate during participation in physical activity was measured in chapters V and VII of this thesis. Heart rate was measured continuously via chest-worn monitors (Firstbeat Team Sport System, Technologies Ltd, Finland). Specifically, average and peak heart rate were calculated. Subsequently, the average and peak relative intensity of the activity (%HR_{max}) was calculated. In chapter V, maximal heart rate was predicted using methods previously described (Tanaka et al., 2001) and validated in children (Mahon et al., 2010). In chapter VII, maximal heart rate was classified as the maximum heart rate (HR_{max}) achieved during the MSFT. Classification of the physical activity intensity was then performed using ACSM guidelines (ACSM, 2018; Table 3.2).

Table 3.2. ACSM guidelines for estimation of physical activity intensity using maximum heart rate (HR_{max}) (ACSM, 2018).

Heart rate as a % of HR_{max}	Physical activity intensity
< 57	Very light
57 - 63	Light
64 - 76	Moderate
77 - 95	Vigorous
≥ 96	Near maximal to maximal

3.6.2. Physical Activity Performance

In chapter V and VII of this thesis, participants' physical activity performance was measured using 15 Hz global positioning systems (GPS) (SPI HPU, GPSports, Canberra, Australia). GPS are a valid and reliable tool for providing movement pattern data and this commercially available software has been used successfully in numerous studies on physical activity patterns and performance in youth (MacLeod et al., 2009; Saward et al., 2016; Waldron et al., 2011). The GPS units were worn by each participant in a harness, which held the GPS unit in position between the shoulder blades. The outcome variables of interest were total distance covered, distance covered within age-specific speed zones and number of speed zone entries. These were calculated over the whole physical activity and within each 5 min split of the activity (e.g., 0-5 min, 5-10 min etc.), to examine whether activity patterns changed across the duration of the activity. Age group-specific speed zones were adapted from those published on youth soccer players (Saward et al., 2016) and are presented in Table 3.3. The number of speed zone entries was also used as a measure of the 'nature' of movement (i.e., continuous vs. intermittent). All GPS data were analysed using Teams AMS Software Version 1.2 (GPSports, Canberra, Australia).

Table 3.3. Age-group specific speed zones, adapted from Saward et al. (2019).

Speed ($m \cdot s^{-1}$)	Zone
≤ 0.1	Standing
0.1 - 0.83	Walking
0.84 - 2.84	Low speed running
2.85 - 3.79	Moderate speed running
3.80 - 4.73	High speed running
> 4.73	Sprinting

N.B. For the distance covered in each speed zone, standing and walking zones were combined.

3.7. Measurement of Maturity Offset and Body Composition

Throughout the studies in this thesis, the characteristics of the participants, such as age (y) and maturity offset (y) are reported. Moreover, body composition of participants is reported as a descriptive and/or outcome measure. Body composition measurements included BMI (through the measurement of height and body mass), BMI z-score, waist circumference, and skinfolds.

3.7.1. Height and Body Mass

Height was measured using a stadiometer (Leicester Height Measure, Seca, Hamburg, Germany), which was accurate to 0.1cm. Participants removed footwear and stood with their back to the stadiometer. The participants' head was placed by a researcher in the Frankfort plane and gentle upwards pressure was applied, with hands positioned on each side of the face and fingers on the mastoid process, to help lift their head; this enables the measurement of true height, also known as stretched height.

Body mass was measured using a Seca 770 digital scale (Seca, Hamburg, Germany), accurate to 0.1kg. Participants removed footwear, emptied their pockets and removed any heavy clothing (e.g., thick jumpers). This facilitated the most accurate, non-intrusive measurement of body mass.

3.7.2. Maturity Offset

Alongside stretched standing height, stretched sitting height was recorded and subsequently leg length was calculated (stretched standing height – stretched sitting height) to allow the estimation of maturity, using the redeveloped sex-specific regression equations by Moore et al. (2015) (Eq. 1a & 1b). Specifically, the method of Moore et al. (2015) calculates age (y) from peak height velocity (APHV), as an estimate for maturity offset (MO; y, pre- or post-APHV) in young people. The non-invasive method and re-developed equations accurately predict

90% of MO cases within ± 1 y in external samples, which is an improvement on the original equation by Mirwald et al., (2002) which achieved 80%.

To obtain stretched sitting height, participants sat on an anthropometric box which was positioned against a flat wall. A one-meter ruler was aligned vertically with a spirit level and secured to the flat wall behind the box with electrical tape. The same stretched technique described previously was utilised to gain an accurate measure of sitting height. This technique was conducted only by researchers with certified training in the assessment of anthropometric measures (International Society for the Advancement of Kinanthropometry [ISAK]; Esparza-Ros et al., 2019; Norton et al., 2011).

Age from peak height velocity, calculated using the following equations:

Eq. 1a

Boys:

-8.128741 + (0.0070346 x *(age x sitting height))*

Eq. 1b

Girls:

-7.709133 + (0.0042232 x *(age x height))*

N.B. Age = y, height and sitting height = cm.

3.7.3. Body Mass Index and Body Mass Index z-scores

BMI was calculated by dividing body mass (kg) by the square of the stretched standing height (m^2). BMI z-scores were calculated using the LMS Growth Microsoft Excel add-in (Pan & Cole, 2011) and based on age and sex-specific British 1990 growth reference data (Cole et al., 1995). BMI z-score represents the distance an individual's BMI is from the population mean for their sex and age; it is expressed as a multiple of the population standard deviation (SD), meaning the further the individual's BMI is from the population mean for their age and sex, the larger their BMI z-score will be. Positive and negative BMI z-scores represent distance above and below the population mean, respectively.

3.7.4. Waist and Hip Circumference

Waist and hip circumference were measured according to the World Health Organization (WHO, 2008) and ISAK (Esparza-Ros et al., 2019; Norton et al., 2011) guidelines. Specifically, waist circumference was measured using a tape measure at the narrowest point of the torso between the xiphoid process of the sternum and the iliac crest, to the nearest 0.1 cm, and hip circumference was measured using a tape measure at the greatest posterior protuberance, perpendicular to the long axis of the trunk, to the nearest 0.1 cm. Measurements were taken twice for each participant, with the mean of the measurements being used as the criterion value. If there was a difference ≥ 1% between individual measurements, a third measurement was taken and the median was used as criterion value.

Waist circumference was used as a surrogate measure for central adiposity. Reference standards for waist circumference in young people of varying nationalities have been developed (e.g., Fernandez et al., 2004; Fredriks et al., 2005; McCarthy et al., 2001; Moreno et al., 1997) and literature suggests that this measure provides a practical and effective method for measuring body composition in young people (Wells et al., 2002). Moreover, waist circumference in combination with BMI with help to address the major limitations of BMI (i.e., its inability to differentiate between elevated adiposity and elevated lean mass) and enables the identification of those young people whose high BMI has greatest health impact (Must & Anderson, 2006).

3.7.5. Skinfold Thickness

Throughout the studies presented within this thesis (chapters IV–VII), body composition was also assessed through skinfold thickness (mm) using Harpenden Skinfold Callipers (Baty International, UK), accurate to the nearest 0.1 mm. Skinfold measurements were taken from four sites: the tricep, subscapular, supraspinale and front thigh. The triceps skinfold site is the point on the posterior surface of the arm, in the mid-line, at the level of a previously marked midacromiale-radiale. The subscapular skinfold site is located 2 cm along a line running laterally and obliquely downward from the subscapulare landmark (the under most tip of the inferior angle of the scapula) at a 45-degree angle. The supraspinale skinfold site is the point at the intersection of the line from the iliospinale (the point on the under most part of the tip of the anterior superior iliac spine) to the anterior axillary border, and the horizontal line from the iliocristale (the point on the superior aspect of the iliac crest that coincides with the projection of the mid-axillary line). Finally, the front thigh skinfold site is the mid-point of a line between the patellare (the mid-point of the posterior superior border to the patella) and the inguinal point (the point halfway along a line between the anterior superior iliac spine and the top of the pubic symphysis).

Skinfold measurements were completed according to ISAK procedures (Esparza-Ros et al., 2019; Norton et al., 2011), by an anthropometrist, trained and qualified by ISAK. All measurements were taken twice in rotation (i.e., all measures taken once then repeated), and on the right-hand side of body. The mean of the two measurements was used as the criterion value; however, if there was a difference of ≥ 10 % between two individual measurements, a third measurement was taken and the median was used as the criterion value. The sum of the four skinfold thicknesses (mm) was used as proxy for body composition, specifically adiposity, as used previously in similar study populations (e.g., Dring et al., 2019). This was preferred to the estimation of body fat percentage from skinfold measurements, which can lead to large random and systematic errors (Reilly et al., 1995).

3.8. Measurement of Cardiorespiratory Fitness

For each of the studies presented in this thesis (chapters IV–VII), participants completed the MSFT (Ramsbottom et al., 1988). The MSFT is a valid and reliable field measurement of cardiorespiratory fitness, which accounts for individual training effects (Ramsbottom et al., 1988, Ruiz et al., 2011; Tomkinson et al., 2019a) and mimics the typical activity patterns of children and adolescents (Tomkinson et al., 2019b). It has been used extensively in similar field-based studies in young people (e.g., Cooper et al., 2018; Soga et al., 2015; Williams et al., 2020).

The MSFT is an incremental running test that involves participants running between two cones placed 20 m apart until volitional exhaustion, or until they are unable to keep time with the audio signal which dictates the required running speed. The running speed commences at 8.0 $km \cdot h^{-1}$ (stage 1) and increases to 9.0 $km \cdot h^{-1}$ after one min (stage 2) for the next stage. Following the second stage, the pace increases by 0.5 $km \cdot h^{-1}$ for each subsequent stage completed (Ramsbottom et al., 1988). Participants completed the MSFT outside, on tarmac, in groups of no more than 15. Prior to commencing the test, participants were briefed on the protocol and informed that the aim of the test was to complete as many shuttles as possible. During the test, participants were 'paced' by a member of the research team to ensure they were able to stick to the designated speed. The remaining researchers provided verbal encouragement to the participants throughout, in order to encourage maximal effort from participants. Moreover, participant's heart rate was recorded via a chest-worn heart rate monitor (Firstbeat Team Sport System, Technologies Ltd, Finland) and monitored by a researcher throughout the test. When a participant was unable to reach the 20 m line prior to the audio signal twice in a row, or at the point of volitional exhaustion, they stopped running and their level and shuttle score was recorded. The final shuttle achieved was recorded and then converted into distance run (m). The total distance covered (m) during the MSFT was used as the criterion value for cardiorespiratory fitness in chapters V–VII of this thesis.

3.9. Measurement of Cognitive Function

With the exception of chapter V, where cognitive function was not measured, all studies within this thesis (chapter IV, VI & VII) measured participant's cognitive function using the Stroop test, Sternberg paradigm and Flanker task. These cognitive tests were utilised as they measure higher-order, self-regulatory executive functions including inhibitory control (Stroop test and

Flanker task), working memory (Sternberg paradigm) and cognitive flexibility (Flanker task). These cognitions are thus related to goal-directed behaviours, planning and learning. Moreover, they influence behaviour in the classroom and academic achievement.

The tests were administered via a laptop computer (Lenovo ThinkPad T450; Lenovo, Hong Kong) using a customer build software called the Hogervorst-Bandelow Cognitive Test Battery. The test battery lasted approximately 15 min. For each test, instructions were presented on screen and were repeated verbally by an investigator prior to the completion of the test. Questions were encouraged and then confirmation of understanding was sought from participants before proceeding. Each test (and test level) was preceded by 3–6 practice stimuli and participants received feedback regarding whether their responses were correct or not. The practice stimuli re-familiarised participants with the test and acted to negate any potential learning effects. Once the tests started, no feedback was provided.

Participants completed the tests in a classroom and were seated separately to ensure no interaction during the tests occurred. Sound cancelling headphones were worn and the lights were dimmed to minimise external disturbances and enhance screen visibility. Participants were instructed to respond to each test as quickly and as accurately as possible. For each task, including the Stroop task, stimulus response was recorded via a button press rather than a verbal response, as used in some studies (Harveson et al., 2016; Ishihara et al., 2017; Park & Etnier, 2019). This may have influenced response times due to the addition of motor response (i.e., movement time) to processing time (Lynn & Ja-Song, 1993). However, button press Stroop tasks are used widely within research in this area, which allows comparison of the results between studies (e.g., Browne et al., 2016; Cooper et al., 2018; Martins et al., 2021; Williams et al., 2020).

The cognitive tests used within this thesis are reported to be reliable for use in the young adolescent population (12.8 ± 0.5 y; Cooper et al., 2015). Moreover, a pilot study was conducted to establish, prior to use, the appropriateness and reliability of these cognitive tests with children aged 8-11 y. Furthermore, the cognitive tests and testing protocol have been used extensively in physical activity-cognition research in young people (e.g., Buck et al., 2008; Chen et al., 2014a; Ishihara et al., 2017; Morris et al., 2019; Williams et al., 2020). For all tests, the criterion variables of interest were the response times of correct responses (ms) and the percentage (%) of correct responses made.

3.9.1. Stroop test

The Stroop test consists of two levels, simple and complex, which measure attention and inhibitory control, respectively (Stroop, 1935; Miyake et al., 2000). During both levels, a test word which is always a colour (e.g., red, blue) appears in the centre of the screen. A target word and a distractor word are randomly placed to the right and left of the test word; the target word position is counterbalanced between the left and right side within each test level. On the simple level, all words are presented in white ink and the participant must select the (target) word which matches the centre (test) word, using the right or left arrow key on the keyboard; this level consisted of 20 stimuli. On the complex level, the words are presented in coloured ink and participants must select the (target) word which matches the colour that the central (test) word is displayed in, rather than the word itself. For example, if the test word was 'green' displayed in blue ink, the correct response would be the word blue. The complex level consisted of 40 stimuli. During both levels, the choices remained on screen until the participant responded, with an inter-stimulus interval of 1 s.

3.9.2. Sternberg paradigm

The Sternberg paradigm consists of three levels of ascending difficulty (one-item, three-item and five-item) and measures visual working memory (Sternberg, 1969). At the beginning of each level participants are assigned a target number or letters which they must remember. On the one-item level, which contained 16 stimuli, the target was always the number '3'. On the three- and five-item levels, which each contained 32 stimuli, the target was three and five randomly generated letters, respectively. During the test, the number ‘3’ (one-item level) and letters (all levels) appeared consecutively in the centre of the screen. Participants were instructed to press the right arrow key on the keyboard if it matched their assigned target number/letters and the left arrow key if it was a distractor number/letter (which did not match their assigned target number/letters). During all levels, the items remained on screen until the participant responded, with an inter-stimulus interval of 1 s. The correct response was counterbalanced between the left and right arrow key for each level.

3.9.3. Flanker task

The Flanker task consists of two types of stimuli, congruent and incongruent; measuring attention (congruent stimuli) and inhibitory control and cognitive flexibility (incongruent stimuli) (Eriksen & Eriksen, 1974). During the test, five arrows appear on the centre of the screen. Participants were instructed to press the arrow key on the keyboard (left or right) which corresponded to the direction of the middle (target) arrow. Congruent stimuli involved arrows which all point in the same direction (e.g., <<<<< or >>>>>). For incongruent stimuli, the target arrow and the flanking arrows point in opposite directions (e.g., <<><< or >><>>). The Flanker task consisted of 60 stimuli, with an equal number of congruent and incongruent stimuli presented in a randomised order. The items remained on screen until the participant has responded, with a varied inter-stimulus interval of 400–4000 ms. While a three-stage Flanker, which incorporates an additional ‘rule’, is sometimes used to measure cognitive flexibility (or ‘shifting’) (Egger et al., 2018; Jäger et al., 2015), this thesis used a one-stage Flanker which measured cognitive flexibility through requiring participants to switch their response between congruent and incongruent stimuli, which were incorporated into one stage.

3.10 Statistical Analysis

A variety of statistical procedures were used to analyse the data presented in chapters IV–VII; thus a detailed account of these procedures is provided within each experimental chapter. However, some information regarding the methods of analysing the cognitive function data that were consistent within the studies (chapters IV, VI & VII) presented in this thesis are provided below.

Data from the cognitive function tests in chapters IV, VI and VII were first attended to in the open-source software R (www.r-project.org, version 2.9.1). Minimum (< 100 ms) and maximum (1000–4000 ms, depending on task complexity) response time cut-offs were applied to eliminate any unreasonably fast (anticipatory) or slow (distracted) responses; and response time data were log transformed to correct for the right-hand skew of typical human response times. This method is widely used in similar studies (Cooper, et al., 2016, 2018; Williams et al., 2020, Draheim et al., 2016). Cognitive function data were then analysed using methods which are distinct to each chapter, due to the nature and design of each study. The statistical assumptions for the statistical tests used to analyse cognitive data were assessed prior to use and were conducted in SPSS. This included checking whether the data was normally distributed via the Shaprio-Wilk Test, using Levene's test for homogeneity of variances (for one-way ANOVA) and Mauchly's sphericity test (for one-way and two-way repeated measures ANOVA). Other assumptions for the parametric tests used included a continuous dependent variable, and no significant outliers. When any of these assumptions were not met, a non-parametric alternative test was used. Further specific details of these statistical procedures are provided within each experimental chapter.

Throughout the thesis, statistical significance was accepted as $p < 0.05$. Furthermore, Cohen's d change over time effect size calculation was utilised when appropriate (Chapters IV, VI & VII), in line with recommendations for quantifying the effectiveness of a pre-test post-test intervention (Dezron et al., 2005). Cohen's d effect sizes were calculated using the following equation: exercise group (EG), control group (CG), pre-test (t1), post-test (t2), sample (N), standard deviation (SD):

$$\text{ES}= \frac{(M_{EG,t2} - M_{EG,t1}) - (M_{CG,t2} - M_{CG,t1})}{SD_{pooled}}$$

$$\text{SD}_{\text{pooled}} = \sqrt{\frac{(N_{EG}-1)SD_{EG}^{2} + (N_{CG}-1)SD_{CG}^{2}}{N_{EG}+N_{CG}-2}}$$

Cohen’s d effect sizes were interpreted as per convention: negligible effect (≥−0.15 and <.15), small effect (≥.15 and <.40), medium effect (≥.40 and <.75), large effect (≥.75 and <1.10), very large effect (≥1.10 and <1.45), and huge effect (>1.45; Dezron et al., 2005).

Chapter IV

Effect of Differing Durations of High-Intensity Intermittent Activity on Cognitive Function in Adolescents

4.1. Introduction

The existing evidence suggests that an acute bout of physical activity can improve subsequent cognitive function across a range of domains in young people, including attentional capacity (Budde et al., 2008), executive function (Audiffren et al., 2009), and working memory (Chen et al., 2014a). These cognitive processes are responsible for self-regulation and goal-orientated behaviours (Banich, 2009) and are fundamental to learning (Diamond, 2013). Therefore, participation in physical activity has the potential to improve cognitive performance and academic achievement in young people (McPherson et al., 2018). Moreover, current literature highlights several factors which may mediate the physical activity-cognition relationship, including an increase in cerebral blood flow (Ogoh & Ainslie, 2009), neurogenesis (Moon et al., 2016), and activation of brain regions involved in cognitive processes (e.g., cerebellum, prefrontal cortex) (Budde et al., 2008; Sathe, 2021; Serrien et al., 2007).

The majority of the literature on the acute effects of physical activity on cognition in adolescents has employed running and cycling modalities which were continuous in nature (for review see Pontifex et al., 2019). Research demonstrates, however, that young people's activity patterns are typically intermittent in nature, involving short bursts of high-intensity activity interspersed with rest (Bailey et al., 1995; Howe et al., 2010) and rarely consist of sustained moderate or vigorous activity (Armstrong & Welsman, 2006). Additionally, high-intensity intermittent activity is enjoyable to youth (Malik et al., 2017), which is a particularly important consideration when looking to develop ecologically valid forms of physical activity with the aim of achieving long-term, sustained, behaviour change (Howe et al., 2010). One of the few physical activity-cognition studies to utilise high-intensity intermittent physical activity in adolescents found that both working memory and executive function were improved following 60 min of games-based basketball activity, compared to rest, and that enhancements to executive function lasted 45 min following the activity (Cooper et al., 2018). Additionally, high-intensity intermittent sprinting (10 x 10 s running sprints) has been shown to enhance adolescent's inhibitory control and information processing (Cooper et al., 2016). High-intensity intermittent running may thus provide an ecologically valid, efficacious type of physical activity for enhancing cognition in youth.

The physical activity-cognition relationship is however a complicated one, and several review papers and meta-analyses highlight that the characteristics of physical activity, such as the modality, intensity and duration, have a moderating effect on the subsequent effects on cognition (Chang et al., 2012; Donnelly et al., 2016; Janssen et al., 2014b; Li et al., 2017; Williams et al., 2019). Moreover, the characteristics of a physical activity are inherently linked, meaning the duration of an exercise will interact with the modality and intensity to determine the overall dose (Williams et al., 2019). Whilst a wide range of exercise modalities, intensities and durations have been used across the literature, very few studies have systematically compared physical activity of different characteristics (e.g., modality, intensity and duration) within the same study. Such studies would provide invaluable insight into how to optimise the cognitive benefits following physical activity in young people.

One such key variable in the physical activity-cognition relationship is activity duration. In particular, establishing the minimum duration of activity required for improvements to cognition may be particularly useful for school staff and policy makers, who are keen to support young people's learning through physical activity, but frequently cite time constraints as a barrier hindering its implementation in schools (McMullen et al., 2014; Naylor et al., 2015; van den Berg et al., 2017). A systematic review on the effects of acute physical activity on attention in youth (4-18 y) noted that short activity bouts (~ 20 min) had a positive effect on attention, while some longer activity bouts (e.g., 45 min) had no effect (Janssen et al., 2014b). A meta-analytic review on adults and youth, however, concluded that activity of short durations (~ 10 min) had a negligible effect on cognitive performance, while activity lasting > 11 min had positive effects (Chang et al., 2012). Moreover, a recent review of the child and adolescent literature concluded that activity ~ 30 min duration has positive effects across cognitive domains in children, and that activity lasting 10–30 min is most beneficial in adolescents (Williams et al., 2019). The heterogeneity in the conclusions of reviews and meta-analyses results from the heterogeneity between the studies which have been used to make these conclusions. The studies adopt different modalities and intensities of physical activity, and different cognitive outcome measures, all of which make it difficult to directly compare the effects of activity bouts of different durations with each other. A more informed understanding of the physical activity duration-cognition relationship can only begin to be established once there is sufficient primary research which directly compares physical activity of differing durations within the same study (whilst holding other key variables, such as intensity and modality, constant).

Of the few studies to utilise multiple durations of physical activity, two were conducted by Howie and colleagues (Howie et al., 2014, 2015). Both studies examined the effect of 5, 10 and 20 min of moderate to vigorous classroom-based activity, compared to 10 min of sedentary activity, on the cognitive performance of children (aged 9-12 y) (Howie et al., 2014, 2015). Children presented higher math fluency scores after 10 and 20 min of physical activity, when compared to 10 min of sedentary activity (Howie et al., 2015). Moreover, on-task behaviour was improved after 10 min of physical activity and there was a trend towards improved on-task behaviour after 20 min of physical activity, again when compared to the sedentary condition (Howie et al., 2014). In contrast, no improvements in executive function or working memory were evident after any of the physical activity bouts (Howie et al., 2015). However, whilst these studies investigated the effect of different physical activity durations, separate analyses were conducted meaning the effects of each duration of physical activity were not compared to one another; thus limiting the conclusions that can be drawn.

To date, only one study has directly compared the effects of physical activity of differing durations on cognitive function in adolescents. The study compared the effects of 10, 20 and 30 min of moderate intensity (40–60% of heart rate reserve) cycling on adolescents' (11–14 y) selective attention and working memory (van den Berg et al., 2018). The authors reported no effect on selective attention or working memory performance following any duration of physical activity, compared to a time-matched resting control. Moreover, no differential effects of the physical activity durations on post-physical activity cognition was observed. However, a between-subjects design was utilised to compare the physical activity durations, with a different group of children performing each duration of physical activity. Individual differences between the groups, such as in baseline cognitive ability and cardiorespiratory fitness, may have thus influenced the results (Williams et al., 2019). Additionally, it is possible that the cycling intensity utilised in the study was not high enough to elicit a cognitive response when completed for ≤ 30 min. This is also in accordance with the wider adolescent literature, where for example no effects to executive function following cycling at a light intensity (60 % heart rate max) for 20 min were observed, but enhancements to executive function following incremental cycling to exhaustion were reported (Berse et al., 2015).

Therefore, the present study aims to examine the effects of 30 min and 60 min of high-intensity intermittent running, compared to rest, on immediate and delayed (45 min post physical activity) cognitive function in adolescents. The study thus builds on previous research by utilising an ecologically valid modality of physical activity and by directly comparing multiple durations of physical activity using a within-subjects, randomised crossover design. Based on the literature to date, the hypothesis of the present study is that high-intensity intermittent running will enhance subsequent cognition, whilst the comparison of 30 and 60 min high-intensity intermittent running is exploratory.

4.2. Methods

4.2.1. Participants

To determine the required sample size for the present study a series of power calculations were estimated based on research into the effects of exercise on cognitive function in young people (Cooper et al., 2015; Cooper et al., 2018). The power calculation was conducted in G-Power software (Faul et al., 2007). Based on the study of Cooper et al. (2018) and an effect size of 0.25, it was estimated that 40 participants were required in the present study. Forty-one participants were recruited to participate in the study. However, based on the exclusion criteria, three participants were removed from the study due to the presence of a congenital heart condition (n = 1), and an inability to complete the 60 min of physical activity (n = 2). Therefore, thirty-eight participants (15 boys, 23 girls) completed the study.

During familiarisation, body mass (Seca 770 digital scale, Hamburg, Germany), stature and sitting stature (Leicester Height Measure, Seca, Hamburg, Germany) were measured (section 3.7.1). These measures were subsequently used to calculate maturity offset (Moore et al., 2015; section 3.7.2), BMI and BMI z-score (section 3.7.3). Moreover, waist circumference was measured and four skinfold measurements (tricep, subscapular, supraspinale and front thigh) were taken, according to International Society for the Advancement of Kinanthropometry procedures (section 3.7.4 & 3.7.5). For descriptive purposes, anthropometric characteristics are displayed in Table 4.1.

Table 4.1. Participant characteristics for the group overall, as well as for boys and girls separately. Data are mean ± SD.

	Overall (*n* = 38)	**Boys (*n* = 15)**	**Girls (*n* = 23)**	***p* value** [a]
Age (yrs)	12.4 ± 0.4	12.3 ± 0.5	12.4 ± 0.4	0.507
Height (cm)	157.7 ± 7.5	155.9 ± 9.1	159.0 ± 6.2	0.227
Body mass (kg)	45.0 ± 7.2	44.2 ± 7.5	45.5 ± 7.1	0.573
BMI ($kg \cdot m^{-2}$)	18.0 ± 1.9	17.9 ± 2.0	18.1 ± 1.7	0.779
BMI z-score	-0.02 ± 0.82	0.19 ± 0.83	-0.16 ± 0.8	0.251
Maturity offset (yrs) [b]	-1.4 ± 0.6	-1.8 ± 0.4	-1.2 ± 0.6	0.236
Waist circumference (cm)	65.0 ± 4.9	64.5 ± 4.2	65.4 ± 5.4	0.580
Sum of skinfolds (mm)	44.5 ± 13.7	39.9 ± 9.4	47.5 ± 15.4	0.097
MSFT distance (m)	1240 ± 320	1380 ± 340	1140 ± 280	0.029

Note. [a] Independent samples t-test for comparison between boys and girls. [b] Calculated using the method of Moore et al. (2015).

4.2.3. Study Design

Following approval from the University ethical advisory committee, participants were recruited from local secondary schools in the East Midlands, UK. Consent from the Headteacher of each school was acquired. Following which, informed assent was gained from participants alongside informed consent and a health screen from parents/guardians (section 3.2).

The study employed a within-subject, randomised, orderbalanced, crossover design which involved children completing a familiarisation session followed by three main trials (30 min high-intensity intermittent running, 60 min high-intensity intermittent running and rest), which were each separated by seven days. The Latin Square Design was used to randomise the order in which participants completed the three main trials.

During familiarisation, the experimental protocols were explained to participants and participants practiced the procedures to be completed during the main trials. This included the battery of cognitive function tests and the high-intensity intermittent physical activity. The physical activity protocol employed for this study was the Loughborough Intermittent Shuttle Test (LIST). This physical activity protocol enables other physical activity characteristics (e.g., intensity) and external factors (e.g., physical environment, cognitive engagement) to be controlled while manipulating the physical activity duration to explore the effects on cognition. This level of control is not possible with other types of intermittent physical activity such as games-based physical activity. Furthermore, during familiarisation participants also completed the MSFT (Ramsbottom et al., 1988).

Prior to the first main trial, participants followed pre-visit requirements regarding dietary intake, physical activity and caffeine consumption (section 3.4). On arrival to school (~8.30 am) on the day of each experimental trial, participants were fitted with a heart rate monitor (Team Sports System, Firstbeat Technologies Ltd., Jyvaskyla, Finland), which was worn throughout the trial. As both breakfast consumption (Cooper et al., 2011) and composition (Cooper et al., 2012) affect young people's subsequent cognitive functioning, participants were provided with a standardised breakfast (section 3.5), as used successfully in studies with adolescents (Cooper et al., 2018; Dring et al., 2020; Williams et al., 2020). Participants had 15 min to consume the standardised breakfast. Figure 4.1. displays a schematic of the experimental protocol.

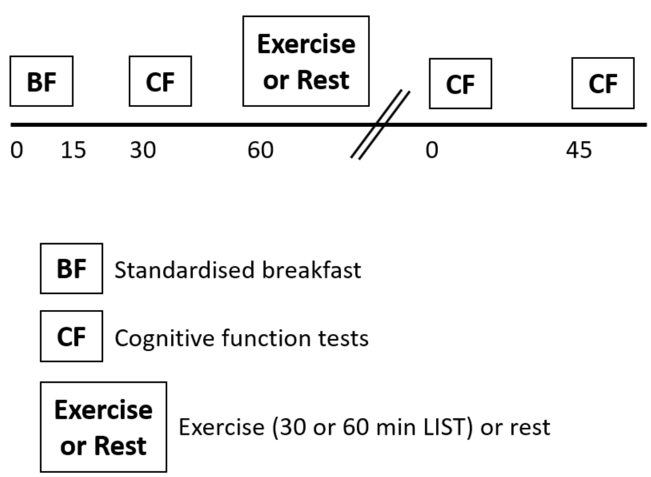

Figure 4.1. Experimental trial protocol

4.2.4. Multi-Stage Fitness Test

During familiarisation, participants completed the MSFT in line with the methods described in section 3.8 of this thesis; the shuttle level attained in the MSFT was used to estimate $\dot{V}O_2$ peak, using an adolescent specific equation (Barnett et al., 1993). This was conducted to determine the running speeds for the LIST physical activity protocol.

4.2.5. Physical Activity and Rest Protocol

During the physical activity trials, participants completed either 30 min or 60 min of high-intensity intermittent running, in an adapted form of the Loughborough Intermittent Shuttle Test (LIST) (Nicholas et al., 2000). The LIST was conducted in each participating school's sports hall and involved participants running between two markers, 20 m apart, to pre-determined speeds dictated by an audio signal. The LIST protocol in the present study consisted of three 20 m shuttles at walking pace, a 15 m sprint followed by rest (8 s total duration), three 20 m shuttles running at 85% $\dot{V}O_2$ peak and three 20 m shuttles running at 55% of $\dot{V}O_2$ peak. This pattern was repeated eight times, lasting ~12 min; this equaled one block (as presented in Figure 4.2). The 30 min trial consisted of 2 of these blocks and the 60 min trial 4 blocks, with a 3 min recovery provided between each block. During the resting trial, and at all times during the physical activity trial with the exception of during the 30- or 60-min LIST, participants were seated at rest and conversed with peers in a calm manner.

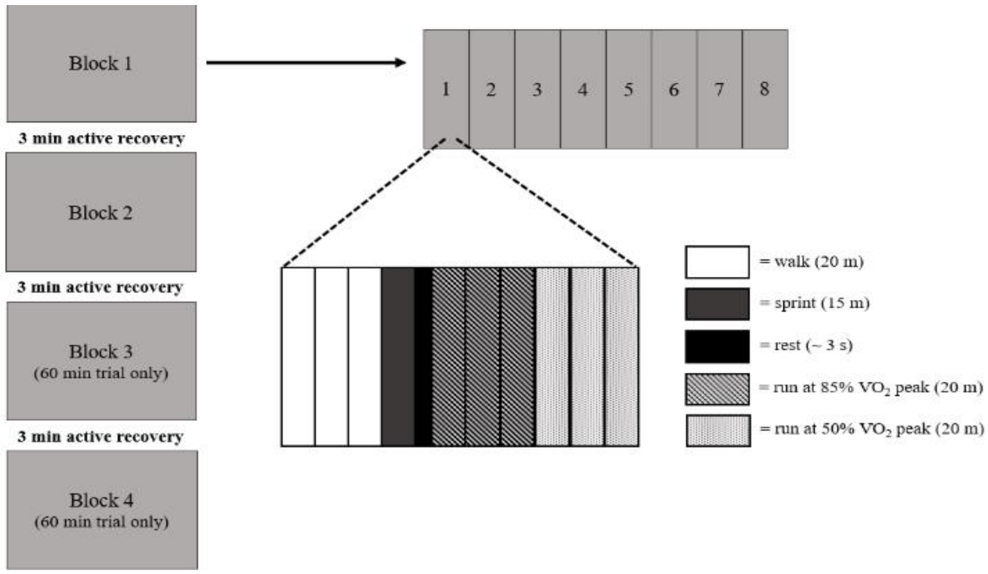

Figure 4.2. LIST protocol (adapted from Nicholas et al., 2000).

4.2.6. Cognitive Function Tests

The battery of cognitive function tests consisted of the Stroop test, Sternberg paradigm and Flanker task (section 3.9). The test battery was completed 30 min pre-, immediately post- and 45 min post-physical activity, and at the corresponding time points on the resting trial. Fifteen laptops were used to enable the participants within each group to complete the tests simultaneously. The outcome variables of interest for all tests were the response time (ms) of correct responses (i.e., reaction time + movement time) and the percentage (%) of correct responses made.

4.2.7. Statistical Analysis

Cognitive function data were analysed using the open-source software, R (www.r-project.org; section 3.10). Data was checked for normal distribution using the Shapiro-Wilk test. Response time analyses were then conducted using mixed-effect models, implemented via the *nlme* package, which yields *t* statistics. Accuracy analyses were also analysed using mixed-effect models but using the lme4 package due to the binomial nature of the accuracy data. This approach yields *z* statistics. All analyses were conducted using a two-way trial by time interaction and effect sizes were calculated (Cohen's d), in line with recommendations for quantifying the effectiveness of a pre-test post-test intervention (Dezron et al., 2005). Cohen's d effect sizes were interpreted as per convention: negligible effect (≥−0.15 and <.15), small effect (≥.15 and <.40), medium effect (≥.40 and <.75), large effect (≥.75 and <1.10), very large effect (≥1.10 and <1.45), and huge effect (>1.45). Data for each level of the cognitive tests were analysed separately, given that the different levels require different cognitive processes. For all analyses, statistical significance was accepted as $p \leq 0.05$. Cognitive data are presented as mean ± standard error of the mean (SEM); all other data are presented as mean ± SD.

4.3. Results

4.3.1. Cognitive Function

The data for each of the cognitive function tests, on each trial and at each time point, can be found in Table 4.2. For clarity and ease of interpretation, cognitive function data in figures are presented as change across the morning.

4.3.1.1. Stroop Test

Response times: On the simple level of the Stroop test, response times improved 45 min post-physical activity on the 30 min LIST trial, compared to both the resting control trial (trial by time interaction, $t_{(6544)} = 2.95$, $p = 0.003$, d = 0.28) and the 60 min LIST trial (trial by time interaction, $t_{(6544)} = 3.49$, $p = 0.001$, d = 0.34; Figure 4.3). There was also a tendency for response times to improve to a greater extent immediately post-physical activity on the 30 min LIST trial, compared to the resting control trial, but this did not reach statistical significance (trial by time interaction, $t_{(6544)} = 1.90$, $p = 0.058$, d = 0.16; Figure 4.3). The pattern of change in response times across the morning on the complex level of the Stroop test was not different between the trials (trial by time interactions, $p = 0.212–0.946$).

Accuracy: Accuracy, on both the simple and complex levels of the Stroop test, was similar across the morning on all trials (trial by time interactions, $p = 0.123–0.969$).

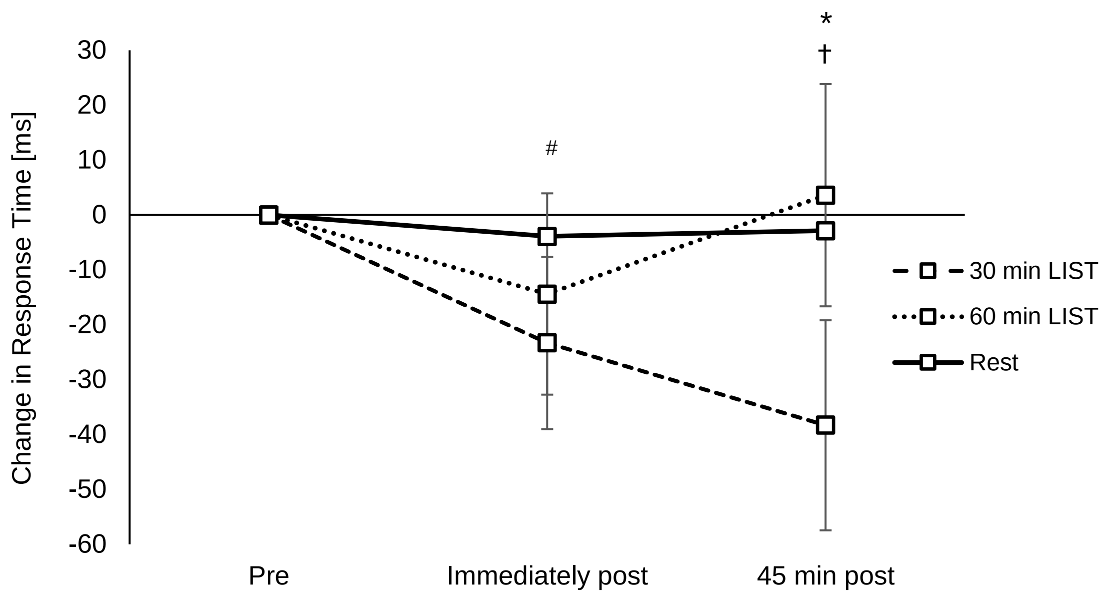

Figure 4.3. Change in response times across the morning on the 30 min LIST, 60 min LIST and resting control trials, on the simple level of the Stroop test. Faster response times following 30 min LIST vs. 60 min LIST * and rest †; both $p < 0.05$. Tendency for faster response times following 30 min LIST vs. rest; $p = 0.058$ #.

Table 4.2. Cognitive function data across the morning on the 30 min physical activity, 60 min physical activity and resting control trials. Data are mean ± SEM.

Test	**Level**	**Variable**	**30 min physical activity trial**			**60 min physical activity trial**			**Resting**		
			Pre	Immediately post	45 min post	Pre	Immediately post	45 min post	Pre	Immediately post	45 min post
Stroop test	Simple	Response time (ms)	741 ± 19	717 ± 24	703 ± 22	732 ± 21	718 ± 26	736 ± 24	727 ± 22	723 ± 24	724 ± 22
		Accuracy (%)	98.4 ± 0.5	96.2 ± 0.8	97.0 ± 0.8	97.6 ± 0.6	96.2 ± 0.8	95.7 ± 0.9	97.3 ± 0.5	96.0 ± 0.7	95.4 ± 1.3
	Complex	Response time (ms)	1009 ± 34	974 ± 37	955 ± 34	1019 ± 36	971 ± 39	972 ± 44	1003 ± 37	952 ± 39	964 ± 39
		Accuracy (%)	95.4 ± 0.6	95.7 ± 0.8	94.5 ± 1.1	95.9 ± 0.5	94.6 ± 0.7	94.4 ± 0.7	95.1 ± 0.6	93.4 ± 1.1	93.7 ± 1.3
Sternberg paradigm	One-item	Response time (ms)	531 ± 19	541 ± 21	468 ± 15	529 ± 19	491 ± 22	499 ± 22	511 ± 17	483 ± 19	489 ± 16
		Accuracy (%)	97.2 ± 1.0	97.0 ± 1.0	94.4 ± 1.0	97.3 ± 1.0	97.0 ± 1.0	96.2 ± 1.0	96.9 ± 1.0	95.6 ± 1.0	95.6 ± 1.0
	Three-item	Response time (ms)	672 ± 17	650 ± 17	621 ± 16	663 ± 20	668 ± 30	660 ± 36	647 ± 20	649 ± 19	629 ± 21
		Accuracy (%)	97.3 ± 0.6	95.0 ± 0.9	93.3 ± 0.7	96.1 ± 0.6	94.8 ± 0.7	95.0 ± 0.7	96.7 ± 0.6	94.7 ± 0.7	94.7 ± 0.9
	Five-item	Response time (ms)	831 ± 25	812 ± 24	789 ± 17	808 ± 28	807 ± 30	801 ± 31	823 ± 23	789 ± 22	757 ± 22
		Accuracy (%)	94.7 ± 0.8	91.6 ± 1.1	91.9 ± 1.0	93.8 ± 0.8	92.1 ± 1.2	92.3 ± 1.1	92.5 ± 1.1	91.5 ± 1.0	89.9 ± 1.8
Flanker task	Congruent	Response time (ms)	559 ± 15	529 ± 14	521 ± 14	567 ± 19	552 ± 21	553 ± 21	548 ± 15	544 ± 18	549 ± 17
		Accuracy (%)	98.9 ± 0.3	98.0 ± 0.5	98.7 ± 0.3	98.7 ± 0.3	98.3 ± 0.5	98.2 ± 0.4	99.2 ± 0.3	98.2 ± 0.8	97.9 ± 0.6
	Incongruent	Response time (ms)	587 ± 13	563 ± 15	556 ± 15	592 ± 20	593 ± 21	586 ± 20	587 ± 16	581 ± 20	582 ± 17
		Accuracy (%)	95.8 ± 0.6	95.4 ± 0.7	94.0 ± 0.9	95.6 ± 0.6	94.5 ± 0.8	95.3 ± 0.7	95.9 ± 0.6	93.9 ± 0.7	94.7 ± 0.9

4.3.1.2. Sternberg Paradigm

Response times: On the one-item level of the Sternberg paradigm, response times slowed immediately following the 30 min LIST compared to both the resting control trial (trial by time interaction, $t_{(5331)} = -3.14$, $p = 0.002$, d = 0.34) and the 60 min LIST trial (trial by time interaction, $t_{(5331)} = -4.36$, $p < 0.001$, d = 0.41; Figure 4.4). However, 45 min post-physical activity, response times were improved following the 30 min LIST compared to the resting control trial (trial by time interaction, $t_{(5331)} = 3.62$, $p < 0.001$, d = 0.37), and tended to be improved to a greater extent following 30 min LIST compared to 60 min LIST (trial by time interaction, $t_{(5331)} = 1.74$, $p = 0.084$, d = 0.28), and following 60 min LIST compared to the resting control trial (trial by time interaction, $t_{(3522)} = 1.82$, $p = 0.069$, d = 0.07; Figure 4.4).

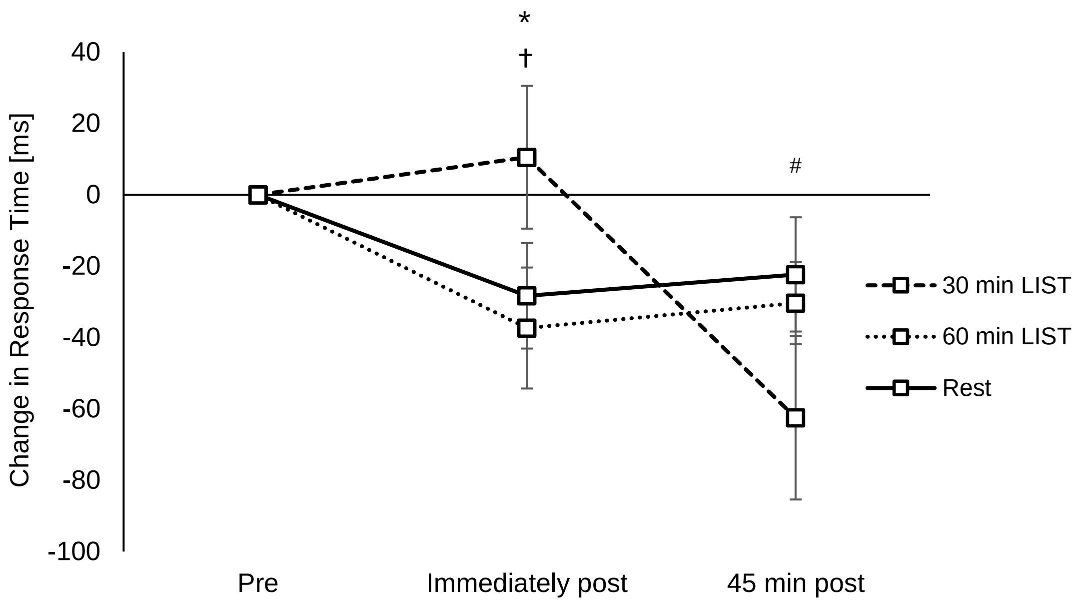

Figure 4.4. Change in response times across the morning on the 30 min LIST, 60 min LIST and resting control trials, on the one-item level of the Sternberg paradigm. Slower response times following 30 min LIST vs. 60 min LIST * and rest †; faster response times following 30 min LIST vs. rest #; all $p < 0.05$.

On the three-item level of the Sternberg paradigm, response times were improved to a greater extent 45 min post-physical activity on the 30 min LIST trial, compared to both the resting control trial (trial by time interaction, $t_{(10670)} = 2.49$, $p = 0.013$, d = 0.29) and the 60 min LIST trial (trial by time interaction, $t_{(10670)} = 30.7$, $p = 0.002$, d = 0.41; Figure 4.5).

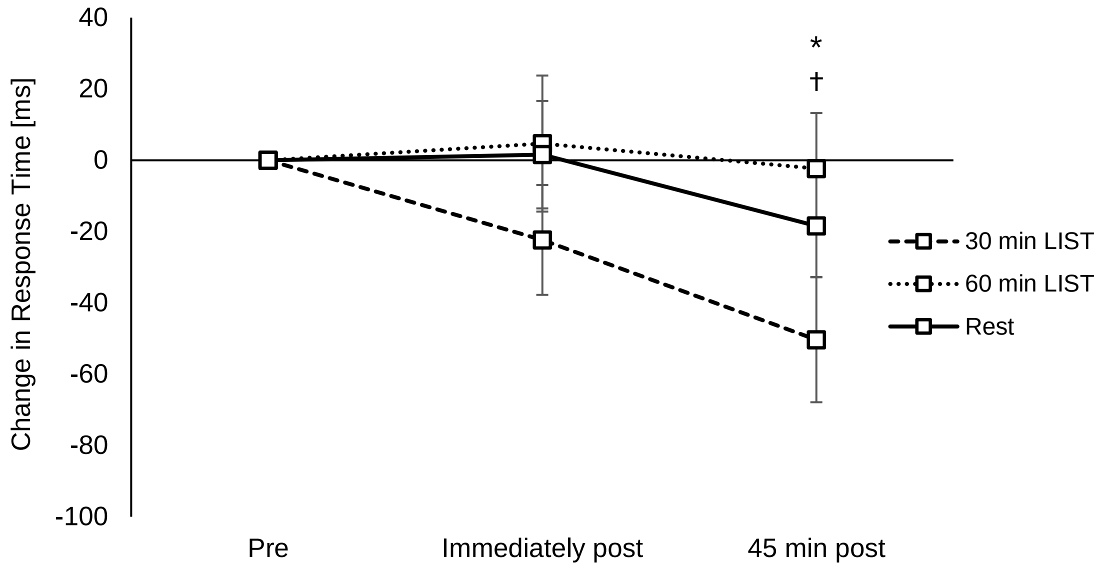

Figure 4.5. Change in response times across the morning on the 30 min LIST, 60 min LIST and resting control trials, on the three-item level of the Sternberg paradigm. Faster response times following 30 min LIST vs. 60 min LIST * and rest †; all $p < 0.05$.

On the five-item level of the Sternberg paradigm, response times improved to a greater extent immediately (trial by time interaction, $t_{(6718)} = -1.96$, $p = 0.050$, d = 0.21) and 45 min (trial by time interaction, $t_{(10670)} = -3.22$, $p = 0.001$, d = 0.37) following resting, compared to the 60 min LIST (Figure 4.6). Response times were also improved to a greater extent 45 min post-physical activity on the 30 min LIST trial, compared to the 60 min LIST trial (trial by time interaction, $t_{(10670)} = -3.07$, $p = 0.002$, d = 0.22; Figure 4.6).

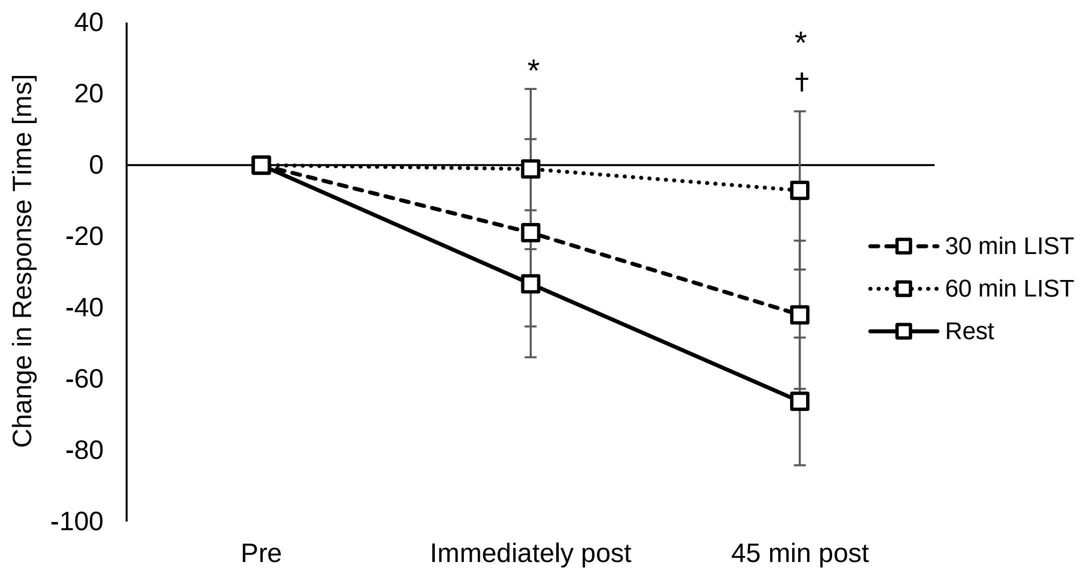

Figure 4.6. Change in response times across the morning on the 30 min LIST, 60 min LIST and resting control trials, on the five-item level of the Sternberg paradigm. Faster response times following rest vs. 60 min LIST *; faster response times following 30 min LIST vs. 60 min LIST †; all $p < 0.05$.

Accuracy: Accuracy, on all three levels of the Sternberg paradigm, was similar across the morning on all trials (trial by time interactions, p = 0.151–0.969), with the exception of the three-item level where accuracy was better maintained 45 min post-physical activity on the 60 min LIST trial compared to the 30 min LIST trial (trial by time interaction, $t_{(11286)}$ = 2.14, p = 0.032, d = 0.75; Figure 4.7).

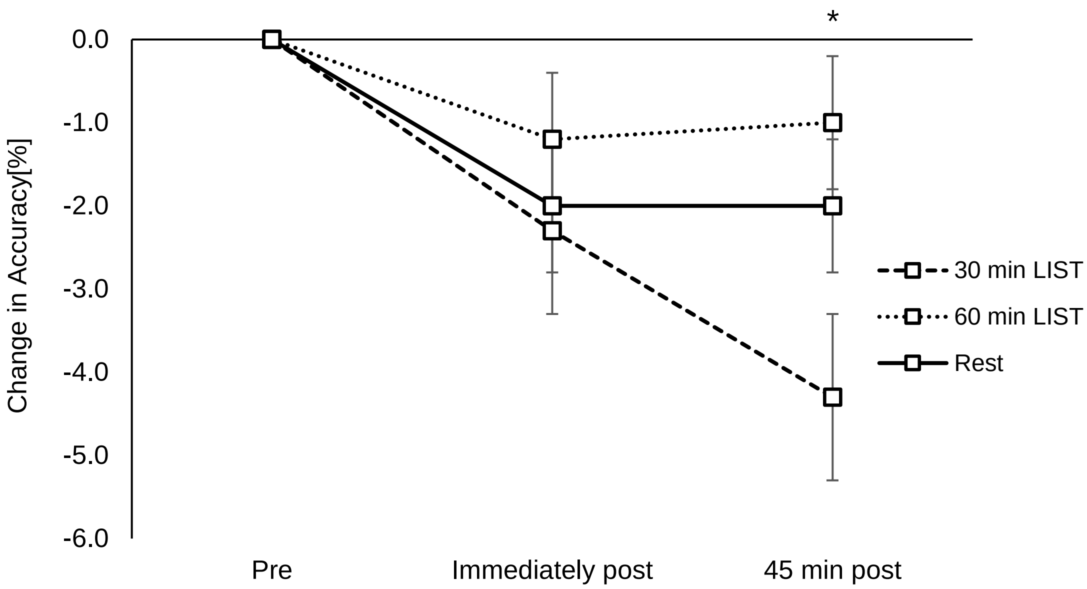

Figure 4.7. Change in accuracy across the morning on the 30 min LIST, 60 min LIST and resting control trials, on the three-item level of the Sternberg paradigm. Greater accuracy following 60 min vs. 30 min LIST *; $p < 0.05$.

4.3.1.3. Flanker Task

Response times: Response times on the congruent level of the Flanker task were improved on the 30 min LIST trial immediately (trial by time interaction, $t_{(10070)}$ = -2.19, p = 0.029, d = 0.29) and 45 min (trial by time interaction, $t_{(10070)}$ = -3.85, p < 0.001, d = 0.43) post-physical activity compared to the resting trial (Figure 4.8). Furthermore, response times were improved to a greater extent 45 min post-physical activity on the 30 min LIST, compared to the 60 min LIST, trial (trial by time interaction, $t_{(10070)}$ = -2.57, p = 0.010, d = 0.23; Figure 4.8).

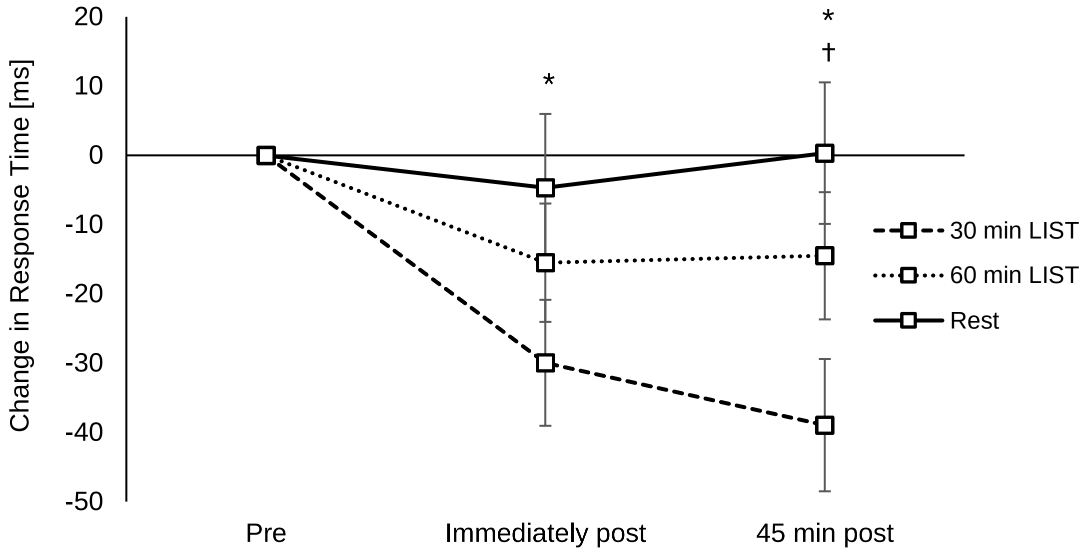

Figure 4.8. Change in response times across the morning on the 30 min LIST, 60 min LIST and resting control trials, on the congruent level of the Flanker task. Faster response times following 30 min LIST vs. rest * and 60 min LIST †; all $p < 0.05$.

Response times on the incongruent level of the Flanker task improved to a greater extent 45 min post-physical activity on the 30 min LIST trial compared to the resting control trial (trial by time interaction, $t_{(9768)} = -2.61$, $p = 0.009$, d = 0.28; Figure 4.9); and there was a tendency for response times to be improved immediately post-physical activity on the 30 min LIST trial, compared to the 60 min LIST trial (trial by time interaction, $t_{(9768)} = -1.79$, $p = 0.073$, d = 0.24; Figure 4.9).

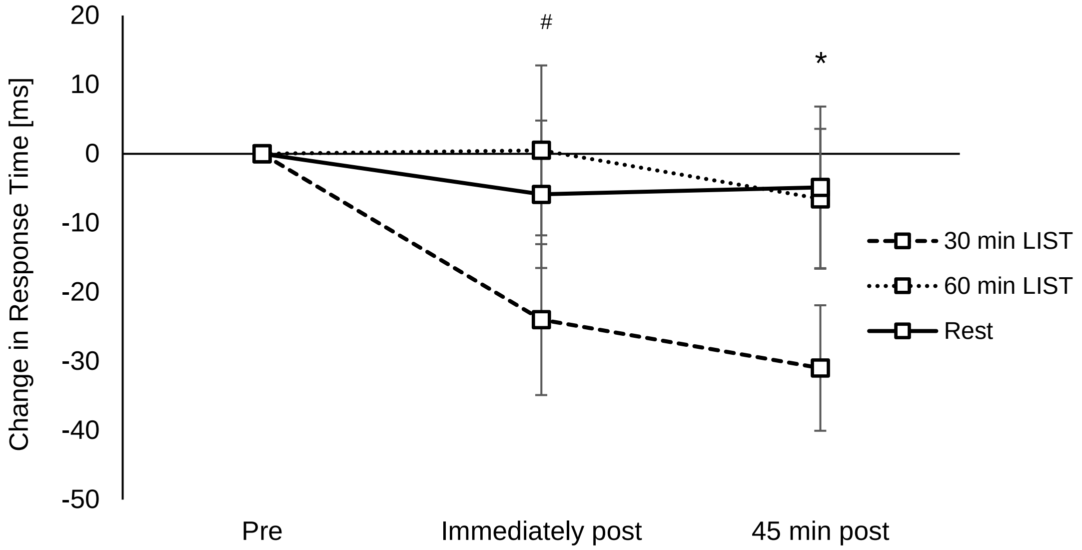

Figure 4.9. Change in response times across the morning on the 30 min LIST, 60 min LIST and resting control trials, on the incongruent level of the Flanker task. Faster response times following 30 min LIST vs rest *; $p < 0.05$. Tendency for faster response times following 30 min vs. 60 min LIST #; $p = 0.073$.

Accuracy: Accuracy, on both levels of the Flanker task, was similar across the morning on all trials (trial by time interactions, p = 0.568 – 0.962), with the exception of the congruent level whereby there was a tendency for accuracy to be improved 45 min post-physical activity on the 30 min LIST trial compared to the resting control trial (trial by time interaction, $z_{(10404)} = 1.67$, $p = 0.095$, d = 0.50; Figure 4.10).

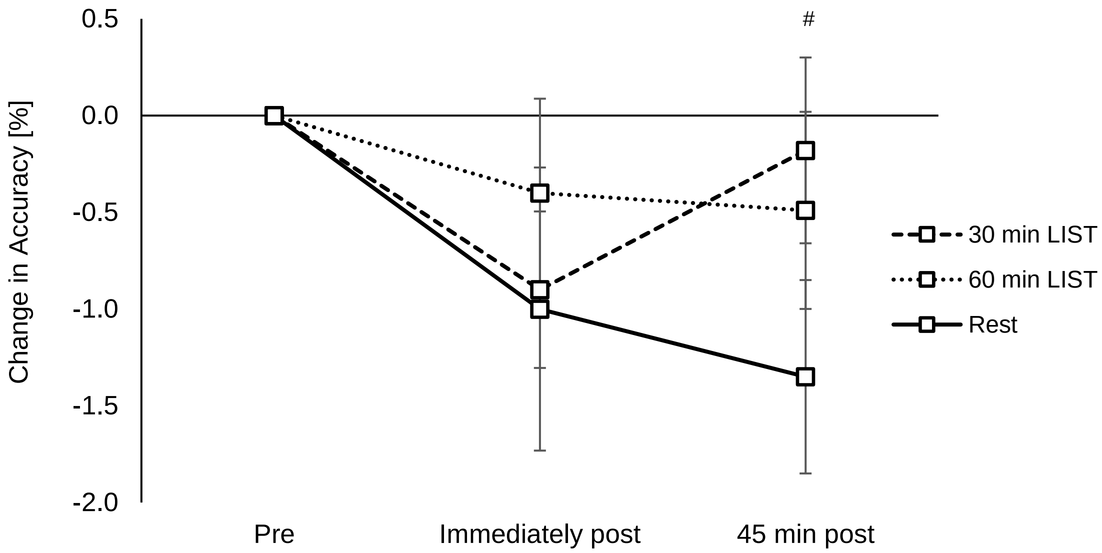

Figure 4.10. Change in accuracy across the morning on the 30 min LIST, 60 min LIST and resting control trials, on the congruent level of the Flanker task. Tendency for greater accuracy following 30 min LIST vs. rest #; $p = 0.095$.

4.4. Discussion

The present study is the first to directly compare, using a within-subject crossover design, the acute effects of different durations of physical activity on cognition in young people. The main finding of the present study was that there were some duration specific effects on the physical activity-cognition relationship, whereby participation in 30 min, compared to 60 min of high-intensity intermittent running was more beneficial to both immediate and delayed (45 min post) cognitive function. This novel finding suggests that high-intensity intermittent running may be an effective type of physical activity for enhancing cognition in adolescents, even at shorter durations of 30 min. Furthermore, the present study found that cognitive function was enhanced following high-intensity intermittent running regardless of duration, when compared to following resting.

Firstly, compared to following resting, working memory performance was enhanced following 60 min of high-intensity intermittent running, with small-to-medium sized effect ($d = 0.07–0.41$); this was evidenced through faster response times immediately post-activity and a tendency for faster response times 45 min post-activity, on the one-item level of Sternberg paradigm. Moreover, attention and information processing improved immediately and 45 min following the 30 min high-intensity intermittent running, compared to rest, as demonstrated by reduced response times on the simple level of the Stroop test and congruent level of the Flanker task, as well as better maintained accuracy on the congruent level of the Flanker task. Furthermore, inhibitory control was also enhanced 45 min following the 30 min high-intensity intermittent running, compared to rest, which was evidenced by reduced response times on the incongruent level of the Flanker task. The results of the present study thus demonstrate that participation in an acute bout of high-intensity intermittent running is beneficial to both immediate and delayed (45 min post) cognition, and is favourable compared to rest regardless of activity duration.

When comparing the effects of 30 min and 60 min of high-intensity intermittent running, differing effects to cognition were observed. Firstly, while accuracy on the three-item level of

Sternberg paradigm decreased following both physical activity and rest, it was better maintained 45 min following 60 min, compared to 30 min of high-intensity intermittent running. However, information processing was improved to a greater extent immediately following 30 min, compared to 60 min of high-intensity intermittent running. This was shown through faster response times on the simple level of the Stroop test. Moreover, inhibitory control tended to be better immediately following the 30 min, compared to 60 min of high-intensity intermittent running, as demonstrated by faster response times on the incongruent level of the Flanker task. With regards to 45 min post physical activity, 30 min compared to 60 min of high-intensity intermittent running led to enhanced information processing, attention and inhibitory control. This was evidenced by faster response times on the simple level of Stroop test, and on the congruent and incongruent level of Flanker task. Furthermore, working memory performance was also improved 45 min following 30 min, compared to 60 min, of high-intensity intermittent running, which was demonstrated through faster response times on all levels of Sternberg paradigm. These findings suggest that 30 min of high-intensity intermittent running may be more effective than 60 min of high-intensity intermittent running, for enhancing acute cognitive performance in young people.

The key finding that 30 min of high-intensity intermittent running was advantageous over 60 min is interesting, given that previous research which compared exercise of multiple durations found no effects to cognition following exercise ~ 30 min (Howie et al., 2014, 2015; van den Berg et al., 2018). One study, for example, reported no effects to adolescent's working memory or selective attention from 10, 20 or 30 min of moderate-to-vigorous intensity cycling, compared to rest (van den Berg et al., 2018). However, as highlighted in a prominent review, the modality and intensity of the physical activity undertaken is also important, as these quantitative characteristics of the physical activity interact with the duration to influence the overall 'dose' of the activity (Pontifex et al., 2019). Therefore, high-intensity intermittent running, such as that employed in the present study, may be a particularly efficacious modality and intensity of physical activity for enhancing cognition, even at shorter durations.

Additionally, the finding that 30 min, compared to 60 min of high-intermittent running was more beneficial to adolescent's cognition, may be due to the longer duration being too demanding for some participants. Specifically, while young people typically choose to engage in high-intensity intermittent activity during both discretionary physical activity (Howe et al., 2010; Armstrong et al., 2006) and self-paced physical activity interventions (Chapter 5), the majority of young people do not meet the government recommended 60 min of daily physical activity (Public Health England, 2021; Guthold et al., 2020). Moreover, while this sample presented higher cardiorespiratory fitness (Table 4.1) compared to the population average, according to 2017 European normative values (Tomkinson et al., 2017), levels of cardiorespiratory fitness in the population have declined in recent years and so 'higher than average' does not necessarily equal high fitness (Eberhardt et al., 2020). Therefore, the fewer beneficial effects seen after 60 min high-intensity intermittent running may be due to this duration of high-intensity activity being too physiologically demanding, particularly for less fit adolescents, resulting in high levels of fatigue which can detrimentally affect cognitive performance (Cooper et al., 2018; McMorris & Hale, 2012).

The findings from this study, and the other duration studies (Howie et al., 2014, 2015; van den Berg et al., 2018) suggest that there may be an inverted-U curvilinear relationship between physical activity duration and subsequent cognition. Specifically, the available data suggest that the positive effects of physical activity on cognition are lesser following shorter (~ 20 min) and longer (~ 60 min) durations of exercise; whilst greater benefits are seen following medium (~ 30 min) durations. However, as aforementioned, the modality and intensity of the physical activity undertaken is likely to influence the nature of the relationship (Pontifex et al., 2019). Therefore, additional dose-response studies, which utilise different modalities and intensities of physical activity, are necessary to be able to elucidate the full nature of the physical activity duration-cognition relationship. Moreover, future research should seek to compare the effects to cognition from participation in shorter durations (e.g., 5, 10, 15 and 20 min) of high-intensity intermittent running than used in the present study, to establish whether this modality of exercise is superior to others in its ability to enhance cognition, even at shorter durations. Nonetheless, a key novel finding of the present study is that 30 min of high-intensity intermittent running was more beneficial to subsequent cognition in adolescents than 60 min of high-intensity intermittent running.

The findings of the present study are valuable to schools and policy makers, as attention, inhibitory control and working memory are fundamental for goal-orientated behaviours, concentration and learning (Diamond, 2013; McPherson et al., 2018; Daly-Smith et al., 2018; Riggs et al., 2003; Tomporowski et al., 2008), and the findings demonstrate that only 30 min of high-intensity intermittent running, which is markedly more feasible to implement in school compared to 60 min of high-intensity intermittent running, is required to enhance these cognitions. The findings also reveal that these cognitive processes are enhanced 45 min following the cessation of 30 min high-intensity intermittent running. This information can be used to tailor school-based interventions and physical education sessions (e.g., the time at which they are implemented) to support learning and academic performance throughout the school day. Moreover, 30 min high-intensity intermittent running, compared to rest, was recently found to lower adolescents' post-activity blood glucose concentration and acute post-prandial insulinaemic response, suggesting that young people also gain benefits to cardiometabolic health, such as enhanced insulin sensitivity, from participation in this type and duration of physical activity (Dring et al., 2020) Therefore, implementing 30 min of high-intensity intermittent running into the school day will benefit young people's cardiometabolic health, as well as their cognition. Furthermore, young people enjoy participating in high-intensity intermittent physical activity (Malik et al., 2017, 2019), thus high levels of investment (Diamond, 2012) will assist with long-term adherence and sustained behaviour change (Howe et al., 2010).

4.5. Conclusions

In conclusion, the present study produced two main novel findings. Firstly, greater benefits to cognition were observed following participation in 30 min, compared to 60 min, of high-intensity intermittent running. This was evidenced by better information processing and inhibitory control immediately- and 45 min- following 30 min compared to 60 min of activity, in addition to enhanced attention and working memory 45 min following 30 min compared to 60 min of activity. Secondly, participation in an acute bout of high-intensity intermittent running enhanced immediate and delayed (45 min post) cognition in adolescents and was advantageous compared to resting, regardless of the duration. Future research should seek to compare the effects of shorter durations (e.g., 5 vs 10 vs 20 min) of high-intensity intermittent running on cognition. Moreover, future research should continue to explore the time-course of effects to cognition following high-intensity intermittent running, to establish whether any beneficial effects last beyond 45 min following cessation of the exercise. The findings of the present study, and of this future research, will be particularly valuable to school staff and policy makers, as high-intensity intermittent physical activity could be implemented within the school day to enhance adolescent's cognition and, subsequently, learning and academic achievement.

4.6. Practical Recommendations

School staff and education policy makers should enable opportunities for active breaks from lessons. A valuable use of this break time would involve implementing 30 min of high-intensity intermittent activity. Children will experience cognitive benefits immediately and 45 minutes following the activity, so the active break would be best placed during the first part of a lesson to support learning throughout the lesson. To promote learning throughout the school day, these active breaks should not be tagged onto other physical activities such as physical education, break or lunch time.

Chapter V

Activity Patterns of Primary School Children during Participation in The Daily Mile

5.1. Introduction

Since its development in 2012, the school-based physical activity initiative The Daily Mile, has gained research interest as it has been widely and rapidly adopted and has received substantial funding. Currently, The Daily Mile is implemented in more than 13,900 schools in 86 countries (The Daily Mile, 2022b). Moreover, £1.5 million of National Lottery money has been provided to implement the initiative in every primary school in the United Kingdom (Sport England, 2018). The initiative involves children completing ~1 mile (approximately 15-20 min) of self-paced physical activity (i.e., walking, jogging, running, sprinting) each day; typically comprising of laps of an outdoor playground or sports pitch. In recent years, the effect of both acute and chronic participation in The Daily Mile on young people has been examined. Emerging evidence suggests that chronic participation in The Daily Mile over a period of six months results in beneficial effects for both adiposity (1.4 mm reduction in sum of skinfolds) and physical fitness (40 m increase in MSFT performance), when compared to children who did not participate in The Daily Mile (Chesham et al., 2018). With regards to cognitive function, acute participation in The Daily Mile has been suggested to enhance subsequent inhibitory control and verbal working memory (Booth et al., 2020); though ambiguity remains as others reported no effect on attention, shifting, inhibitory control or working memory (Morris et al., 2019).

To better understand the impact of The Daily Mile on health and cognitive outcomes in young people, quantification of the physical activity undertaken is required. The need for quantification of the physical activity undertaken is supported by previous research which shows that the intensity and modality of physical activity, for example, affect the acute and chronic effects of physical activity on both health and cognition (Doré et al., 2019; Janssen et al., 2014b; Pontifex et al., 2019; Williams et al., 2019). Moreover, determining the activity patterns of children during participation in The Daily Mile will also establish how the activity contributes to government physical activity guidelines (Department of Health and Social Care, 2020). Given the multitude of physical activity interventions available to schools, it is important to fully understand the 'dose' of physical activity involved and subsequent effects on health and cognition, to ensure that the most holistically beneficial intervention is implemented.

Although qualitative studies have sought to explore the dose of physical activity accrued during school-based running programmes such as The Daily Mile (Chalkley et al., 2020a; Harris et al., 2020), only one study to date has quantitatively examined children's physical activity during The Daily Mile (Morris et al., 2019). Specifically, the study used accelerometery to assess time spent in MVPA (Morris et al., 2019). The authors noted that children (9.0 ± 0.5 y) engaged in 10.7 ± 2.7 min of MVPA during participation in The Daily Mile. However, large variability between individuals was found. For example, the most active child spent the entire duration (15 min) of The Daily Mile engaged in MVPA (achieving 50% of the Department of Health and Social Care target of 30 min in-school MVPA per day), yet the least active child spent only 33% of The Daily Mile engaged in MVPA (accumulating only 17% of the 30 min in-school target) (Department of Health and Social Care, 2020). While valuable, these findings highlight the need for additional research which provides a more comprehensive explanation of the activity patterns of children during The Daily Mile.

It is also important to consider how inter-individual differences, such as sex and physical fitness, may influence the physical activity patterns of young people during The Daily Mile. With regards to sex, it is well established that boys are more physically active than girls during both childhood (Loyen et al., 2016) and adolescence (Guthold et al., 2020). Moreover, a number of studies have examined the activity patterns of children during school-based physical activity (Ridgers et al., 2006, 2011; Mooses et al., 2017; Chalkley et al., 2020a). One study, for example, reported that girls engaged in more sedentary time (40% vs. 30%) and light physical activity (36% vs. 33%) during recess, whilst boys engaged in more moderate (20% vs. 27%) and vigorous (4% vs. 11%) physical activity (Tercedor et al., 2019). Moreover, boys have been reported to spend more time in MVPA during physical education classes, compared to girls (42% vs. 35%) (Chen et al., 2014b). However, contrasting evidence demonstrated that girls participated in more MVPA during recess periods compared to boys (38% vs. 31% of recess time, respectively) (Mota et al., 2005). Taken together, these findings suggest that it is vital that sex is considered in research which aims to investigate and/or evaluate physical activity interventions in young people. Moreover, a recent study found that boys travelled a greater distance compared to girls during an extracurricular running-based intervention, Marathon Kids, where children aimed to run a Marathon over an academic year (Chalkley et al., 2020a). To date however, no research has examined how participant sex may influence the activity patterns of children during participation in The Daily Mile. Moreover, no studies have explored whether other aspects of children's activity patterns (e.g., speed and the intermittent vs. continuous nature of physical activity) may be different between the sexes during participation in physical activity interventions.

Furthermore, it is well documented that repeated participation in physical activity enhances cardiorespiratory fitness in young people (Sun et al., 2013). A cross-sectional study, for example, confirmed an association between physical activity (measured using accelerometery) and cardiorespiratory fitness (measured via an indirect maximal cycle ergometer test) in 9- and 15-year-old children (Kristensen et al., 2010). Moreover, a six-month school-based intervention study reported an improvement in aerobic fitness (measured using the 20 m shuttle run test) in children (6-10 y) who participated in two additional 60 min moderate intensity physical activity sessions a week (baseline: level 3 ± 1; follow up: level 4 ± 1), compared to controls (baseline: level 3 ± 1, follow up: level 3 ± 1) (Thivel et al., 2011). However, to our knowledge, there is no empirical evidence examining how cardiorespiratory fitness affects free-living physical activity and no study to date has examined the effect of cardiorespiratory fitness on physical activity patterns during The Daily Mile. Knowledge of the impact of cardiorespiratory fitness on activity patterns during The Daily Mile would facilitate further understanding of the absolute and relative 'dose' of physical activity received by each individual and the likely subsequent effects on important outcomes such as health and cognitive performance.

Therefore, the aim of the present study is to examine the activity patterns of primary school children during The Daily Mile and to explore the potential moderating role of participant sex and cardiorespiratory fitness on the activity patterns of children during participation.

5.2. Methods

5.2.1. Study Design

This cross-sectional descriptive study involved a familiarisation trial, followed by a main trial. At the beginning of the familiarisation trial (~9.00am), anthropometric measures of height, body mass, waist circumference, skinfolds (tricep, subscapular, supraspinale, front thigh) and sitting height were taken (section 3.7). Height and body mass measurements enabled the calculation of BMI and BMI z-score (section 3.7.3). Furthermore, sitting height was used to determine an estimation of maturity (by calculating years from peak height velocity) (Moore et al., 2015). Immediately following the completion of anthropometric measures (~9.45am), participants completed a MSFT (section 3.8); this enabled a measurement of cardiorespiratory fitness to be obtained for each participant (Ramsbottom et al., 1988). Participants were also familiarised to The Daily Mile during the familiarisation trial.

5.2.3. Participants

A power calculation was conducted in G-Power software (G*Power version 3.1; Faul et al., 2007). Based on the study by Tercedor et al. (2019) and an effect size of 0.5, it was estimated that 76 participants were required in the present study. Following ethical approval from the Nottingham Trent University School of Science and Technology Ethical Advisory Committee, primary schools within the East Midlands, UK were contacted via email and invited to participate in the study. The location of participating schools varied and included rural village, urban town and inner city. Six schools were implementing The Daily Mile at the time of the study and two schools had never implemented the initiative. The process of recruiting participants varied within each school, according to the preferences of the headteacher. However, headteachers were informed that a diverse sample of participants was required (i.e., varying physical activity, fitness, and academic level) and in most schools all children from years five and six (9–11 y) were invited to participate.

In accordance with the guidelines for school-based research, headteacher consent was gained in addition to written informed consent and a health screen from parents/guardians of participating children. Moreover, children provided their written assent to participate in the study (section 3.2). A total of 80 (40 female) primary school children aged 9–11 years participated in the study. However, due to technical issues with eight GPS units during data collection, data for 72 participants were included in the analysis. Participants from six schools were year five children (n = 52 [29 female], 10.1 ± 0.2 y) and participants from two schools were year six children (n = 20 [9 female], 11.3 ± 0.3 y).

5.2.4. Experimental Procedures and Measurements

5.2.4.1. Multi-Stage Fitness Test

The MSFT was conducted in line with the descriptions provided earlier in this thesis (section 3.8), in order to gain a valid and reliable measurement of cardiorespiratory fitness for each participant (Ramsbottom et al., 1988; Ruiz et al., 2011; Tomkinson et al., 2019a). Participants were assigned to a fitness quartile (quartile 1: lowest fit, 4: highest fit), based on distance covered (m) in the MSFT. Participants were split into quartiles as research demonstrates that significant differences in health are observed between those in the lowest fitness quartile (quartile 1, bottom 25%) and those in other quartiles (quartiles 2-4, other 75%; Bugge et al., 2012; Buchan et al., 2015; Dring et al., 2019). For example, young people within the lowest fitness quartile have been shown to have low-grade chronic inflammation and a greater risk of cardiometabolic disease (Dring et al., 2019). This split was performed according to sex, resulting in an equal number of boys and girls within each fitness quartile.

5.2.4.2. The Daily Mile

Participants were familiarised to The Daily Mile protocol during a familiarisation trial. During the main trial, participants completed The Daily Mile, which consisted of 20 min of outdoor activity, under the supervision of the researchers. Although The Daily Mile was originally designed to be implemented for 15 min a day, over time there has been a change in focus within schools towards getting children to complete one mile a day, in line with the name. Based off the evidence gathered by our research group on physical activity in young people, we considered that 20 min would be necessary for children to cover one mile. We thus wanted to examine activity patterns during this time. The activity was self-paced; participants chose whether and when they walked, jogged, ran or sprinted. Participants completed The Daily Mile in groups of between 5-16 (mean: 12 ± 3) and were informed that they could complete it alone and/or with others. Moreover, participants wore normal school uniform with appropriate footwear. The protocol was designed to mimic 'The Daily Mile', and other similar initiatives, currently being implemented in primary schools across the UK.

5.2.4.3. Heart Rate and Rating of Perceived Exertion

Heart rate was recorded during participation in The Daily Mile (section 3.6.1). Maximal heart rate was predicted using methods previously described (Tanaka et al., 2001) and validated in children (Mahon et al., 2010). Average and peak heart rate were subsequently expressed as a percentage of maximum heart rate (section 3.6.1). Classification of the physical activity intensity was then performed using ACSM guidelines (ACSM, 2018). Upon completion of The Daily Mile, participants were presented with the Children's OMNI Scale in order to gain a valid and reliable rating of perceived exertion (RPE) (Gammon et al., 2016; Robertson et al., 2000; Utter et al., 2002). The OMNI scale is a scale ranging from 0 (not tired at all) to 10 (very, very tired) (Utter et al., 2002). It incorporates pictographs with descriptive anchors. This psychological measure of intensity is thought to integrate physiological cues (e.g., heart rate) and psychosocial factors (e.g., emotional state, perception of pain) (Pontifex et al., 2019).

5.2.4.4. Global Positioning Systems

During participation in The Daily Mile, participant's activity patterns were measured using GPS (section 3.6.2). For all data, satellite coverage was 8 ± 1 satellites and horizontal dilution of precision was 0.48 ± 0.02. The variables of interest were: total distance covered (m), distance covered within age-specific speed zones (m) and number of speed zone entries. These were calculated over the whole 20 min and within each 5 min split of The Daily Mile (0–5 min, 5–10 min, 10–15 min and 15–20 min), to examine whether activity patterns changed across the duration of The Daily Mile. Age group-specific speed zones were adapted from those published on youth soccer players (Saward et al., 2016; section 3.6.2). For the distance covered in each speed zone, standing and walking zones were combined. The number of speed zone entries was also used as a measure of the 'nature' of movement (i.e., continuous vs. intermittent).

5.2.5. Statistical analysis

Data were analysed in Statistical Package for the Social Sciences (SPSS) (Version 24; SPSS Inc., Chicago, IL., USA). The assumptions required for each parametric test were examined prior to use, including checking whether the data was normally distributed via the Shaprio-Wilk Test, using Levene's test for homogeneity of variances (for one-way ANOVA) and Mauchly's sphericity test (for one-way and two-way repeated measures ANOVA). As the assumption of normality was violated, differences in heart rate and RPE between sexes were analysed using the Mann-Whitney U test (the non-parametric alternative to an independent sample t-test). Cohen's d effect sizes were calculated; an effect size of 0.2, 0.5 and 0.8 corresponded to a small, medium and large sized effect, respectively. Moreover, as the assumption of normality was violated, differences between fitness quartiles in heart rate and RPE were analysed using Kruskall-Wallis H test (the non-parametric alternative to a one-way ANOVA).

When analysing activity patterns (total distance covered, distance covered in each speed zone and number of speed zone entries) over time (i.e., for each 5 min split), one-way repeated measures analysis of variance (ANOVA) were conducted and partial eta squared (η_p^2) effect sizes were calculated and interpreted as per convention (small = 0.01, medium = 0.06, and large = 0.14). Moreover, examine the effect of fitness quartile on activity patterns during The Daily Mile, one-way ANOVA were utilised and omega squared effect sizes were calculated. Post-hoc pairwise comparison tests were used to examine the differences in activity patterns between each 5 min split and between the fitness quartiles. Multiple comparisons were corrected for using a Bonferroni correction. In order to maintain the type 1 error rate (α) and level of significance at $p \leq 0.05$ (to support ease of interpretation), the *p* value from each relevant test was times by the number of comparisons (e.g., 6). This *p* value was then compared to the alpha level $p \leq 0.05$ to determine significance. Cohen's d effect sizes were calculated. To examine how activity patterns were affected by fitness in each 5 min split, two-way ANOVA (fitness by split time; with repeated measures for split time) were conducted and partial eta squared effect sizes were calculated. To examine the effect of sex on activity patterns during The Daily Mile, independent samples t-tests were used and Cohen's d effect sizes were calculated. Furthermore, to examine how activity patterns differed between the sexes in each 5 min split, two-way ANOVA (sex by split time; with repeated measures for split time) were conducted and partial eta squared (η_p^2) effect sizes were calculated. Statistical significance was accepted as $p \leq 0.05$. Data are presented as mean ± SD.

5.3. Results

5.3.1. Participant Characteristics

Participant characteristics are displayed in Table 5.1, for the sample overall and also split by boys and girls.

Table 5.1. Participant characteristics for the group overall, as well as for boys and girls separately. Data are mean ± SD.

	Overall (*n* = 72)	**Boys (*n* = 34)**	**Girls (*n* = 38)**	***p* value [a]**
Age (y)	10.4 ± 0.7	10.4 ± 0.7	10.4 ± 0.7	0.576
Height (cm)	143.9 ± 8.4	144.8 ± 7.7	142.9 ± 8.9	0.391
Body mass (kg)	36.3 ± 8.7	37.4 ± 9.5	35.2 ± 7.7	0.289
BMI ($kg \cdot m^{-2}$)	17.3 ± 2.6	17.6 ± 2.8	17.0 ± 2.3	0.342
BMI z-score	0.1 ± 1.1	0.2 ± 1.1	-0.2 ± 1.1	0.084
Waist circumference (cm)	61.9 ± 8.0	62.9 ± 8.4	60.6 ± 7.1	0.319
Sum of skinfolds (mm)	51.6 ± 24.1	51.8 ± 26.1	51.1 ± 23.4	0.962
Maturity offset (y) [b]	-2.0 ± 0.9	-2.7 ± 0.6	-1.4 ± 0.7	< 0.001

Note. [a] Independent samples t-test for comparison between boys and girls. [b] Calculated using the method of Moore et al. (2015).

5.3.2. Heart Rate and Rating of Perceived Exertion

During participation in The Daily Mile, average heart rate (main effect of sex, U = 103, $p = 0.015$, d = 0.67), peak heart rate (main effect of sex, U = 116, $p = 0.038$, d = 0.06) and the overall relative physical activity intensity (main effect of sex, U = 147, $p = 0.006$, d = 0.61) were significantly higher in boys, compared to girls (Table 5.2). Moreover, there was a tendency for average heart rate to be highest in the highest fit (quartile 4) participants and lowest in the lowest fit (quartile 1) participants, however this effect did not reach statistical significance ($p = 0.052$; Table 5.2). Additionally, there was no difference in peak heart rate ($p = 0.198$) and overall relative physical activity intensity was similar between fitness groups during The Daily Mile ($p = 0.41$; Table 5.2). Furthermore, no difference in RPE was observed between the sexes ($p = 0.090$) or fitness quartiles ($p = 0.149$; Table 5.2).

Table 5.2. Participants average and peak heart rate during The Daily Mile, and rating of perceived exertion.

		Average heart rate		Peak heart rate		Rating of perceived exertion
		beats·min^{-1}	% HR_{max}[a]	beats·min^{-1}	% HR_{max}[a]	
Whole Sample		163 ± 27	81 ± 13	193 ± 18	96 ± 9	5 ± 2
Sex	Boys	172 ± 27	85 ± 14	194 ± 23	96 ± 11	5 ± 2
	Girls	155 ± 24 *	77 ± 12 *	193 ± 11 *	96 ± 6	6 ± 3
Physical fitness	Quartile 1 (lowest fit)	145 ± 26	72 ± 13	187 ± 21	93 ± 11	6 ± 3
	Quartile 2	166 ± 20	83 ± 10	197 ± 6	98 ± 3	5 ± 2
	Quartile 3	166 ± 29	83 ± 15	189 ± 25	94 ± 12	4 ± 2
	Quartile 4 (highest fit)	174 ± 30	87 ± 15	201 ± 4	100 ± 2	6 ± 2

[a] percentage of age predicted maximum heart rate (HR_{max}) during The Daily Mile. HR_{max} predicted based upon (HR_{max} = 208 – 0.7[age]) (Mahon et al., 2010). * boys > girls, all $p < 0.05$

5.3.3. Distance Covered

5.3.3.1. Whole Sample

Average distance covered by participants during The Daily Mile was 2511 ± 550 m (range: 1616–4132 m). When considering the distance covered during each 5 min split, a significant main effect of time was observed ($F_{(2, 183)}$ = 71.0, p < 0.001, η_p^2 = 0.473). Specifically, participants covered the greatest distance in the first 5 min of The Daily Mile (748 ± 141 m) and distance covered gradually decreased with each following 5 min split (5-10 min: 627 ± 160 m; 10-15 min: 582 ± 169 m; 15-20 min: 554 ± 162 m; Figure 5.1).

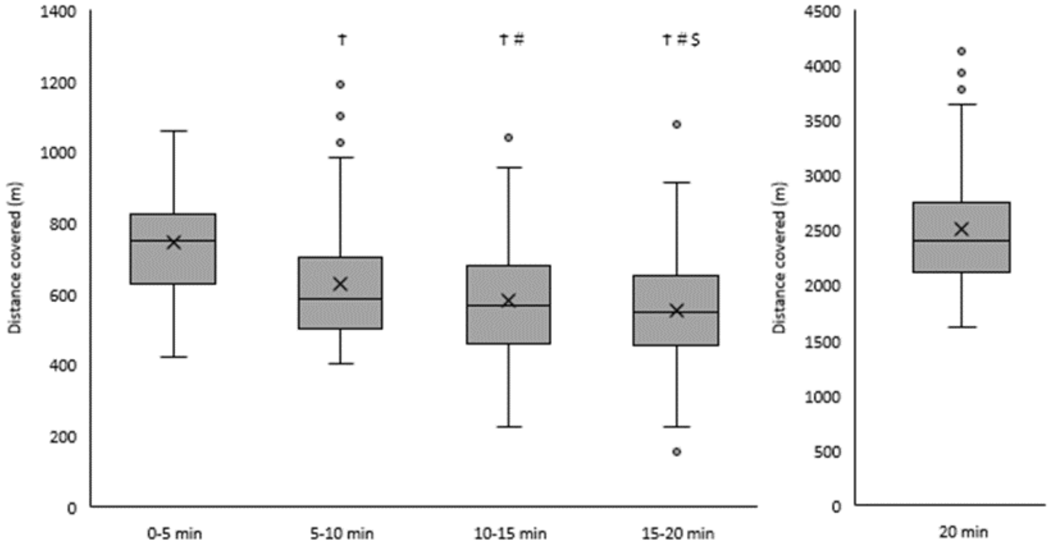

Figure 5.1. Distance covered (m) by participants during each 5 min split, and the total 20 min, of The Daily Mile. Boxplots represent the median (centre line), mean (cross), inter-quartile range (grey box), range (whiskers) and outliers (grey circles). Main effect of time, p < 0.001. † Denotes significant difference from Split 1. # Denotes a significant difference from Split 2. $ Denotes a significant difference from Split 3 (all p < 0.08).

5.3.3.2. Sex

Total distance covered during the full 20 min of The Daily Mile was greater in boys compared to girls (Boys: 2717 ± 606 m, Girls: 2305 ± 398 m; main effect of sex, $t_{(67)}$ = -3.6, p = 0.001, d = 0.80). Moreover, when considering the distance covered across each 5 min split, there was a significant sex by time interaction ($F_{(2, 193)}$ = 3.7, p = 0.019, η_p^2 = 0.045). Specifically, the difference in distance covered between boys and girls was greatest in the first 5 min, and decreased across the remainder of The Daily Mile (Figure 5.2).

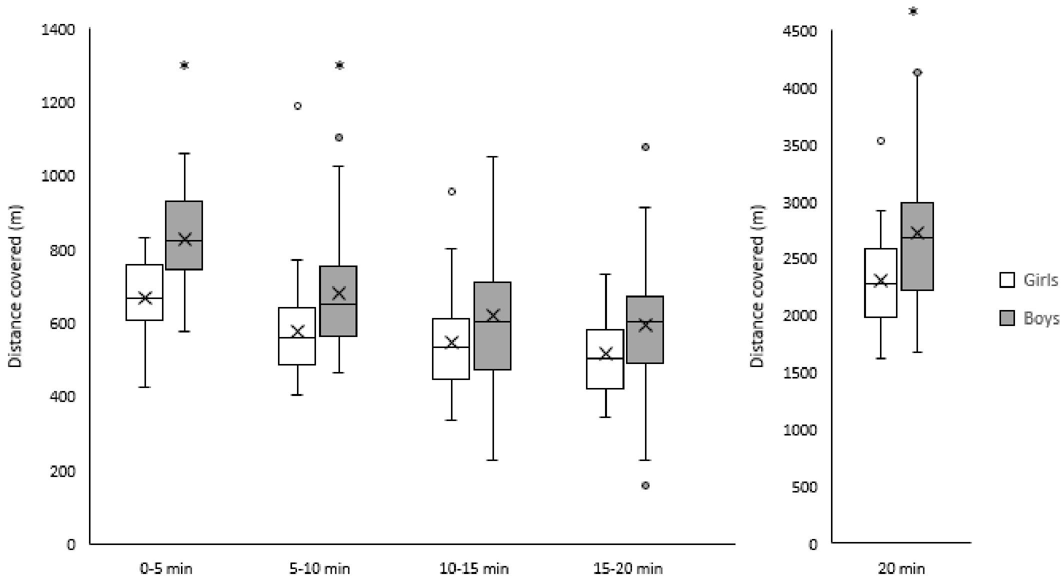

Figure 5.2. Distance covered (m) by boys and girls during each 5 min split, and the total 20 min of The Daily Mile. Main effect of sex, $p = 0.001$; sex by time interaction, $p = 0.019$. *Indicates distance covered by boys significantly greater than girls ($p < 0.05$).

5.3.3.3. Cardiorespiratory Fitness

Participant fitness had a significant effect on distance covered in The Daily Mile (main effect of fitness, $F_{(3, 68)} = 10.4$, $p < 0.001$, $\omega^2 = 0.29$). Specifically, participants in quartile 4 (highest fitness) covered a greater distance than quartile 1 (mean difference = 828 m, $p < 0.001$, d = 1.61), quartile 2 (mean difference = 673 m, $p < 0.001$, d = 0.25), and quartile 3 (mean difference = 494 m, $p = 0.015$, d = 0.90) participants (Figure 5.3). However, there were no differences in distance covered between the other fitness quartiles (all $p > 0.05$), and there was no significant fitness by time interaction ($p = 0.821$).

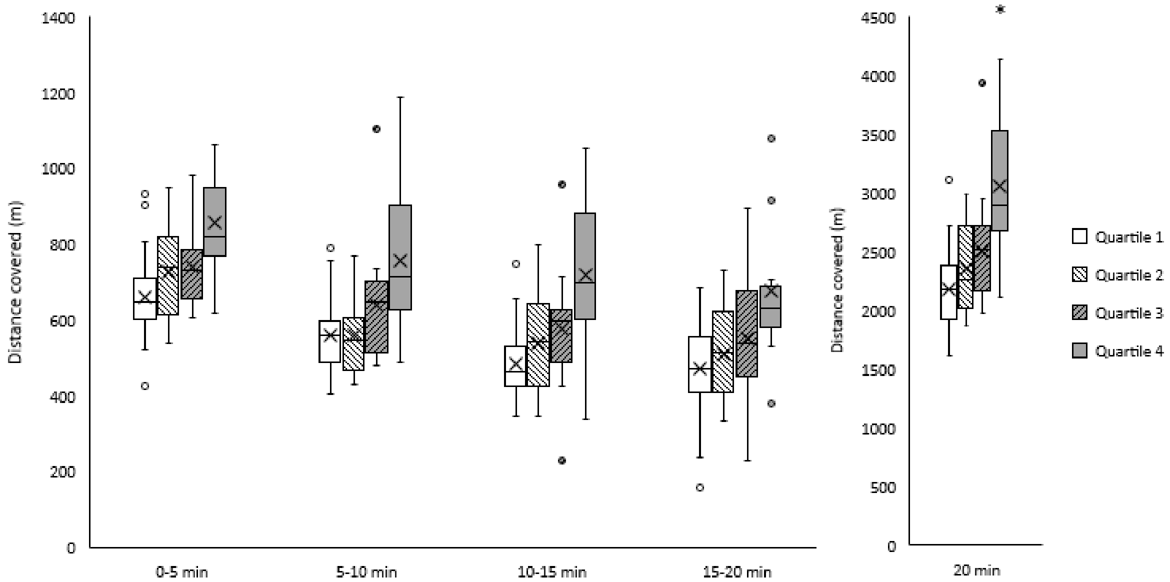

Figure 5.3. Distance covered (m) by participants in each fitness quartile (Quartile 1: lowest fit, Quartile 4: highest fit) during each 5 min split and the total 20 min of The Daily Mile. Main effect of fitness, $p < 0.001$. * Indicates distance covered by participants in quartile 4 greater than participants in quartiles 1, 2 and 3 (all $p < 0.008$).

5.3.4. Distance Covered in each Speed Zone

5.3.4.1. Whole Sample

During the total 20 min of The Daily Mile, and within each 5 min split, participants covered the greatest distance in low-speed running (speed zone 2) and moderate speed running (speed zone 3). The least distance was covered while walking (speed zone 1) and sprinting (speed zone 5). Moreover, distance covered in low speed running and sprinting remained relatively stable across each 5 min split of The Daily Mile (main effect of time, zone 2: $p = 0.166$; zone 5: $p = 0.081$). However, distance covered while walking varied significantly over time ($F_{(1, 115)} = 10.0$, $p = 0.001$, $\eta_p^2 = 0.112$). Specifically, distance covered while walking was lowest in the first 5 min (split 1 vs. 2: $p = 0.002$, d = 0.43; split 1 vs. 3, $p = 0.002$, d = 0.51; split 1 vs. 4: $p < 0.001$, d = 0.62) and highest in the last 5 min (split 2 vs. 4: $p = 0.005$, d = 0.44; split 3 vs. 4: $p = 0.004$, d = 0.34). Moreover, distance covered while running at a moderate speed changed significantly over time ($F_{(2, 173)} = 77.7$, $p < 0.001$, $\eta_p^2 = 0.496$), whereby distance covered at a moderate speed was greatest in the first 5 min (split 1 vs. 2: $p < 0.001$, d = 0.60; split 1 vs. 3: $p < 0.001$, d = 0.94; split 1 vs. 4: $p < 0.001$, d = 1.10) and decreased with each following 5 min (split 2 vs. 3: $p = 0.001$, d = 0.24; split 3 vs. 4: $p = 0.003$, d = 0.22). Furthermore, distance covered while running at a high speed varied significantly over time ($F_{(3, 205)} = 7.7$, $p < 0.001$, $\eta_p^2 = 0.089$). Specifically, distance covered in high-speed running was greatest in the first 5 min (split 1 vs. 2: $p < 0.001$, d = 0.50; split 1 vs. 3: $p < 0.001$, d = 0.65; split 1 vs. 4: $p = 0.014$, d = 0.31), decreased and remained relatively stable for the middle 10 min, then increased significantly in the last 5 min of The Daily Mile (split 3 vs. 4: $p = 0.047$, d = 0.23) (Table 5.3).

5.3.4.2. Sex

Participant sex had a significant effect on distance covered in low, moderate and high speed running zones during The Daily Mile (main effect of sex, zone 2: $t_{(78)} = 3.4$, $p = 0.022$, d = 0.50; zone 3: $t_{(55)} = -3.9$, $p < 0.001$, d = 0.9; zone 4: $t_{(78)} = -2.4$, $p = 0.020$, d = 0.51). Specifically, girls covered a greater distance in low-speed running compared to boys, whereas boys covered a greater distance in moderate and high-speed running compared to girls (Table 5.3). Moreover, there was a significant sex by time interaction effect on distance covered in moderate speed ($F_{(2, 178)} = 6.8$, $p = 0.001$, $\eta_p^2 = 0.081$) and high speed ($F_{(3, 207)} = 3.6$, $p = 0.018$, $\eta_p^2 = 0.044$) running over time. Specifically, boys covered a greater distance in moderate speed running throughout each 5 min of The Daily Mile and in high-speed running in the last 5 min, compared to girls (Table 5.3).

5.3.4.3. Cardiorespiratory Fitness

Participant fitness had a significant effect on distance covered in low and moderate speed running during The Daily Mile (main effect of fitness, zone 2: $F_{(3, 68)} = 3.7$, $p = 0.015$, $\omega^2 = 0.14$; zone 3: $F_{(3, 68)} = 9.6$, $p < 0.001$, $\omega^2 = 0.27$, Table 5.3). Specifically, participants in quartile 3 travelled significantly further in low-speed running compared to quartile 4 participants ($p = 0.009$, d = 0.92). Quartile 4 participants, however, travelled significantly further in moderate speed running, compared to participants in all other fitness quartiles (quartile 1 vs. 4: $p < 0.001$, d = 1.21; quartile 2 vs. 4: $p < 0.001$, d = 1.10; quartile 3 vs. 4: $p < 0.001$, d = 1.23).

Regarding the distance covered in each speed zone across the 5 min splits of The Daily Mile, no significant fitness by time interaction effects were observed (zone 1: $p = 0.623$; zone 2: $p = 0.162$; zone 3: $p = 0.602$; zone 4: $p = 0.377$; zone 5: $p = 0.692$).

Table 5.3. Distance covered (m) by participants in each speed zone during The Daily Mile.

				Split 1	Split 2	Split 3	Split 4
			20 min	0-5 min	5-10 min	10-15 min	15-20 min
Walking (Zone 1) ≤ 0.83 m·s^{-1}	All		37 ± 46	4 ± 6	7 ± 10†	10 ± 16†	15 ± 24$^{†\#\$}$
	Sex	Girls	36 ± 35	6 ± 6*	9 ± 11	8 ± 9	13 ± 15
		Boys	38 ± 55	3 ± 6	6 ± 9	13 ± 21	16 ± 31
	Fitness	Q1	60 ± 45^{a}	8 ± 7	11 ± 11	17 ± 12	24 ± 29
		Q2	37 ± 31	6 ± 8	8 ± 10	9 ± 10	14 ± 11
		Q3	38 ± 67	3 ± 4	5 ± 9	13 ± 28	17 ± 36
		Q4	19 ± 33	1 ± 2	5 ± 9	4 ± 8	8 ± 15
Low speed running (Zone 2) 0.84 - 2.84 m·s^{-1}	All		1370 ± 387	342 ± 128	356 ± 119	344 ± 105	328 ± 112
	Sex	Girls	1469 ± 356*	375 ± 109	371 ± 111	370 ± 91*	352 ± 94
		Boys	1272 ± 396	309 ± 137	340 ± 126	318 ± 112	304 ± 124
	Fitness	Q1	1366 ± 292	362 ± 110	370 ± 111	330 ± 63	304 ± 104
		Q2	1394 ± 275	347 ± 120	367 ± 105	352 ± 74	328 ± 79
		Q3	1539 ± 447^{a}	402 ± 128	404 ± 118	374 ± 143	358 ± 125
		Q4	1127 ± 418	257 ± 121	276 ± 117	307 ± 122	286 ± 117
Moderate speed running (Zone 3) 2.85 - 3.79 m·s^{-1}	All		828 ± 663	326 ± 201	204 ± 194†	164 ± 181$^{†\#}$	134 ± 144$^{†\#\$}$
	Sex	Girls	560 ± 361	227 ± 126	134 ± 107	108 ± 98	91 ±91
		Boys	1095 ± 784*	425 ± 215*	273 ± 235*	221 ± 225*	176 ± 174*

				Split 1	Split 2	Split 3	Split 4
			20 min	0-5 min	5-10 min	10-15 min	15-20 min
	Fitness	Q1	562 ± 378[a]	237 ± 162	139 ± 102	95 ± 63	93 ± 88
		Q2	667 ± 411[a]	296 ± 168	152 ± 97	123 ± 115	96 ± 73
		Q3	624 ± 321[a]	254 ± 150	158 ± 99	112 ± 79	99 ± 75
		Q4	1461 ± 968	493 ± 221	362 ± 294	336 ± 286	270 ± 227
High speed running (Zone 4) 3.80 - 4.73 $m \cdot s^{-1}$	All		195 ± 149	67 ± 59	41 ± 48 †	37 ± 49 †	49 ± 54 † $
	Sex	Girls	157 ± 126	53 ± 55	43 ± 53	30 ± 32	30 ± 34
		Boys	233 ± 161*	82 ± 60	39 ± 43	45 ± 61	67 ± 63*
	Fitness	Q1	162 ± 148	9 ± 24	5 ± 16	3 ± 8	8 ± 17
		Q2	179 ± 143	7 ± 12	3 ± 5	23 ± 73	22 ± 69
		Q3	191 ± 167	11 ± 18	30 ± 98	38 ± 158	40 ± 134
		Q4	275 ± 137	10 ± 19	44 ± 115	33 ± 109	34 ± 89
Sprinting (Zone 5) > 4.73 $m \cdot s^{-1}$	All		82 ± 252	8 ± 17	19 ± 72	26 ± 100	29 ± 89
	Sex	Girls	84 ± 232	9 ± 20	18 ± 77	29 ± 94	28 ± 89
		Boys	80 ± 273	8 ± 15	20 ± 69	22 ± 106	29 ± 90*
	Fitness	Q1	25 ± 48	9 ± 24	5 ± 16	3 ± 8	8 ± 17
		Q2	55 ± 107	7 ± 12	3 ± 5	23 ± 73	22 ± 69
		Q3	119 ± 402	11 ± 18	30 ± 98	38 ± 158	40 ± 134
		Q4	122 ± 137	10 ± 19	44 ± 155	33 ± 109	34 ± 89

Q: quartile. † Denotes significant difference ($p \le 0.05$) from Split 1. # Denotes a significant difference from Split 2. $ Denotes a significant difference from Split 3. *Indicates the sex that covered a significantly greater distance during the specified time frame. [a] Represents a significant difference from quartile 4 participants.

5.3.5. Speed Zone Entries

5.3.5.1. Whole Sample

During participation in The Daily Mile, the mean number of speed zone entries for each participant was 646 ± 175. There was, however, a large variance between participants in the number of speed zone entries (range 156–1365) (Table 5.4). Moreover, the number of speed zone entries made by participants during The Daily Mile differed over time ($F_{(3, 206)} = 38.2$, $p < 0.001$, $\eta_p^2 = 0.326$). Specifically, participants completed the greatest number of entries in the first 5 min of The Daily Mile when compared to all other 5 min splits (split 1 vs. 2: $p < 0.001$, d = 0.94; split 1 vs. 3: $p < 0.001$, d = 0.94; split 1 vs. 4: $p < 0.001$, d = 0.83, Table 5.4).

5.3.5.2. Sex

Boys completed significantly more speed zone entries compared to girls during the total 20 min of The Daily Mile (main effect of sex, $t_{(78)} = -4.8$, $p < 0.001$, d = 1.04). There were, however, large ranges in the mean number of zone entries within each sex (Girls: 156–1227; Boys: 362–1365, Table 5.4). Moreover, there was no difference in the number of entries made between sexes within any of the 5 min splits (sex by time interaction, $p = 0.343$).

5.3.5.3. Cardiorespiratory Fitness

The highest fit (quartile 4) and lowest fit (quartile 1) participants presented the greatest mean number of zone entries during the 20 min of The Daily Mile (Table 5.4). However, there were no significant differences in the number of entries made during the total 20 min (main effect of fitness, $p = 0.198$) or each 5 min split (fitness by time interaction, $p = 0.393$) between fitness quartiles.

Table 5.4. Mean ± SD (range) speed zone entries made by participants during The Daily Mile.

			Split 1	Split 2	Split 3	Split 4
		20 min	**0-5 min**	**5-10 min**	**10-15 min**	**15-20 min**
All		646 ± 275 (156-1365)	217 ± 79 (63-426)	148 ± 75 † (13-406)	139 ± 87 † (5-485)	146 ± 90 † (7-445)
Sex	**Girls**	523 ± 218 (156-1227)	179 ± 65 (75-322)	121 ± 65 (13-274)	108 ± 58 (5-321)	118 ± 76 (7-365)
	Boys	770 ± 274* (362-1365)	255 ± 74 (63-426)	175 ± 75 (73-406)	170 ± 99 (38-485)	173 ± 94 (73-445)
Fitness	**Q1**	632 ± 282 (258-1227)	193 ± 78 (84-380)	138 ± 68 (47-274)	153 ± 72 (29-321)	151 ± 100 (7-365)
	Q2	594 ± 196 (253-976)	219 ± 67 (75-322)	140 ± 67 (19-271)	115 ± 68 (34-286)	124 ± 60 (25-241)
	Q3	589 ± 277 (156-1295)	197 ± 82 (90-340)	131 ± 72 (13-261)	127 ± 68 (5-269)	137 ± 93 (25-428)
	Q4	766 ± 316 (362-1365)	243 ± 78 (63-423)	183 ± 72 (82-285)	154 ± 106 (42-364)	190 ± 106 (42-445)

Q: Quartile. † Denotes a significant difference (*p* £ 0.05) from Split 1. * Indicates number of speed zone entries by boys significantly greater than girls.

5.4. Discussion

This is the first study to quantify the activity patterns (including distance covered in different speed zones and the number of speed zone entries) alongside the physiological responses of children participating in The Daily Mile. The total distance covered was 2511 m (~1.5 miles), mostly while running at low and moderate speeds. Average heart rate was 163 ± 27 beats·min^{-1}, peak heart rate was 193 ± 18 beats·min^{-1}, the relative physical activity intensity was 81 ± 13% of age-predicted HR_{max} and average RPE was 5 ± 2 (which equates to 'tired') upon completion of The Daily Mile. Participants covered the greatest distance, and were also most intermittent, during the first 5 min of The Daily Mile, compared to the later stages. Moreover, boys and the highest fit children ran further and faster compared to girls and less fit children. Boys' average heart rate, peak heart rate and their relative physical activity intensity was higher than in girls, and boys' activity was also more intermittent.

Although the children covered an average distance of 2511 m, equating to approximately 1.5 miles, there was a large range in the distances covered by participants, from ~ 1 mile to 2.5 miles, between boys and girls and between high fit and low fit participants. It has been previously suggested that the 'dose' of physical activity is a key determinant of the subsequent effects on participant health and cognition (Pontifex et al., 2019; Chang et al., 2012; Hills et al., 2015) and thus it is possible the health and cognition benefits would vary between participants in the present study. However, whilst the relative physical activity intensity was higher in boys compared to girls, the relative physical activity intensity (average 81 ± 13 %) did not differ between low and high fit children and all participants ran at least one mile; suggesting a potentially similar and positive health benefit for children of all fitness levels participating in The Daily Mile.

In the present study, the mean number of speed zone entries for each participant was 646 (a high number of entries demonstrating that participants frequently changed pace), so although there was a wide range of speed zone entries between participants from 156 to 1365 entries, all children were to some extent intermittent in their activity patterns during The Daily

Mile. These findings support previous research suggesting that children typically choose to engage in sporadic, high intensity intermittent activity during discretionary physical activity (Armstrong & Welsman, 2006; Howe et al., 2010). This intermittent choice of activity may be based on enjoyment, as it has been previously shown in young people aged 12–15 that enjoyment ratings are higher for intermittent than for continuous cycling physical activity, and that enjoyment remains high even when bouts of physical activity are at near maximal intensity (Malik et al., 2017, 2019). Giving young people the choice to stop and start and to speed up and slow down during The Daily Mile may also be important for physiological health and cognitive function benefits, as glycaemic control and executive function were better in adolescents following intermittent in comparison with continuous physical activity (Cockcroft et al., 2017; Lambrick et al., 2016). Therefore, the findings of the present study support the use of The Daily Mile as an intermittent form of activity in young people.

With regards to how activity patterns changed over time, during the first 5 min of The Daily Mile, children covered a higher total distance and a higher distance in the moderate- and high-speed running zones in comparison with the remaining 5 min splits. Furthermore, their activity was also the most intermittent during the first 5 min, as demonstrated by a higher number of speed zone entries. This information is valuable to school staff because it demonstrates that even if only 5 min can be spared on any given day (e.g., due to time constraints or weather concerns), it is worth using this time to implement The Daily Mile, as physical activity during this time is of a high ‘dose’, and thus could still be beneficial for the young people. The total distance covered and distance covered while running at a moderate speed gradually decreased with each following 5 min, while distance covered while walking gradually increased. These changes are likely due to participants experiencing rising levels of fatigue as The Daily Mile progressed (Cairns, 2006). Moreover, while distance covered in high-speed running remained stable during the middle 10 min of The Daily Mile, distance covered in this zone increased slightly in the last 5 min. Additionally, speed zone entries, and thus intermittent activity, decreased over the middle 10 min of The Daily Mile but increased slightly in the last 5 min. These findings suggest that children may invest additional effort when they know that they are approaching the end of a bout of physical activity; thus providing young people with information that there is 5 min remaining during The Daily Mile may increase the distance covered towards the end of the activity.

When examining the effect of participant cardiorespiratory fitness, as measured by the MSFT in the present study, on activity patterns in The Daily Mile, participants in quartile 4 (highest fitness) covered between ~800 m and ~500 m more than participants in quartiles 1, 2 and 3. The intermittent/continuous nature of activity, however, was not affected by cardiorespiratory fitness. These findings highlight the importance of considering each participant's physical fitness when evaluating the effectiveness of physical activity interventions. Importantly, although there was a tendency for the highest fit children to have the highest average heart rate, and for the lowest fit children to have the lowest average heart rate, there were no statistically significant differences in heart rate (average and peak), or RPE, between fitness quartiles during participation in The Daily Mile. Thus, while the absolute dose of activity may be different between children of different fitness levels (as the highest fit children tend to run further and faster), the relative dose of the activity is similar. This is an important novel finding of the present study given that the relative, compared to absolute, dose of physical activity is more likely to determine the physiological responses (Mann et al., 2013). The Daily Mile initiative is, therefore, advantageous as children of all fitness levels are able to participate, receive a similar 'relative' dose of physical activity and are thus likely to gain similar benefits for health and cognitive function.

Participant sex was a significant moderator of activity patterns during The Daily Mile. Boys covered a greater distance compared to girls overall, and within each 5 min split of The Daily Mile. Moreover, whilst girls covered a greater distance running at a low-speed, boys covered a greater distance while running at faster speeds. Overall, this resulted in boys running further than girls, whose activity was slower paced. This greater distance covered by the boys would be expected due to their higher $\dot{V}O_2$ peak (e.g., 16% higher in 8–11 y boys compared to girls) (Dencker et al., 2007) and their better performance in the MSFT in the present study which may reflect a combination of both a higher $\dot{V}O_2$ peak and a better training status. Moreover, the boys' average heart rate (172 $\pm$ 27 beats·min^{-1}) was higher than girls (155 $\pm$ 24 beats·min^{-1}) during The Daily Mile, reflecting a higher relative physical activity intensity for the boys, which supports the suggestion that the boys were better trained. In addition, the boys could have chosen to undertake more physical activity and a different type of physical activity. Previous literature demonstrates that boys tend to view unstructured physical activity time (e.g., recess) as an opportunity to engage in competitive behaviours, whereas girls tend to engage in social behaviours (Blatchford et al., 2003). A recent ethnographic study on The Daily Mile reported that girls interacted more during participation, linking arms and chatting, and this was suggested to reduce MVPA (Hanckel et al., 2019). Therefore, sex-specific social behaviours, in addition to differences in $\dot{V}O_2$ peak and training status, may also be responsible for the differences in activity patterns observed between the sexes in the present study. Furthermore, evidence suggests that boys experience greater improvements in cardiorespiratory fitness from chronic participation in school-based physical activity interventions (Hartwig et al., 2021). The greater relative physical activity intensity observed in boys compared to girls during The Daily Mile may therefore result in boys gaining greater benefits to health and cognitive function from participation over time.

Previous research has highlighted that more in-school physical activity opportunities are necessary, as not enough children are meeting the daily 30 min MVPA target (Department of Health and Social Care, 2020). Notwithstanding the differences in activity patterns between boys and girls and children of different fitness levels, the findings of the present study demonstrate that The Daily Mile is an effective intervention which allows all young people to accrue physical activity during the school day. Specifically, in the 20 min Daily Mile in the present study, all young people covered at least one mile. However, while the findings suggest that The Daily Mile contributes towards this target, the contribution is more significant for boys. Moreover, current evidence on the chronic effects of The Daily Mile on children's cardiorespiratory fitness is contradictory. While some studies found improvements to cardiorespiratory fitness at 12 weeks (Brustio et al., 2019, 2020; de Jonge et al., 2020), others reported no effects to cardiorespiratory fitness following six (Marchant et al., 2020) or 12 months of participation (Breheny et al., 2020). Future research could thus consider whether making adaptations to The Daily Mile and/or implementing a different activity may be more successful in contributing to these targets and improving cardiorespiratory fitness in both sexes. For example, previous observational research on The Daily Mile has shown that children spend the greatest time performing MVPA during The Daily Mile when it is being promoted by teachers (Harris et al., 2019). Therefore, school staff implementing The Daily Mile could focus on encouraging girls to engage in more physical activity during participation to ameliorate the differences in activity patterns between boys and girls demonstrated in the present study. Alternatively, perhaps an activity with slightly more structure may be more effective in eliciting a greater activity engagement from girls. It must, however, be remembered that the simple and social nature of The Daily Mile are factors considered core to its popularity and success as a school-based intervention (Harris et al., 2019; Ryde et al., 2018).

While this paper has several strengths, it is not without limitations. For example, it is possible that the recruitment process resulted in selection bias, with less physical activity -focused schools and less fit children opting out of participation. However, the schools which participated in the study varied in size (105–660 pupils) and location (rural village–inner city), and whether they had previously implemented any active mile initiatives. Additionally, participating children displayed a wide range of cardiorespiratory fitness, body mass and adiposity; thus representing a diverse sample. Nevertheless, our data should be interpreted with the potential selection bias in mind. The findings of the present study are specific to a 20 min Daily Mile. Whilst we feel that the activity patterns of children will be similar with other durations (e.g., 15 min), the exact effects warrant further investigation. Moreover, group sizes during participation in The Daily Mile varied (5–16 children) due to the logistical challenges of conducting the testing within each school and it is possible that the activity patterns of children may differ when participating in larger groups such as a whole class. However, the present study provides novel quantitative insight into the activity patterns of young people participating in The Daily Mile. Furthermore, many of the schools were implementing The Daily Mile at the time of participation in the study. While the length of implementation at these schools ranged from 2 to 12 months, prior engagement will have impacted the novelty of the physical activity. This may have influenced participants' activity patterns, as the novelty or familiarity of an activity can effect an individual's tolerance to it (Pontifex et al., 2019). The more familiar an individual is to an activity, the greater tolerance they have to it; this can promote enhanced performance (Pontifex et al., 2019). However, an individuals' tolerance to an activity is also heavily impacted by their baseline cardiorespiratory fitness (Pontifex et al., 2019), and as discussed, participants within the present study varied in fitness level.

5.5. Conclusions

This study is the first to report activity patterns during The Daily Mile. Overall, participants engaged in moderate-to-vigorous intensity physical activity and on average covered ~1.5 miles. Furthermore, the findings of the present study demonstrate that boys run further and faster than girls, and that boy's activity is more intermittent, during The Daily Mile. Moreover, this study demonstrates that whilst high fit children run further and faster than lower fit children during The Daily Mile, the relative physical activity intensity is similar between fitness groups; this suggests that The Daily Mile facilitates a similar relative 'dose' of physical activity for children of all fitness levels. Furthermore, by quantifying the dose and nature of physical activity during The Daily Mile, this study has enabled a greater understanding of how acute and chronic participation may impact children's health and cognition. Future research should seek to explore how children's activity patterns change over time with regular participation in The Daily Mile and should examine the potential moderating role of sex and cardiorespiratory fitness in these relationships.

5.6. Practical Recommendations

The Daily Mile should be implemented in school daily to support physical activity targets. Even if only 5 min is available on any given day, it is still worthwhile implementing The Daily Mile as children covered the greatest distance and were most intermittent during this time, so benefits from participation are likely. School staff should inform children of how much time is left during participation in The Daily Mile, particularly when in the last 5 min, as children increase the distance they cover in high-speed zones and become more intermittent in the last 5 min, suggesting that they invest additional effort in the activity when provided with this information. Differences in activity patterns and relative physical activity intensity is observed between boys and girls, with boys engaging at a higher absolute and relative dose. The differences in activity patterns may lead to differences in impact of The Daily Mile on body composition, cardiorespiratory fitness and cognitive function from long term participation. School staff can support an increase in girl's physical activity through verbal encouragement (Harris et al., 2019) and through their own personal engagement (Marchant et al., 2020). It is paramount, however, that the core components of The Daily Mile (e.g., simple, social nature) which are important for enjoyment and fundamental to its popularity and success as a school-based intervention (Harris et al., 2020; Ryde et al., 2018) are not changed in this process.

Chapter VI

The Daily Mile: Acute Effects on Children's Cognitive Function and Factors Affecting their Enjoyment

6.1. Introduction

The Daily Mile is a school-based physical activity initiative that involves children completing ~1 mile (approximately 15–20 min) of outdoor, self-paced physical activity each day, typically consisting of laps of the school playground. Since its development in 2012, it has gained popularity and is now implemented in more than 13,900 schools in 86 countries (The Daily Mile, 2022b). The simple, inclusive and informal nature of The Daily Mile are thought to be key factors contributing to its popularity (Malden & Doi, 2019; Ryde et al., 2018). However, surprisingly little is known regarding the efficacy of The Daily Mile as a physical activity initiative (Fairhurst & Hotham, 2017). Whilst it has been suggested that The Daily Mile may be beneficial for children's health (Chesham et al., 2018), another commonly cited benefit of The Daily Mile is that it can enhance cognition. However, only two studies have explored the acute effects of participation in The Daily Mile on children's cognitive function, with contrasting findings. Specifically, Morris et al. (2019) demonstrated no effect of participation in The Daily Mile on executive function or Maths fluency, when compared to continued classroom activity. This study employed a between-subjects design however, and thus may have been confounded by inter-individual variability (e.g., due to differences in baseline cognition between the groups) (Williams et al., 2019). Additionally, Morris et al. (2019) utilised a relatively brief (30 s) and simple version of the Stroop test to assess executive function; whilst research suggests that more demanding cognitive tasks may be more sensitive to the beneficial effect of physical activity (Pontifex et al., 2019). It is thus possible that the brief Stroop test lacked sufficient cognitive demand to demonstrate any enhancements to executive function that may result from participation in The Daily Mile.

In contrast to the findings of Morris et al. (2019), Booth et al. (2020) reported that participation in The Daily Mile led to greater improvements in inhibitory control and verbal working memory, compared to both near exhaustive exercise and seated rest. Additionally, compared to near exhaustive exercise, The Daily Mile led to greater improvements in visuospatial memory. However, the research design involved remote data collection, meaning class teachers within each school administered the project. As noted by the authors, this approach to data collection may have impacted the order in which the physical activity and resting tasks were completed and the fidelity of, and adherence to, the tasks (Booth et al., 2020). Moreover, the three activities may have been administered at different times of day and the cognitive tests may have been administered at different times following each activity, with advice to teachers being to conduct the tests within 20 minutes of each activity. Literature demonstrates that significantly larger cognitive effects are observed following physical activity performed during the morning, when compared to physical activity performed in the afternoon; and that physical activity-induced effects to cognition are time sensitive, with enhancements to some domains presenting immediately and others after a delay (Chang et al., 2012). Therefore, a lack of control over experimental procedures may have influenced the results of the study.

The inconsistent findings of the limited studies in this area mean that policymakers and schools are currently implementing The Daily Mile without a full understanding of the acute effects on subsequent cognition in the classroom. Therefore, the primary aim of the research project is to examine the acute effects of participation in The Daily Mile on the cognitive domains of inhibitory control, cognitive flexibility and working memory. These executive functions are higher-order, self-regulatory cognitive processes (Carlson, 2005; Diamond, 2013). Consequently, executive functions are related to behaviour in the classroom (Riggs et al., 2003), and academic achievement (McPherson et al., 2018). Furthermore, evidence suggests that executive functions are malleable (Diamond & Lee, 2011) and can be influenced by physical activity (Drollette et al., 2012; Kamijo et al., 2011). Specifically, with regards to The

Daily Mile, whilst Booth et al. (2020) reported improvements to inhibitory control and working memory from acute participation in The Daily Mile, Morris et al. (2019) reported no effects to inhibitory control, cognitive flexibility or working memory. Therefore, the effect of The Daily Mile on these executive functions requires further examination, in order to make inferences regarding the effect of participation on children's cognition and, subsequently, academic performance.

Another important consideration in the implementation of The Daily Mile is how young people perceive participation in the initiative. While qualitative research on The Daily Mile is increasing, studies thus far have focused on the factors which influence implementation of the initiative (e.g., flexible delivery, creating the right physical environment), and have primarily examined the perceptions of school staff (Malden & Doi, 2019; Ryde et al., 2018). No studies have investigated whether young people enjoy participating in The Daily Mile, or the factors influencing their enjoyment. Understanding children's level of enjoyment in a physical activity is essential, as their level of enjoyment will influence the effort they invest in the activity (Diamond, 2012). Moreover, fostering enjoyment in physical activity during the formative years facilitates long-term motivation for, and engagement in, physical activity (Cardinal et al., 2013; Nasuti & Rhodes, 2013), thus promoting health and well-being. Furthermore, enjoyment of physical activity has been shown to predict fitness improvements in children aged between 8 and 10 years (Elbe et al., 2017). It is thus vital that physical activity research evaluates children's enjoyment of interventions, as it will inevitably influence their effectiveness.

Therefore, the aim of the present study was two-fold: to examine the acute effects of participation in The Daily Mile on inhibitory control, cognitive flexibility and working memory, and to explore children's perceptions and enjoyment of participating in The Daily Mile through focus groups.

6.2. Methods

6.2.1. Participants

A power calculation (G*Power version 3.1; Faul et al., 2007) with power = 0.95 and α = 0.05, specified a minimum sample size of *n* = 92 would be satisfactory to detect a small (*d* = 0.2) effect size, typical of work in this area (Booth et al., 2020; Cooper et al., 2018). A total of 104 (56 male, 48 female) primary school children aged 9–11 years participated in the study. Eighty-seven (54 male, 33 female) of the 104 participants took part in focus groups, with 14 focus groups conducted in total. The 17 participants who failed to attend the focus groups were unable to participate due to school commitments (e.g., choir practice). Participant characteristics are displayed in Table 6.1.

Table 6.1. Participant characteristics for the group overall, as well as for boys and girls separately. Data are mean ± SD.

	Overall (*n* = 104)	**Boys (*n* = 56)**	**Girls (*n* = 48)**	***p* value [a]**
Age (yrs)	10.4 ± 0.7	10.4 ± 0.7	10.4 ± 0.6	0.923
Height (cm)	143.3 ± 8.1	143.6 ± 7.6	142.9 ± 8.7	0.661
Body mass (kg)	36.1 ± 8.1	37.1 ± 8.7	34.9 ± 7.2	0.170
BMI ($kg{\cdot}m^{-2}$)	17.4 ± 2.6	17.8 ± 2.8	16.9 ± 2.1	0.084
BMI z-score	0.1 ± 1.1	0.3 ± 1.1	-0.2 ± 0.9	0.005
Maturity offset (yrs) [b]	-2.0 ± 0.8	-2.6 ± 0.5	-1.4 ± 0.7	2.967
Waist circumference (cm)	61.3 ± 7.1	61.8 ± 7.3	60.5 ± 6.7	0.423
Sum of skinfolds (mm)	54.2 ± 25.0	53.3 ± 27.7	55.5 ± 21.8	0.444
MSFT Distance (m)	760 ± 320	860 ± 380	660 ± 220	0.002

Note. [a] Independent samples t-test for comparison between boys and girls. [b] Calculated using the method of Moore et al. (2015).

6.2.2. Study Design

Following approval from the institution's ethical advisory committee, primary schools in the East Midlands, UK were contacted via email and invited to participate. In total, ~100 primary schools were contacted and 8 primary schools agreed to participate in the study. In those schools who agreed to participate, children from years five and six (9–11 y) were invited to participate in the study. The location of participating schools ranged from rural village to inner city, the schools varied in size (105–660 pupils) and distance from the University (5–25 km). Six schools were implementing The Daily Mile at the time of the study; the length of implementation at these schools ranged from 2–12 months. Two schools had never implemented the initiative. Headteacher consent was obtained, along with written informed consent and a health screen from parents/guardians of participating children. Additionally, participants provided their written assent to be involved in the study (section 3.2).

The study employed a within-subject randomised crossover counterbalanced design. The study involved a familiarisation trial which took place 7 days prior to the first experimental trial. Participants then completed two experimental trials (Physical Activity [The Daily Mile] and Control [Resting]), which were also separated by 7 days. During the familiarisation trial, the purpose and protocol of the study was explained to participants, with questions welcomed, and all participants had a practice of all study procedures (incl. battery of cognitive function tests and The Daily Mile). During familiarisation, participants also completed the MSFT to provide a valid and reliable measurement of cardiorespiratory fitness (section 3.8; Ramsbottom et al., 1988, Ruiz et al., 2011; Tomkinson et al., 2019a). Participants were assigned to a fitness group (higher fitness or lower fitness), based on distance covered (m) in the MSFT (Dring et al., 2019). Participants were split into higher and lower fitness groups, as opposed to fitness quartiles as used in Chapter V, for ease of interpretation of the three-way trial by time by fitness group analysis. This split was performed according to sex, resulting in an equal number of boys and girls within each fitness group. Moreover, during familiarisation anthropometric measures such as body mass and skinfolds were taken (section 3.7). The focus group was performed upon completion of the physical activity trial. Figure 6.1 presents the experimental protocol.

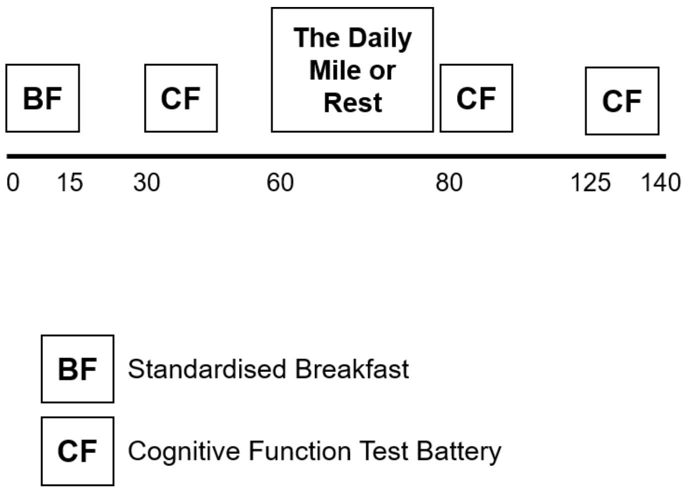

Figure 6.1. Experimental Protocol

6.2.3. Experimental Procedures and Measurements

6.2.3.1 Pre-trial Control

Prior to both experimental trials, participants followed pre-visit requirements regarding physical activity, dietary intake and caffeine consumption (section 3.4). Shortly following arrival, participants were provided with a standardised breakfast (section 3.5).

6.2.3.2. Physical Activity and Rest Protocol

The physical activity protocol consisted of The Daily Mile, which involved 20 minutes of self-paced activity completed outdoors (laps of the school playground or sports pitch), in groups of 5–16 participants (mean: 12 ± 3). While The Daily Mile was originally designed to be implemented for 15 min a day, many schools have focused on getting children to complete one mile a day, in line with the name. Based off the evidence gathered by our research group on physical activity in young people, we considered that 20 min would be necessary for children to cover one mile. The findings from Chapter V demonstrated that while the average distance covered during a 20 min Daily Mile was 1.5 miles, the distance covered by participants varied widely (1 – 2.5 miles) and it took the full 20 min for all children to complete one mile. A 20 min Daily Mile was thus utilised in this study to examine participants' enjoyment and the effects on cognitive function. Participants were encouraged by researchers to try their best but were able to choose their own pace (walk/jog/run/sprint) and whether to complete The Daily Mile alone or with peers. Participants wore normal school uniform with appropriate footwear. The physical activity protocol was designed to replicate The Daily Mile, as it is currently implemented in schools. During the resting trial (and at all times during the physical activity trial, with exception of the 20 min Daily Mile), participants sat in a classroom and conversed in a calm manner with their peers.

6.2.3.3. Cognitive Function Tests

The cognitive function test battery consisted of the Stroop test, Sternberg paradigm and the Flanker task (section 3.9). Participants completed these tests prior to, immediately following and 45 min following The Daily Mile and rest condition. Sixteen laptops were utilised to enable the participants within each group to complete the tests simultaneously. The tests were administered in line with the procedures described in section 3.9. For all tests, outcome measures were response time (ms) of correct responses (i.e. reaction time + movement time) and the percentage (%) of correct responses made.

6.2.3.4 Focus Groups

Focus groups were utilised to explore children's perceptions and enjoyment of participation in The Daily Mile within the study. Focus groups have previously been shown to be an effective method for gaining insight regarding the thoughts and perspectives of children (Gibson, 2007; Vaughn et al., 1996). A semi-structured guide, which included open-ended questions and prompts, enabled an exploration of children's experience of The Daily Mile through appropriate language (see appendix E) (Gibson, 2012; Greene & Hogan, 2005). To create a supportive and productive environment, the focus groups took place in a quiet classroom within the participants' school and involved groups of between 5–8 children, grouped by age (Kennedy et al., 2001; Sparkes & Smith, 2013). Two lead moderators and two assistant moderators were involved in data collection, with one lead and one assistant moderator of mixed sex in each focus group, as deemed appropriate for focus groups with children (Morgan et al., 2002). To ensure consistency in approach between moderators, a manual was produced and followed. The duration of the focus groups varied according to group size and lasted between 12–27 min (18 ± 4 min). This time frame is deemed sufficient to gain in-depth responses to questions and appropriate for ensuring that children's concentration is maintained (Vaughn et al., 1996).

6.2.4. Data Analysis

Cognitive function data was first attended to in the software R (section 3.10). Cognitive data were then analysed in SPSS (Version 24; SPSS Inc., Chicago, IL., USA). The assumptions required for each parametric test were examined prior to use; this included checking whether the data was normally distributed via the Shaprio-Wilk Test and whether the variances of the differences between the related groups were equal using Mauchly's sphericity test. The data was also checked to ensure there were no significant outliers. As all the assumptions were met, cognitive data were analysed using a two-way trial by time repeated measures ANOVA. Cohen's d effect sizes were calculated, in line with recommendations for quantifying the effectiveness of a pre-test post-test intervention (Dezron et al., 2005); effect sizes were interpreted as per convention: negligible effect (≥−0.15 and <.15), small effect (≥.15 and <.40), medium effect (≥.40 and <.75), large effect (≥.75 and <1.10), very large effect (≥1.10 and <1.45), and huge effect (>1.45). Subsequently, to examine the effect of sex and fitness on the physical activity-cognition relationship, three-way (trial by time by sex, and trial by time by fitness) repeated measures ANOVAs were conducted, with sex and fitness as between-subject factors; partial eta squared (η_p^2) effect sizes were calculated and interpreted as per convention (small = 0.01, medium = 0.06, and large = 0.14). Participants were assigned to high (top 50 % for each sex) and low (bottom 50% for each sex) fitness groups, based on distance covered in the MSFT. Data for each level of the cognitive tests were analysed separately, given that the different levels require different cognitive processes. Multiple comparisons were corrected for using a Bonferroni correction. In order to maintain the type 1 error rate (α) and level of significance at $p \leq 0.05$ (to support ease of interpretation), the *p* value from each relevant test was times by the number of comparisons (e.g., 3 for comparison between trials over time). This *p* value was then compared to the alpha level $p \leq 0.05$ to determine statistical significance. Cognitive data are presented as mean ± SEM.

All focus groups were audio recorded and transcribed verbatim, with 115 pages of transcript produced in total. The transcripts for each focus group were checked against the recordings to ensure accuracy. During transcription, the data was deidentified by using codes for each participant. Data were analysed using qualitative content analysis, with an inductive and semantic approach employed (Vaismoradi et al., 2013, 2016, 2019). This involved a rigorous and recursive process of immersing oneself in the data and obtaining the sense of the data as a whole (preparation phase), interpreting the content of the text through the systematic classification process of coding and identifying categories which represented similar meanings/patterns of communication (organising phase), and reporting the analysis process and results through categories and a story line (reporting phase) (Elo & Kyngas, 2008; Vaismoradi et al., 2013). Moreover, category development was influenced by the frequency of occurrence of a topic, which was important in relation to the research question, within the data, and included an intensive examination of language and meaning (Vaismoradi et al., 2016, 2019). This analysis method was deemed most appropriate due to its (post)positivist underpinning with the analysis seeking to develop categories which are truly representative of the perspectives of the participants (Braun & Clarke, 2020; Vaismoradi et al., 2013). Furthermore, this inductive analysis approach is valuable for exploratory work in an area where not much is known (Greene & Thorogood, 2004). To develop methodological rigor, a critical friend approach was adopted. This approach is not based on forming a consensus between colleagues regarding the data, but instead supports a rigorous interpretation of the results through group reflection and critical feedback, that is both plausible and defendable (Smith & McGannon, 2018).

6.3. Results

6.3.1. Cognitive Function

Response time and accuracy data at each time point, across the physical activity and resting trials, for each cognitive function test (including data split by sex and fitness) are displayed in Table 6.2.

6.3.1.1. Stroop Test

Response times, simple level. Overall, there was no difference in response times between the physical activity and resting trials (main effect of trial, p = 0.605). Moreover, the pattern of change in response times across the morning was similar between the physical activity and resting trials (trial by time interaction, p = 0.104). Overall, response times were faster in boys (881 ± 22 ms), compared to girls (968 ± 24 ms; main effect of sex, $F_{(1, 86)}$ = 6.0, p = 0.016, η_p^2 = 0.065). Response times were also faster in high-fit (885 ± 24 ms) compared to low-fit (978 ± 24 ms) participants (main effect of fitness, $F_{(1, 86)}$ = 7.8, p = 0.007, η_p^2 = 0.083). However, the effect of physical activity on response times was not influenced by sex or fitness (trial by time by sex interaction, p = 0.635; trial by time by fitness interaction, p = 0.738).

Response times, complex level. There was no difference in response times between physical activity and resting trials (main effect of trial, p = 0.520). However, response times tended to be slower immediately following physical activity compared to resting (trial by time interaction, $F_{(2, 186)}$ = 3.0, p = 0.057, d = 0.25, Figure 6.2). Response times were similar between boys and girls (main effect of sex, p = 0.120). Additionally, sex did not influence the effect of physical activity on response times (trial by time by sex interaction, p = 0.674). Response times were faster in the high-fit (1143 ± 32 ms), compared to low-fit (1283 ± 32 ms) group (main effect of fitness, $F_{(1, 86)}$ = 9.5, p = 0.003, η_p^2 = 0.100). However, fitness did not influence the effect of physical activity on response times (trial by time by fitness interaction, p = 0.484).

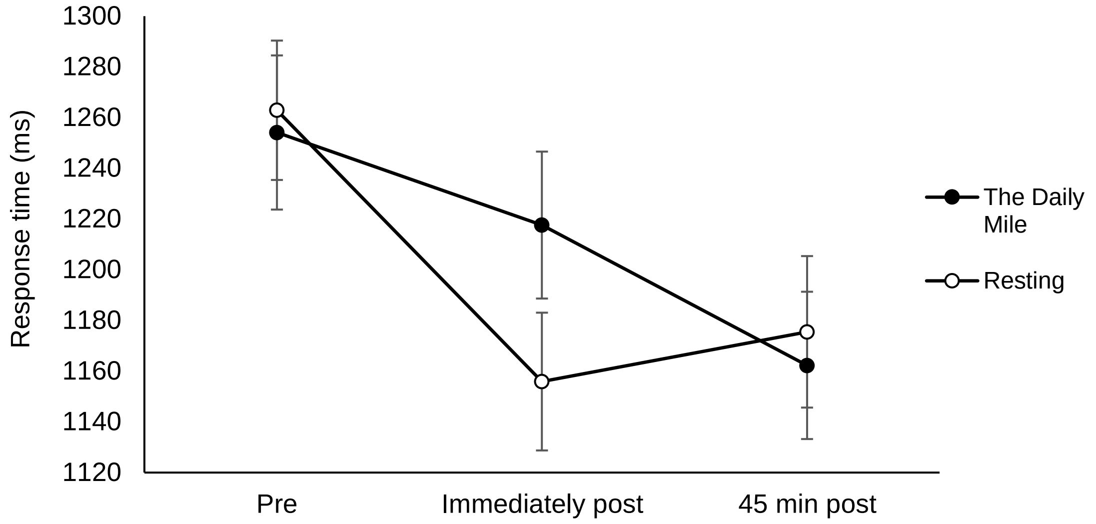

Figure 6.2. Response times (ms) across the morning on the complex level of the Stroop test, for physical activity (The Daily Mile) and resting (Control) trials (trial by time interaction, $p = 0.057$).

Accuracy, simple level. Overall, accuracy was similar between the physical activity and resting trials (main effect of trial, $p = 0.873$). Moreover, the pattern of change in accuracy across the morning was similar between physical activity and resting trials (trial by time interaction, $p = 0.406$). There was no difference in accuracy between the sexes or between fitness groups (main effect of sex, $p = 0.348$; main effect of fitness, $p = 0.951$). Furthermore, the effect of physical activity on accuracy was not influenced by sex or fitness (trial by time by sex interaction, $p = 0.357$; trial by time by fitness interaction, $p = 0.389$).

Table 6.2. Cognitive function across physical activity and rest trials for the whole sample and split by participant sex and fitness. Data are mean ± SEM.

Test	Level	Variable	Participant Group	Resting trial Pre	Resting trial Immediately post	Resting trial 45 min post	Physical Activity trial Pre	Physical Activity trial Immediately post	Physical Activity trial 45 min post	
Stroop test	Simple	Response time (ms)	Overall	952 ± 21	883 ± 22	915 ± 23	928 ± 22	923 ± 22	924 ± 22	
			Girls	1025 ± 31	914 ± 32	963 ± 35	980 ± 30	963 ± 34	963 ± 38	b
			Boys	890 ± 27	858 ± 30	875 ± 30	884 ± 30	889 ± 29	891 ± 25	
			Low Fit	1013 ± 35	956 ± 35	958 ± 33	982 ± 37	985 ± 33	975 ± 39	c
			High Fit	919 ± 24	833 ± 25	903 ± 34	887 ± 25	879 ± 31	888 ± 26	
		Accuracy (%)	Overall	97.2 ± 0.4	94.5 ± 0.8	93.8 ± 0.9	97.1 ± 0.4	95.2 ± 0.8	93.0 ± 0.8	
			Girls	98.6 ± 0.4	95.3 ± 1.0	94.3 ± 1.3	96.6 ± 0.7	95.2 ± 1.0	93.4 ± 1.3	
			Boys	96.0 ± 0.6	93.8 ± 1.2	93.4 ± 1.1	97.5 ± 0.6	95.2 ± 1.1	92.6 ± 1.1	
			Low Fit	96.8 ± 0.6	95.8 ± 0.9	94.0 ± 1.3	97.3 ± 0.6	95.5 ± 0.9	92.2 ± 1.5	
			High Fit	97.8 ± 0.5	93.4 ± 1.3	94.4 ± 1.1	96.9 ± 0.7	94.7 ± 1.3	93.9 ± 1.0	
	Complex	Response time (ms)	Overall	1263 ± 27	1156 ± 27	1176 ± 30	1254 ± 30	1218 ± 29	1162 ± 29	
			Girls	1306 ± 41	1214 ± 43	1228 ± 45	1291 ± 47	1256 ± 46	1165 ± 53	
			Boys	1227 ± 37	1107 ± 34	1131 ± 39	1223 ± 40	1185 ± 37	1160 ± 30	
			Low Fit	1335 ± 39	1246 ± 45	1261 ± 48	1332 ± 51	1290 ± 44	1235 ± 47	c
			High Fit	1215 ± 38	1081 ± 28	1128 ± 35	1185 ± 37	1159 ± 41	1090 ± 37	
		Accuracy (%)	Overall	93.7 ± 0.7	90.9 ± 0.8	91.5 ± 0.9	93.5 ± 0.7	92.6 ± 0.09	90.3 ± 1.0	
			Girls	95.1 ± 0.9	92.5 ± 1.3	92.8 ± 1.2	93.7 ± 0.9	92.9 ± 1.0	90.1 ± 1.8	
			Boys	92.5 ± 1.0	89.6 ± 1.3	90.4 ± 1.3	93.2 ± 0.9	92.4 ± 1.1	90.4 ± 1.2	
			Low Fit	93.2 ± 1.0	91.0 ± 1.5	91.8 ± 1.4	93.6 ± 0.9	92.8 ± 1.0	90.1 ± 1.8	
			High Fit	94.7 ± 0.9	91.1 ± 1.2	92.0 ± 1.2	93.6 ± 1.0	92.2 ± 1.3	90.1 ± 1.4	
Sternberg paradigm	One-item	Response time (ms)	Overall	644 ± 15	612 ± 16	603 ± 18	632 ± 15	619 ± 16	621 ± 16	
			Girls	676 ± 18	656 ± 26	623 ± 26	664 ± 25	660 ± 22	635 ± 26	b
			Boys	618 ± 22	577 ± 18	587 ± 25	606 ± 18	586 ± 23	610 ± 19	
			Low Fit	653 ± 19	627 ± 26	629 ± 23	648 ± 26	641 ± 24	656 ± 25	
			High Fit	646 ± 24	606 ± 21	596 ± 30	616 ± 17	612 ± 25	594 ± 22	
		Accuracy (%)	Overall	95.7 ± 0.6	91.9 ± 1.2	93.4 ± 1.0	95.1 ± 0.8	94.7 ± 0.8	93.7 ± 0.9	
			Girls	96.9 ± 0.7	93.0 ± 1.6	93.9 ± 1.5	95.2 ± 1.2	95.1 ± 1.1	93.6 ± 1.6	
			Boys	94.7 ± 0.9	91.0 ± 1.7	92.9 ± 1.4	95.0 ± 1.0	94.5 ± 1.2	93.8 ± 1.0	
			Low Fit	96.6 ± 0.7	91.1 ± 1.8	93.5 ± 1.3	94.7 ± 1.2	93.8 ± 1.3	93.8 ± 1.3	
			High Fit	95.6 ± 0.9	93.5 ± 1.6	94.9 ± 1.2	95.0 ± 1.1	95.2 ± 1.1	93.5 ± 1.3	
	Three-item	Response time (ms)	Overall	811 ± 16	803 ± 20	777 ± 19	832 ± 30	819 ± 18	803 ± 18	
			Girls	841 ± 18	781 ± 26	779 ± 25	810 ± 27	835 ± 26	804 ± 27	d
			Boys	786 ± 24	820 ± 29	776 ± 28	849 ± 50	806 ± 25	803 ± 24	

			Low Fit	828 ± 26	845 ± 36	826 ± 32	849 ± 31	871 ± 27	854 ± 27	c
			High Fit	803 ± 20	772 ± 19	746 ± 22	818 ± 56	782 ± 25	764 ± 25	
		Accuracy (%)	Overall	94.8 ± 1.2	92.6 ± 0.7	90.1 ± 0.9	93.8 ± 0.6	93.2 ± 0.8	91.3 ± 0.9	
			Girls	95.3 ± 0.8	93.2 ± 1.2	91.1 ± 1.3	94.0 ± 1.2	93.7 ± 0.9	91.4 ± 1.5	
			Boys	94.5 ± 0.9	92.1 ± 1.1	89.3 ± 1.3	93.6 ± 1.9	92.8 ± 1.0	91.2 ± 1.0	
			Low Fit	94.2 ± 1.0	91.8 ± 1.2	89.3 ± 1.5	95.4 ± 0.9	93.3 ± 0.9	91.1 ± 1.3	
			High Fit	95.7 ± 0.7	94.0 ± 0.7	91.7 ± 1.1	91.7 ± 2.3	92.8 ± 1.2	91.8 ± 1.1	
	Five-item	Response time (ms)	Overall	981 ± 23	932 ± 23	890 ± 24	990 ± 23	980 ± 25	939 ± 21	a
			Girls	981 ± 28	938 ± 33	877 ± 30	995 ± 34	959 ± 34	921 ± 35	
			Boys	982 ± 35	928 ± 33	901 ± 37	987 ± 30	997 ± 35	954 ± 25	
			Low Fit	1009 ± 40	959 ± 39	917 ± 42	1028 ± 36	1038 ± 41	959 ± 31	
			High Fit	966 ± 27	920 ± 27	878 ± 27	949 ± 30	924 ± 30	915 ± 31	
		Accuracy (%)	Overall	89.7 ± 1.1	84.3 ± 1.4	83.1 ± 1.4	89.2 ± 0.9	87.1 ± 1.3	84.9 ± 1.3	
			Girls	91.1 ± 1.4	84.9 ± 2.1	83.9 ± 2.0	89.4 ± 1.4	87.4 ± 1.8	85.6 ± 2.1	
			Boys	88.5 ± 1.7	83.8 ± 1.8	82.5 ± 1.9	89.1 ± 1.1	86.6 ± 1.8	84.3 ± 1.8	
			Low Fit	87.7 ± 1.9	82.2 ± 2.4	81.8 ± 2.5	89.3 ± 1.3	84.9 ± 2.0	84.7 ± 2.1	
			High Fit	91.3 ± 1.4	86.6 ± 1.5	85.7 ± 1.2	89.0 ± 1.3	88.6 ± 1.7	85.4 ± 1.8	
Flanker task	Congruent	Response time (ms)	Overall	657 ± 15	649 ± 15	630 ± 15	676 ± 15	662 ± 15	651 ± 14	
			Girls	701 ± 23	697 ± 24	665 ± 25	707 ± 24	678 ± 22	682 ± 23	b
			Boys	620 ± 18	609 ± 18	601 ± 18	649 ± 18	649 ± 21	626 ± 18	
			Low Fit	686 ± 21	701 ± 25	676 ± 21	711 ± 23	702 ± 23	693 ± 22	c
			High Fit	647 ± 21	612 ± 17	599 ± 22	643 ± 20	629 ± 20	611 ± 19	
		Accuracy (%)	Overall	97.5 ± 0.4	95.1 ± 0.8	95.5 ± 0.8	98.0 ± 0.3	97.5 ± 0.5	96.4 ± 0.6	a
			Girls	97.5 ± 0.5	95.6 ± 1.4	95.8 ± 1.1	98.3 ± 0.5	97.3 ± 0.8	96.1 ± 1.0	
			Boys	97.6 ± 0.5	94.7 ± 0.9	95.2 ± 1.0	97.7 ± 0.5	97.6 ± 0.4	96.7 ± 0.7	
			Low Fit	97.4 ± 0.5	94.7 ± 1.1	96.3 ± 0.9	98.6 ± 0.4	97.4 ± 0.6	96.1 ± 1.0	
			High Fit	97.8 ± 0.5	96.9 ± 0.5	95.4 ± 1.1	97.5 ± 0.6	97.4 ± 0.6	96.5 ± 0.8	
	Incongruent	Response time (ms)	Overall	715 ± 21	708 ± 20	676 ± 18	720 ± 16	714 ± 16	689 ± 16	
			Girls	771 ± 38	762 ± 34	707 ± 30	759 ± 29	739 ± 27	720 ± 24	b
			Boys	668 ± 21	664 ± 21	650 ± 20	688 ± 16	693 ± 20	664 ± 21	
			Low Fit	759 ± 34	766 ± 32	733 ± 27	772 ± 26	766 ± 23	733 ± 24	c
			High Fit	693 ± 25	671 ± 22	636 ± 23	675 ± 19	674 ± 23	651 ± 22	
		Accuracy (%)	Overall	92.4 ± 1.4	91.6 ± 1.0	92.6 ± 0.8	94.7 ± 0.6	93.6 ± 0.7	93.4 ± 0.8	a
			Girls	91.1 ± 2.9	92.0 ± 1.8	93.5 ± 1.2	95.5 ± 0.7	92.9 ± 1.1	93.0 ± 1.5	
			Boys	93.5 ± 1.0	91.3 ± 1.0	91.9 ± 1.1	94.0 ± 0.8	94.2 ± 0.8	93.7 ± 0.9	
			Low Fit	92.8 ± 1.8	91.4 ± 1.3	93.1 ± 0.9	95.1 ± 0.9	93.0 ± 1.1	93.5 ± 1.4	
			High Fit	92.0 ± 2.3	92.9 ± 1.4	93.0 ± 1.3	94.1 ± 0.8	93.9 ± 0.8	93.2 ± 1.0	

Note. [a] Main effect of trial. [b] Main effect of sex. [c] Main effect of fitness. [d] Trial by time by sex interaction.

Accuracy, complex level. There was no difference in accuracy between physical activity and resting trials (main effect of trial, p = 0.885). However, accuracy tended to be higher immediately following physical activity compared to resting, but this did not reach statistical significance (trial by time interaction, $F_{(2, 186)}$ = 3.0, p = 0.057, d = 0.31, Figure 6.3). There was no difference in accuracy between the sexes or between the fitness groups (main effect of sex p = 0.205; main effect of fitness, p = 0.871). Moreover, the effect of physical activity on accuracy was not influenced by sex or fitness (trial by time by sex interaction, p = 0.972; trial by time by fitness interaction, p = 0.891).

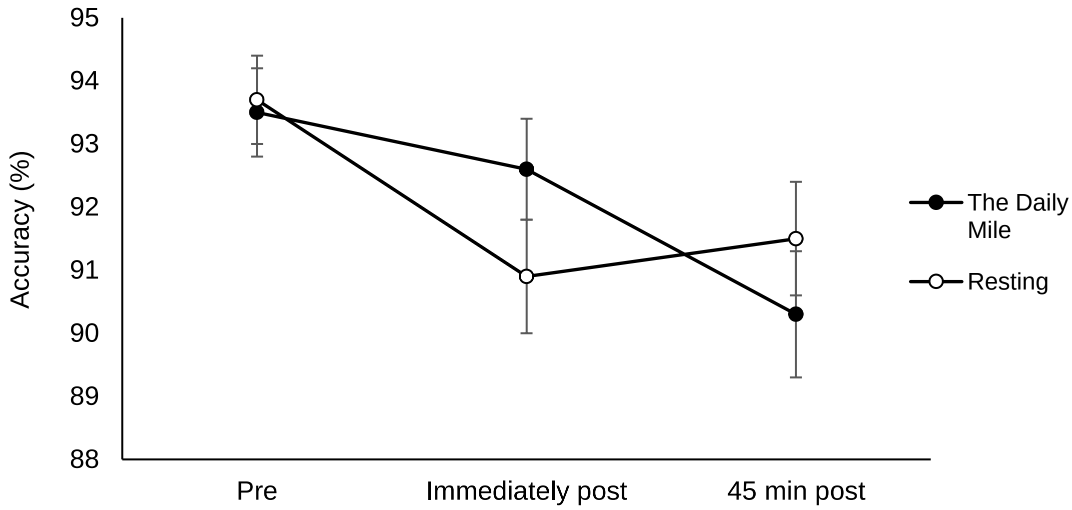

Figure 6.3. Accuracy across the morning on the complex level of the Stroop test, for physical activity (The Daily Mile) and resting (Control) trials (trial by time interaction, p = 0.057).

6.3.1.2. Sternberg Paradigm

Response times, one-item level. Overall, there was no difference in response times between physical activity and resting trials (main effect of trial, p = 0.661). There was also no difference in the pattern of change in response times across the morning between trials (trial by time interaction, p = 0.430). Boys (597 ± 14 ms) had faster response times compared to girls (652 ± 16 ms; main effect of sex, $F_{(1, 86)}$ = 4.9, p = 0.030, η_p^2 = 0.053). However, the effect of physical activity on response times was not influenced by sex (trial by time by sex interaction, p = 0.967). Moreover, there was no difference in response times between fitness groups, and fitness did not influence the effect of physical activity on response times (main effect of fitness, $p = 0.185$; trial by time by fitness interaction, $p = 0.888$).

Response times, three-item level. There was no difference in response times between physical activity and resting trials (main effect of trial, $p = 0.143$). There was also no difference in the pattern of change across the morning between trials (trial by time interaction, $p = 0.914$). There was no difference in response times between boys and girls (main effect of sex, $p = 0.952$). However, sex influenced the effect of physical activity on response times (trial by time by sex interaction, $F_{(1, 86)} = 4.0$, $p = 0.027$, $\eta_p^2 = 0.042$). Specifically, there was a significant trial by time interaction for girls ($F_{(2, 80)} = 4.3$, $p = 0.017$, $\eta_p^2 = 0.097$), but not for boys ($p = 0.317$), whereby girls' response times got slower immediately following The Daily Mile and faster following resting (Figure 6.4). The high-fit group (845 ± 22 ms) presented faster response times compared to the low-fit group (781 ± 22 ms; main effect of fitness, $F_{(1, 86)} = 4.3$, $p = 0.041$, $\eta_p^2 = 0.048$). However, the effect of physical activity on response times was not influenced by fitness (trial by time by fitness interaction, $p = 0.974$).

Response times, five-item level. Response times were slower during the physical activity (972 ± 19 ms) compared to resting (937 ± 20 ms) trial (main effect of trial, $F_{(1, 92)} = 4.9$, $p = 0.030$, $\eta_p^2 = 0.050$). However, the pattern of change in response times across the morning was similar between the physical activity and resting trials (trial by time interaction, $p = 0.314$). There was no difference in response times between the sexes or between fitness groups (main effect of sex, $p = 0.728$; main effect of fitness, $p = 0.119$). Moreover, neither sex nor fitness influenced the effect of physical activity on response times (trial by time by sex interaction, $p = 0.615$; trial by time by fitness interaction, $p = 0.540$).

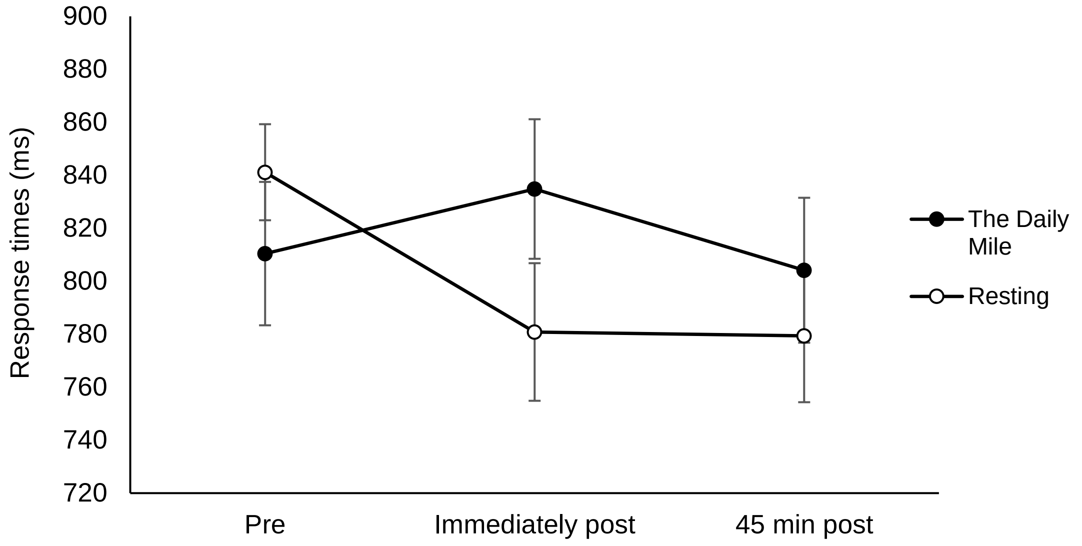

Figure 6.4. Girls' response times (ms) across the morning on the three-item level of Sternberg paradigm for physical activity (The Daily Mile) and resting (Control) trials (trial by time interaction, p = 0.017).

Accuracy, one-item level. Overall, accuracy was similar between physical activity and resting trials (main effect of trial, p = 0.235). Accuracy tended to be higher immediately following physical activity compared to rest, but statistical significance was not met (trial by time interaction, $F_{(2, 186)}$ = 2.7, p = 0.073, d = 0.61, Figure 6.5). There was no difference in accuracy between the sexes or between fitness groups (main effect of sex, p = 0.376; main effect of fitness, p = 0.529). Moreover, the effect of physical activity on accuracy was not influenced by sex or fitness (trial by time by sex interaction, p = 0.972; trial by time by fitness interaction, p = 0.627).

Accuracy, three-item level. There was no difference in accuracy between physical activity and resting trials (main effect of trial, p = 0.700). Moreover, the pattern of change in accuracy across the morning was similar between the physical activity and resting trials (trial by time interaction, p = 0.283). There was no difference in accuracy between the sexes or between fitness groups (main effect of sex, p = 0.426; main effect of fitness, p = 0.175). Furthermore, the effect of physical activity on accuracy was not influenced by sex or fitness (trial by time by sex interaction, p = 0.860; trial by time by fitness interaction, p = 0.484).

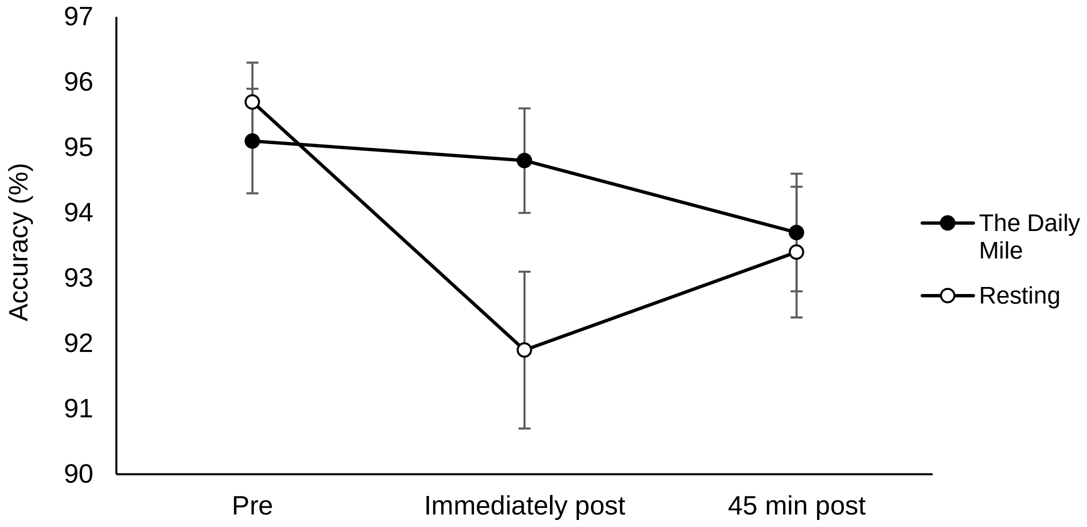

Figure 6.5. Accuracy across the morning on the one-item level of Sternberg paradigm, for physical activity (The Daily Mile) and resting (Control) trials (trial by time interaction, p = 0.073).

Accuracy, five-item level. Accuracy tended to be higher during the physical activity (87.1 ± 0.9 %), compared to the resting (85.7 ± 1.1 %) trial, however this did not reach statistical significance (main effect of trial, $F_{(1, 93)} = 2.8$, $p = 0.099$, $\eta_p^2 = 0.029$). Moreover, there was no difference in the pattern of change in accuracy across the morning between the physical activity and resting trials (trial by time interaction, p = 0.119). There was no difference in accuracy between the sexes or between fitness groups (main effect of sex, p = 0.524; main effect of fitness, p = 0.179). Moreover, the effect of physical activity on accuracy was not influenced by sex or fitness (trial by time by sex interaction, p = 0.722; trial by time by fitness interaction, p = 0.601).

6.3.1.3. Flanker Task

Response times, congruent level. There was no difference in response times between the physical activity and resting trials (main effect of trial, p = 0.980). There was also no difference in the pattern of change in response times across the morning between trials (trial by time interaction, p = 0.865). Response times were faster in boys (626 ± 16 ms) compared to girls (688 ± 18 ms; main effect of sex, $F_{(1, 91)} = 7.0$, $p = 0.010$, $\eta_p^2 = 0.071$). Response times were also faster in high-fit (624 ± 17 ms) compared to low-fit (690 ± 17 ms) participants (main effect of fitness, $F_{(1, 88)} = 7.8$, $p = 0.006$, $\eta_p^2 = 0.082$). However, the effect of physical activity on response times was not influenced by sex or fitness (trial by time by sex interaction, p = 0.474; trial by time by fitness interaction, p = 0.326).

Response times, incongruent level. There was no difference in response times between physical activity and resting trials (main effect of trial, p = 0.537). Moreover, there was no difference in the pattern of change across the morning between the trials (trial by time interaction, p = 0.881). Response times were faster in boys (671 ± 19 ms) compared to girls (743 ± 21 ms; main effect of sex, $F_{(1, 91)} = 6.2$, $p = 0.015$, $\eta_p^2 = 0.063$). Response times were also faster in high-fit (666 ± 21 ms) compared to low-fit (755 ± 21 ms) participants (main effect of fitness, $F_{(1, 86)} = 9.2$, $p = 0.003$, $\eta_p^2 = 0.096$). However, the effect of physical activity on response times was not influenced by sex or fitness (trial by time by sex interaction, p = 0.387; trial by time by fitness interaction, p = 0.437).

Accuracy, congruent level. Accuracy was higher on the physical activity (97.3 ± 0.3 %) compared to resting (96.0 ± 0.5 %) trial (main effect of trial, $F_{(1, 92)} = 6.7$, $p = 0.011$, $\eta_p^2 = 0.068$). However, the pattern of change in accuracy across the morning was similar between physical activity and resting trials (trial by time interaction, p = 0.202). There was no difference in accuracy between sexes or between fitness groups (main effect of sex, p = 0.784; main effect of fitness, p = 0.796). Moreover, the effect of physical activity on accuracy was not influenced by sex or fitness (trial by time by sex interaction, p = 0.578; trial by time by fitness interaction, p = 0.217).

Accuracy, incongruent level. Accuracy was higher on the physical activity (93.9 ± 0.5 %) compared to resting (92.2 ± 0.8 %) trial (main effect of trial, $F_{(1, 92)} = 5.3$, $p = 0.023$, $\eta_p^2 = 0.055$). However, there was no difference in the pattern of change across the morning between physical activity and resting trials (trial by time interaction, p = 0.529). There was no difference in accuracy between sexes or between fitness groups (main effect of sex, p = 0.937; main effect of fitness, p = 0.973). Moreover, the effect of physical activity on accuracy was not influenced by sex or fitness (trial by time by sex interaction, $p = 0.070$; trial by time by fitness interaction, $p = 0.976$).

6.3.2. Focus Groups

Participants highlighted a number of factors which shaped their perception and enjoyment of The Daily Mile. Specifically, six categories were developed: enjoyment of the core components of The Daily Mile, valued social context, perceived benefits from participation, perceived/actual physical activity ability influences enjoyment of The Daily Mile, weather preferences influence enjoyment of The Daily Mile, and how The Daily Mile could be improved (Table 6.3). Illustrative quotes are presented in the table and text, with a focus within the text on sub-categories which were most prevalent in the focus groups and/or most significant in terms of their impact on participants.

6.3.2.1. Enjoyment of the Core Components of The Daily Mile

This category refers to specific features of The Daily Mile initiative that were fundamental to children's enjoyment of it. Within this category, four sub-categories were developed: The Daily Mile supports desire for regular physical activity, children enjoy running, being physically active outside is desirable, and self-paced nature promotes autonomy (Table 6.3).

6.3.2.1.1. The Daily Mile supports desire for regular physical activity

Participants expressed a desire to be more physically active in school and noted that The Daily Mile provides an opportunity for regular physical activity. Consequently, children voiced positive feelings towards the initiative being introduced or continued in their school.

6.3.2.1.2. Being physically active outside is desirable

Almost all participants emphasised their enjoyment of being outside while engaging in physical activity. Participants frequently mentioned that when inside they feel "claustrophobic" (participant 31) and discussed the satisfaction gained from having space, fresh air and being closer to nature when participating in The Daily Mile outside: "It gives you fresh air and also…you're nearer to nature and it makes you more engrossed in what you are trying to do" (participant 24). One participant noted that it felt healthier as a result of this: "it's...healthier because you're getting fresh air and oxygen" (participant 55).

6.3.2.1.3. Self-paced nature promotes autonomy

The majority of participants confirmed that they enjoyed the self-paced nature of The Daily Mile, with many explaining that this was the most significant factor in their enjoyment of The Daily Mile as a physical activity intervention. Participants appreciated that The Daily Mile enabled them to have autonomy over their physical activity intensity: "I think it was good, because you get to choose, because instead of making us run the whole thing round, like jog, you could get your breath and you could have a chance to walk and then get your energy back" (participant 14). Moreover, participants acknowledged that everyone has different physical abilities and that The Daily Mile facilitated an environment where they could each feel comfortable exercising to their own. "Some people run faster than others, and some people will want to stop and start a bit, if they go too far they might want to slow down" (participant 33).

Table 6.3. Higher-order and sub-categories representing factors affecting participants' perceptions and enjoyment of The Daily Mile, with exemplar quotes.

Higher-order category	Sub-category	Quotes
Enjoyment of the core components of The Daily Mile	The Daily Mile supports desire for regular physical activity	"I did enjoy it because it's more exercise" (participant 92)
	Children enjoy running	"I enjoyed it because I really like running" (participant 10)
	Being physically active outside is desirable	"I enjoyed it, I liked it being outside because we had more space than inside, and it was fresh air" (participant 33)
	Self-paced nature promotes autonomy	"Even though I kind of struggle…I could always walk a little bit and…the sporty people can just go around and around and around" (participant 26)
Valued social context	Engaging with peers is fun	"It was quite fun because you can run around with your friends"(participant 2)
	Peers provide distraction from physical activity demands	"I liked how you could talk, because I was talking and didn't notice how I walked so far" (participant 19)
	Peers provide motivation & support	"If you're feeling tired, your friends can motivate you, so you can keep going." (participant 29)
Perceived benefits from participation	Perceived benefits to health	"I like it because…everyone can go and get fit and they'll be good at sport" (participant 105)
	Perceived benefits to learning	"I like The Daily Mile because it...can help you concentrate quite a lot" (participant 42)
Perceived/actual physical ability influences enjoyment of The Daily Mile		"I don't really enjoy it, because it tires me out quite a lot and it's hard" (participant 41) "I liked it…it got really tiring, but it was still fun." (participant 32)
Weather preferences influence enjoyment of The Daily Mile		"it depends how hot it is outside. If it's really warm, I don't think I will enjoy it, but if it's cool I'm going to enjoy it more." (participant 43)
How The Daily Mile could be improved	Children desire variety within physical activity	"I did enjoy it because it's more exercise but I didn't enjoy it 'cause it's a bit boring, you just run around a simple track for 20 minutes, but we could, like, put some obstacles in it" (participant 92)
	Potential for a discretionary competitive element	"It would be nice to run around with our friends and also, like, challenge yourself and race other people" (participant 96)

6.3.2.2. Valued Social Context

Although it is a characteristic of The Daily Mile initiative, the social context is considered as a higher-order category here, as participants discussed extensively the social context (i.e., the opportunity to walk/jog/run alone and/or with others) when asked what they enjoyed about participating in The Daily Mile. Accordingly, three sub-categories were developed, which represent the main reasons behind their enjoyment of the social context: engaging with peers is fun, peers provide distraction from physical activity demands, and peers provide motivation and support (Table 6.3).

6.3.2.2.1. Engaging with peers is fun

Participants discussed that being able to complete The Daily Mile with peers was fun (Table 6.3). Some participants explained that part of the 'fun' was being able to chat with classmates/friends, with The Daily Mile fostering informal social interaction which is not feasible during other types of physical activity, such as team sports: "In a sport...you might have to have a serious chat with someone, like, say, dodge this or there's someone else there, but with The Daily Mile, you just have the chance to talk and not to worry about anything else" (participant 14).

6.3.2.2.2. Peers provide distraction from physical activity demands

Several participants explained that they felt the social context was a good distraction from the demands of the physical activity: "I think that was good, because if you were struggling, then it takes your mind off things" (participant 15). "I think it's good because you're distracted, you're not really focusing on actually running" (participant 31).

6.3.2.3. Perceived Benefits from Participation

This category highlights participant's perceptions of the benefits that can be gained from participating in The Daily Mile. Within this category, two sub-categories were developed: perceived benefits to health and perceived benefits to learning (Table 6.3).

6.3.2.3.1 Perceived benefits to learning

Many participants, when asked what they enjoyed about The Daily Mile, suggested the benefits that can be gained from participation. For example, several children expressed that participation in The Daily Mile provides a much needed “brain break” (participant 93) during lessons, and that this benefits subsequent concentration and learning: “It’s quite good to be outside, instead of being in a room all the time for the whole morning and, as well, it makes people concentrate on their work more” (participant 30). “I like it because...it helps you learn” (participant 105).

6.3.2.4. Perceived/Actual Physical Ability Influences Enjoyment of The Daily Mile

Perceived and/or actual physical ability (e.g., fitness) played a key role in determining participant’s feelings towards The Daily Mile initiative. For example, while several participants expressed that they would happily extend the duration of The Daily Mile as it would enable them to challenge themselves, other participants expressed that they would not be capable of exercising for longer, with a few suggesting that The Daily Mile should be shorter because it is too tiring. Moreover, many participants recognised that participating in The Daily Mile regularly would improve their ability and fitness: “If we did do it every day, this is a good thing. We’ll get more used to it and then get better at it” (participant 18). However, others portrayed a lack of enthusiasm and confidence in ability: “I don’t want to do it every day because like you might get tired, like your body might start aching” (participant 10). For a few participants, perceived/actual physical ability ultimately determined the level of enjoyment they experienced during participation in The Daily Mile: “I don’t really enjoy it, because it tires me out quite a lot and it’s hard” (participant 41) and “I liked it…it got really tiring, but it was still fun” (participant 32).

6.3.2.5. Weather Preferences Influence Enjoyment of The Daily Mile

Although many participants noted that they would enjoy participating in The Daily Mile in any weather conditions, some participants’ enjoyment of The Daily Mile was largely influenced by the weather during participation: “I didn’t like it ‘cause it was cold but...if it wasn’t, if it was warmer I would have” (participant 87). For some participants, these preferences influenced their feelings regarding other aspects of the initiative. For example, a few participants stated that they felt The Daily Mile was too long in duration, however when discussing why they felt this way, participants frequently noted the weather i.e., that the conditions were too hot/too cold: “I didn’t like the amount of time because if it’s outside and it’s cold then you get cold really easily” (participant 92).

6.3.2.6. How The Daily Mile could be Improved

This category refers to suggestions from participants of ways in which The Daily Mile could be improved in order to enhance enjoyment in participation. Two sub-categories were developed: children desire variety within physical activity and potential for a discretionary competitive element.

6.3.2.6.1. Children desire variety within physical activity

When asked, some participants confirmed that there were other types of physical activity (e.g., athletics, circuits, team sports) that they would prefer to do regularly in school. These participants explained that although they find running enjoyable, they prefer physical activity that involves a variety of activities. Consequently, they found The Daily Mile to be repetitive: “It was a bit boring. You’re not really doing anything you’re just running” (participant 102). From further discussion, it was discovered that almost all participants expressed a preference for variety within physical activity and a desire to participate in activities that incorporate running as well as other physical activity components regularly at school. Gaining agreement from the other participants in the focus group, one participant suggested incorporating other components into The Daily Mile: “I did enjoy it because it’s more exercise, but I didn’t enjoy it ‘cause it’s a bit boring, you just run around a simple track for 20 minutes, but we could, like, put some obstacles in it” (participant 92).

6.3.2.6.2. Potential for a discretionary competitive element

A few participants suggested incorporating a competitive element into The Daily Mile. They felt that it's enjoyable to challenge themselves and that competition can provide a good distraction from physical activity demands: "It would be nice to run around with our friends and also, like, challenge yourself and race other people" (participant 96). However, some participants highlighted that they already participate in competitive sports at school and thus enjoy having the opportunity to participate in an activity that is non-competitive: "I prefer not competitive...because our school...we do other competitive stuff whereas it's nice after you're doing lessons just to have a chat. 'Cause sometimes when you get back to your class you can be really tired from trying really hard" (participant 105).

6.4. Discussion

Overall, the findings of the present study show that The Daily Mile did not significantly affect subsequent cognition, compared to resting. However, there was a tendency for improved accuracy on tasks of inhibitory control and visual working memory immediately following participation in The Daily Mile. Moreover, another key finding of the present study was that boys displayed faster response times than girls on the simple level of all cognitive tests, and high fit participants displayed faster response times than low fit participants on both the simple and complex levels of cognitive tests. During the focus groups, participants reported positive perceptions of The Daily Mile and the self-paced, social nature and outdoor location were considered particularly enjoyable components. The findings of the present study provide some clarity to the limited and ambiguous evidence regarding the acute effects of The Daily Mile on children's cognition. Furthermore, this study has enabled novel understanding of the factors which influence children's enjoyment of The Daily Mile.

The present study is the first crossover, order-balanced, randomised control trial to examine the acute effects of The Daily Mile on children's cognition. The results from the sample as a whole demonstrate that The Daily Mile does not significantly affect immediate or delayed (45 min) cognition, across the domains of inhibitory control, cognitive flexibility, and visual working memory. There was, however, a tendency towards improved accuracy on the one-item level of the Sternberg paradigm (visual working memory) and the complex level of the Stroop test (inhibitory control) immediately following The Daily Mile, compared to rest. This was coupled with a tendency for slower response times on the complex level of the Stroop test, suggesting that children tended to be slower but more accurate in inhibitory control and working memory tasks following The Daily Mile. The effect size of these trends were small-to-medium (d = 0.25–0.61), though small effect sizes are typical within physical activity-cognition literature (e.g. Booth et al., 2020; Cooper et al., 2018; Ludyga et al., 2016; Verburgh et al., 2014).

Interestingly, Booth et al. (2020) reported significant improvements in working memory following participation in The Daily Mile, compared to rest. According to Baddeley and Hitch's (1974) model, working memory is comprised of the visuo-spatial sketchpad, which processes visual/spatial information, and the phonological loop, which processes auditory/verbal information. The present study measured visual working memory using the Sternberg paradigm test, tapping into the visuo-spatial sketchpad, while Booth et al. (2020) measured verbal working memory using the reading span task, activating the phonological loop. The discrepancy between the findings of the present study and Booth et al.'s (2020) may thus be, in part, due to the specific type of working memory assessed. However, Morris et al. (2019) utilised the digit recall test, which similarly taps the phonological loop component of working memory and found no effect of The Daily Mile. Moreover, Booth et al. (2020) also observed enhanced inhibitory control following The Daily Mile, while Morris et al. (2019) did not, suggesting that other factors, such as the timing of the cognitive testing, may be responsible for the difference in results between the studies. In Booth et al.'s (2020) study, teachers were instructed to administer cognitive measurements within 20 min of The Daily Mile; whereas the cognitive tasks in the present study, and in the study by Morris et al. (2019), were completed within 5 min of completion of The Daily Mile. Physical activity-induced effects on cognition are both domain and time sensitive, with enhancements to some domains presenting immediately and others presenting after a delay (Williams et al., 2019). The different effects of The Daily Mile on cognitive function observed between these studies could, therefore, be due to the time at which the cognitive tasks were administered following participation. The present study extends previous work by reporting no effects of The Daily Mile on children's cognition 45 min following participation. However, it must also be noted that The Daily Mile did not have any negative effects on subsequent cognition, which coupled with the previously reported benefits on physical activity (Chesham et al., 2018) and fitness (de Jonge et al., 2020), still suggests that The Daily Mile is an effective school-based physical activity intervention.

In the present study, boys presented faster response times than girls on the simple levels of all cognitive tasks, with a small ($\eta_p^2 < 0.06$; Sternberg paradigm test) to medium ($\eta_p^2 < 0.14$; Stroop and Flanker test) sized effect. Interestingly, however, there were no differences in performance between sexes on the complex levels of the Stroop or Sternberg paradigm tests, which elicit higher cognitive demands. Similar findings have been reported in previous research with both children and adults, demonstrating that males, compared to females, are consistently faster on simple, but not complex, reaction time tasks (Dykiert et al., 2012). Additionally, there was no effect of sex on the cognitive responses to physical activity, with the exception of the three-item level of Sternberg paradigm whereby girls' response times got slower following physical activity and got quicker following resting. However, this effect was not observed on the one-item or five-item level of the test, nor did sex influence the effect of The Daily Mile on inhibitory control or cognitive flexibility; in line with previous findings across cognitive domains (Booth et al., 2020).

Moreover, in the current study participants with a higher cardiorespiratory fitness presented faster response times on both the simple and complex levels of the Stroop test and Flanker task, and on the three-item level of Sternberg paradigm. Effect sizes ranged from small ($\eta_p^2 < 0.06$; Sternberg paradigm test) to medium ($\eta_p^2 < 0.14$; Stroop and Flanker test). These findings likely represent the effect of chronic physical activity participation on cognition, a relationship supported by the literature (Hillman et al., 2011; Ludyga et al., 2020). It would, therefore, be valuable for future research to explore whether effects to cognition are gained with chronic participation in The Daily Mile, particularly as chronic physical activity interventions which improve young people's fitness lead to improvements in cognitive function (Xue et al., 2019) and improvements to cardiorespiratory fitness are observed following 12 weeks of participation in The Daily Mile (de Jonge et al., 2020). However, the findings of the present study suggest that the cognitive effects of acute participation in The Daily Mile are similar for young people of all fitness levels, which is in line with previous research on The Daily Mile (Booth et al., 2020). Interestingly, these findings are in contrast to a number of studies within the wider physical activity-cognition literature, which suggest that young people with high cardiorespiratory fitness gain greater post-physical activity enhancements to cognitive function (Cooper et al., 2018; Jäger et al., 2015). The contrast in findings may be due to the fact that The Daily Mile is a self-paced activity and has been shown to elicit a similar relative physical activity intensity in children of all fitness levels (Chapter V); thus participation in The Daily Mile is more likely to produce similar cognitive responses in children of differing fitness levels than physical activity of a set absolute intensity, which is likely to elicit varying relative intensity between participants and thus varying cognitive responses.

The present study is the first to investigate the specific factors which influence children's enjoyment of participating in The Daily Mile. The findings respond to the need for evidence regarding children's enjoyment of physical activity initiatives, which is essential not only for engagement in the initiative but for the development of positive perceptions of physical activity and thus life-long physical activity participation (Cardinal et al., 2013; Humbert et al., 2008). Overall, participants expressed positive feelings towards the core principles of The Daily Mile and a desire to participate in The Daily Mile regularly at school. In particular, children found participation in The Daily Mile enjoyable due to its social context, outdoor location and self-paced nature. These findings support previous research which has recognised children's value of social connections during physical activity (Harris et al., 2019; Kinder et al., 2019) and extend upon them by detailing the factors which promoted an enjoyable social context during

The Daily Mile; specifically, the informal environment which enabled fun, supportive and motivational interactions while exercising. Moreover, the findings of the present study demonstrate that children enjoyed the self-paced nature of The Daily Mile as it enabled them to have choice over their physical activity intensity and thus engage according to their own ability. Together these findings suggest that The Daily Mile facilitates social relatedness and autonomy which, according to Self Determination Theory (Ryan & Deci, 2002), are fundamental psychological needs that when satisfied promote internal motivation for long-term physical activity participation (Sebire et al., 2013). Therefore, for most children participation in The Daily Mile is likely to elicit long-term engagement in the initiative and promote positive perceptions and motivations towards physical activity more generally.

Importantly, however, children expressed a desire for variety in the physical activity they engage in at school and a few children reported feeling bored during The Daily Mile due to its repetitive nature. This is of some concern, given that boredom during physical activity is cited as a primary reason for young people not wanting to participate in physical activity in school (Department for Education, 2013). Moreover, some children suggested that The Daily Mile could be made more enjoyable by incorporating other activities and/or a competitive element. Similarly, teachers implementing The Daily Mile report that some children are motivated by competition and seek it during The Daily Mile (Harris et al., 2019). Therefore, future research could consider making minor modifications to The Daily Mile (e.g., introducing discretionary competitive elements and/or opportunities to vary the nature of activity) and investigate how these affect children's enjoyment and effects to cognition and health.

Among the many strengths of this study are its robust design and control of variables (e.g., dietary intake) which have the potential to impact the physical activity-cognition relationship (Cooper et al., 2011, 2015; Hoyland et al., 2009), and yet have not been controlled in previous Daily Mile-cognition research. It is important to note that the present study utilised a testing protocol where both congruent and incongruent trials were incorporated into one stage; participants were thus required to switch between trials during the test, requiring cognitive flexibility. However, other approaches to measuring cognitive flexibility (or 'shifting') are sometimes used, such as calculating the difference in performance between the congruent and incongruent trials or a three-stage Flanker, which incorporates an additional rule for the final stage (Egger et al., 2018; Jäger et al., 2015). The findings of this study, with regards to cognitive flexibility, should thus be interpreted with this in mind. A potential limitation of the present study is that the effects of acute participation in The Daily Mile on cognition were only examined up to 45 min following participation; and thus the effects across the remainder of the school day, for example, remain unknown. Additionally, the majority of the schools were implementing The Daily Mile at the time of participation in the study. While the length of implementation at these schools ranged from 2 to 12 months, prior engagement will have impacted the novelty of the physical activity, and thus may have influenced children's perceptions of it (e.g., whether they found it boring or repetitive). Children were instructed, however, to comment exclusively on their experience of participating in The Daily Mile within the study, and not on their experiences of the initiative more generally. Nevertheless, the focus group data should be interpreted with this in mind. Moreover, as with all studies of this nature, it is possible that the schools that agreed to participate in the study are not representative of all schools; with a possibility being that schools who are more active were more likely to participate. However, anecdotally, this was not the case in the present study and is partly supported by the fact that two of the schools had never previously implemented The Daily Mile. Additionally, although children were asked to refrain from exercise 24 h prior to each trial, transport to school was not controlled or measured. Furthermore, due to logistical challenges and the number of children who volunteered to participate within each school, group sizes during participation in The Daily Mile were smaller (5–16 children) than they typically are when The Daily Mile is implemented in school. Children's activity patterns and/or enjoyment may differ when participating in larger groups (e.g., whole class), thus the results of this study should be interpreted with this in mind.

Future research could expand on this study, and other qualitative work on The Daily Mile, by examining how teacher and pupil perceptions of the initiative interact to influence implementation success, as teacher's perceptions of physical activity interventions can impact pupil's perceptions, and vice versa (Marchant et al., 2020; McMullen et al., 2014). Furthermore, future research should seek to examine the chronic effects of participation in The Daily Mile on children's cognition, which remain unknown.

6.5. Conclusion

This is the first within-subjects, counterbalanced, randomised control trial to explore the acute effect of The Daily Mile on cognition in children. The findings demonstrate that The Daily Mile has no significant effect on inhibitory control, cognitive flexibility or visual working memory measured immediately or 45 min post physical activity. However, there was a tendency for children to be more accurate immediately following The Daily Mile on a simple visual working memory and complex inhibitory control task. Another key finding was that children enjoyed participating in The Daily Mile, particularly due to its social context and self-paced nature; although some children reported feeling bored due to its repetitiveness. Future research should examine the exact time course of any changes in cognition following acute participation in The Daily Mile; alongside considering the effects of chronic participation in The Daily Mile. Furthermore, future research could examine the effect of a modified Daily Mile, which includes a discretionary competitive element, for example, on children's enjoyment of the initiative, which is important for long-term adherence and any subsequent benefits for cognition and health.

6.6. Practical Recommendations

The Daily Mile is an enjoyable physical activity for children. This means children are likely to present internal motivation to participate and adhere to the activity, and to engage in physical activity more generally. There was a tendency for cognitive benefits immediately following The Daily Mile, however these were not significant. Therefore, The Daily Mile should be implemented as part of a comprehensive whole school approach to physical activity. The initiative should be implemented alongside other formal and informal opportunities for physical activity in school across the school day, and not as an alternative to physical education or break time.

Chapter VII

The Daily Mile: Effects of Five and a Half Weeks of Participation on Children's Cognition, Cardiorespiratory Fitness and Body Composition

7.1. Introduction

It is necessary to understand the impact of chronic participation in The Daily Mile on children's cognitive function, including inhibitory control, executive function and working memory, as these cognitive processes are linked to learning (Diamond, 2013), behaviour in the classroom (Riggs et al., 2004) and academic achievement (McPherson et al., 2018). Moreover, better inhibitory control in childhood is linked to higher income and better physical and mental health in adulthood, including higher ratings of happiness, improved weight management, fewer diseases (e.g., hypertension) and lower incidence of substance abuse problems (Moffitt et al., 2011). Preliminary research on the effects of The Daily Mile on children's cognitive function has focused on the acute impact of participation in a single bout of The Daily Mile, and has reported contradictory findings. Specifically, while two studies reported no effect to cognitive outcomes such as attention, inhibitory control, working memory or executive function (Chapter VI; Morris et al., 2019), one study observed enhancements to both inhibitory control and verbal working memory following acute participation in The Daily Mile, compared to resting (Booth et al., 2020). However, given that The Daily Mile initiative is designed to be implemented daily and over time (e.g., a school term or year), it is important that the effects of chronic participation in the intervention be evaluated. Importantly, no study to date has examined the chronic effects of participation in The Daily Mile on cognition in children.

Interestingly, an after-school exercise training intervention named FITKids (Fitness Improves Thinking in Kids), has been found to enhance children's cognitive function (Hillman et al., 2014). Specifically, the training programme, which involved 36 weeks of ≥ 70 min per day of intermittent MVPA on 5 days per week, improved inhibitory control and cognitive flexibility (Hillman et al., 2014). Children in the intervention group, compared to the waitlist control group, demonstrated a greater pre- to post-test improvement in allocation of attentional resources (increased P3 amplitude) and performance accuracy on the complex levels of the Flanker task (inhibitory control) and colour-shape switch task (cognitive flexibility). This was coupled with a greater pre- to post-test improvement in cardiorespiratory fitness ($\dot{V}O_{2peak}$ measured by incremental treadmill running to volitional exhaustion) and a smaller pre- to post-test increase in BMI (Hillman et al., 2014). The wider physical activity-cognition literature thus suggests that improvements in children's cognition are possible from chronic physical activity training interventions.

To date, the few studies to investigate the effect of chronic participation in The Daily Mile have focused on body composition (e.g., BMI, adiposity) and cardiorespiratory fitness outcomes. Specifically, Chesham et al. (2018) explored the effects of participation in The Daily Mile for 28 weeks on distance covered in the 20-metre multistage fitness test and reported a ~40 m increase, suggesting improved cardiorespiratory fitness (Chesham et al., 2018). Moreover, distance covered in the six-minute run test was reported to increase by 69.6 m following participation in The Daily Mile (3 days per week for 24 weeks; Brustio et al., 2020). However, improvements in cardiorespiratory fitness have also been observed following shorter intervention durations. Participation in The Daily Mile for 3 days per week for 12 weeks, for example, has been shown to improve the level reached in the 18-metre shuttle run test by 1.1 levels (de Jonge et al., 2020) and distance covered in the six- minute run test by 25.2 m (Brustio et al., 2019). These findings are pertinent given that enhanced cardiorespiratory fitness is associated with improved cardiometabolic health in young people, as evidenced by higher blood concentrations of anti-inflammatory cytokine IL-10, and lower blood concentrations of pro-inflammatory cytokines IL-6 and IL-1β (Dring et al., 2019); and lower fasted blood cholesterol concentration, fasted blood glucose concentration and systolic and diastolic blood pressure (Ruiz et al., 2014).

Additionally, enhanced cardiorespiratory fitness is associated with enhanced performance across a number of cognitive domains in young people, including attention

(Páez-Maldonado et al., 2020), information processing (van der Niet et al., 2014), inhibitory control (Hillman et al., 2009), working memory (Kao et al., 2017) and cognitive flexibility (Pontifex et al., 2014). Cardiorespiratory fitness is also considered a key moderator in the acute physical activity-cognition relationship (Chang et al., 2012; Pontifex et al., 2019), as young people with higher cardiorespiratory fitness are reported to gain greater cognitive benefits following physical activity (Cooper et al., 2018; Hogan et al., 2013; Jäger et al., 2015). Thus, chronic participation in The Daily Mile may lead to improvements in children's cognition directly and/or indirectly through improved cardiorespiratory fitness. However, this has not yet been examined through primary research. Moreover, additional research is needed to elucidate when changes in cardiorespiratory fitness emerge during chronic participation in The Daily Mile, and whether improvements can be gained with shorter durations of participation (e.g., < 12 weeks), as this is currently unknown.

Furthermore, it is not yet possible to infer the chronic effects of The Daily Mile on children's body composition; this is partly because the limited literature to date has adopted inconsistent outcome measures, but also because a seminal study (Chesham et al., 2018) has been criticised for aspects of its intervention design in a correspondence published by the same academic journal (Daly-Smith et al., 2019). Specifically, in the original study the intervention group and control group participated in the intervention at different times of year and for different durations (intervention group: October–May, 28 weeks; control group: March–June, 12 weeks); this was suggested to have created unequal dose-response conditions and opportunities for benefits between the two groups due to the impact of seasonality on the outcome measures. For example, adiposity is generally higher, and fitness lower, following the school summer holidays (Shepard & Aoyagi, 2009), creating a greater opportunity for improvement in the intervention group as baseline measures were taken in October. However, in a responding correspondence the authors of the original study argued that, having corrected for sex and age on the day of testing, the variables were independent of time, thus accounting for any differences in dose. Nonetheless, the findings of the study indicated that 7 months of participation in The Daily Mile can result in a 1.4 mm reduction in sum of four skinfolds (triceps, biceps, iliac crest and subscapular). Moreover, participation in The Daily Mile over a 12-month period has also been reported to attenuate the increase in BMI z-scores observed within the population over this time in girls (Brenhey et al., 2020). Furthermore, while one study reported no effects to BMI from 12 or 24 weeks of participation in The Daily Mile, it was only completed 2–3 days per week (Brustio et al., 2020). It is possible that reductions in BMI and other body composition outcomes may be observed from shorter durations if participation occurs daily (5 days per week), as the initiative is intended (The Daily Mile, 2022c). However, no research to date has examined the effect of *daily* participation in The Daily Mile for less than 12 weeks on body composition.

The present study therefore aims to examine the effects of participation in The Daily Mile over five and a half weeks on children's cognitive function, across a range of domains (attention, inhibitory control, working memory and cognitive flexibility). Furthermore, a secondary aim of the present study is to examine the effects of five and a half weeks of daily participation in The Daily Mile on cardiorespiratory fitness (distance covered on the 20-metre MSFT) and body composition (body mass, BMI, BMI z-score, waist circumference, waist-to-hip ratio and sum of skinfolds).

7.2. Methods

7.2.1. Study Design

The Nottingham Trent University Human Ethics Committee approved the study, which employed a quasi-experimental, parallel group, controlled, pre-test post-test design. Participants from one primary school in Nottinghamshire, UK, were split into an intervention group (The Daily Mile intervention) and a control group. The study consisted of four data collection visits (Figure 7.2A). The first visit was a familiarisation trial. The second visit was a baseline trial, which took place two-weeks following the familiarisation trial. The intervention group then completed The Daily Mile intervention, whereas the control group continued with their normal daily school routines, for five and a half weeks. The third visit involved a mid-intervention trial, which took place halfway through the intervention period (week 3) and was only attended by the intervention group. The final visit was a follow-up trial, which was carried out 24 h following the five and a half week intervention. All participants attended the familiarisation, baseline and follow-up visits. The study took place over a nine-week period, during the school summer term (May–July 2021).

7.2.2. Participants

A power calculation (G*Power version 3.1; Faul et al., 2007) with power = 0.95 and α = 0.05, specified a minimum sample size of *n* = 52 would be satisfactory to detect a small (*d* = 0.20) effect size, typical of work in this area (Booth et al., 2020; Chesham et al., 2018; Cooper et al., 2018). To account for potential dropouts within the study an additional 20% was added to the n number to ensure the study would have adequate power. Therefore, the target number of participants for the study was ~ 62.

All children from years five and six (*n* = 93) of a local primary school were invited to participate in the study. Consent from the Headteacher of the primary school was obtained in advance of the study. Following which, written parental consent and child assent was obtained prior to enrolment in the study, along with a health screen, which was completed by the parent/guardian on behalf of the child (section 3.2). Consequently, 71 children (76% of eligible pupils), across three classes, were recruited to participate. Due to logistics, participants were split by class into an intervention group (2 classes, *n* = 50) and a control group (1 class, *n* = 21). The postcodes of consented participants were provided by the school; these were used to calculate relative deprivation and area-level socioeconomic status for each group using the 2019 English Index of Multiple deprivation and Income Deprivation Affecting Children Index (National statistics, Ministry of Housing, Communities & Local Government, 2019). Specifically, postcodes were entered into an online tool (http://dclgapps.communities.gov.uk/imd/iod_index.html, accessed: 10/08/21), which provided the corresponding deprivation decile (1 = most deprived, 10 = least deprived). Furthermore, the number of children from each group receiving free school meals was provided by the school. This was used to calculate pupil premium, as an additional measure of socioeconomic status. Figure 7.1 demonstrates participants' flow through the study including the number of participants and reasons for loss to follow-up. Thirty-five participants completed the study (intervention group *n* = 17, control group *n* = 18). A summary of baseline participant characteristics is presented in Table 7.1.

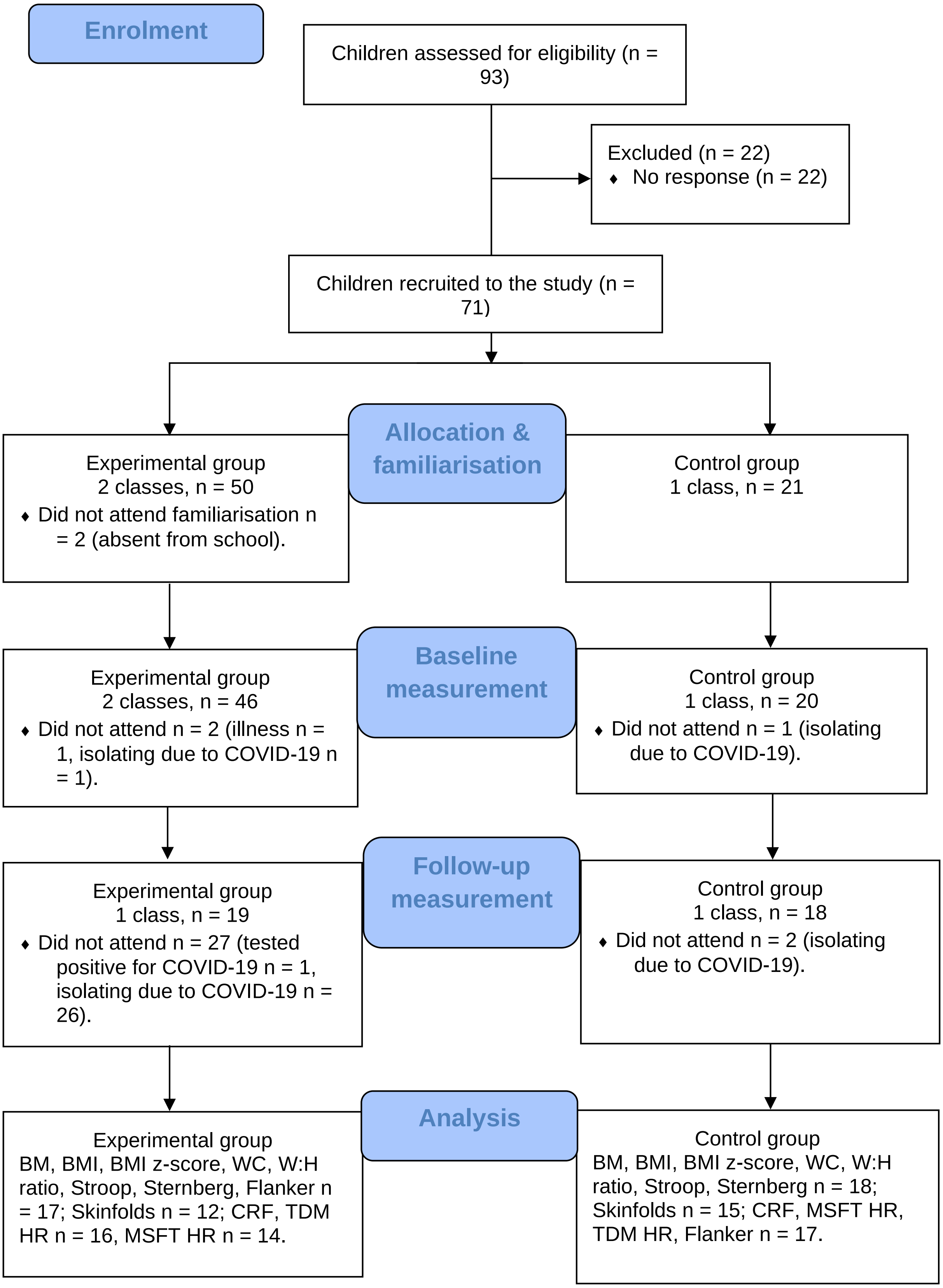

Figure 7.1. CONSORT 2010 flow diagram representing participants and study design. *Note.* BM: Body Mass, BMI: Body Mass Index. WC: Waist Circumference. W:H: Waist-to-Hip ratio. CRF: Cardiorespiratory Fitness. TDM: The Daily Mile. MSFT: Multi-Stage Fitness Test. HR: Heart Rate.

Table 7.1. Descriptive summary of baseline participant characteristics for the final sample (*n* = 35), reported as the whole sample, intervention, and control group.

	Overall (*n* = 35)	**Intervention group (*n* = 17)**	**Control group (*n* = 18)**	***p* value [a]**
Age (y)	11.1 ± 0.5	10.8 ± 0.6	11.3 ± 0.3	0.009
Girls (%)	49	47	50	0.867
Year group (%)				
Year 5	20	41	0	
Year 6	80	59	100	
Maturity offset (y) [b]	-1.29 ± 0.80	-1.32 ± 0.86	-1.26 ± 0.76	0.823
Height (cm)	151.2 ± 5.7	151.3 ± 6.1	151.1 ± 5.5	0.917
Body mass (kg)	43.2 ± 8.8	42.6 ± 8.7	43.7 ± 9.0	0.695
BMI ($kg \cdot m^{-2}$)	18.8 ± 3.1	18.5 ± 3.3	19.0 ± 2.9	0.647
BMI z-score	0.45 ± 1.14	0.38 ± 1.25	0.52 ± 1.06	0.709
Waist circumference (cm)	66.3 ± 8.1	65.8 ± 8.5	66.7 ± 7.9	0.724
Hip circumference (cm)	82.1 ± 7.5	81.2 ± 7.7	82.8 ± 7.4	0.544
Waist-to-hip ratio	0.79 ± 0.10	0.81 ± 0.05	0.77 ± 0.13	0.278
Sum of skinfolds (mm)	55.1 ± 23.3	50.8 ± 23.9	58.5 ± 23.1	0.405
CRF (distance in MSFT)	818 ± 364	801 ± 227	835 ± 438	0.796
Multiple Index of Deprivation [c]	7.9 ± 1.2	8.0 ± 1.2	7.8 ± 1.2	0.594
Income Deprivation Affecting Children Index [c]	6.9 ± 1.6	6.9 ± 1.5	6.9 ± 1.6	0.995
Pupil premium (%) [d]	6.0	6.0	6.0	

Note. CRF: Cardiorespiratory fitness. MSFT: Multi-stage fitness test. [a] Comparison between boys and girls. [b] Calculated using the method of Moore et al. (2015). [c] Calculated according to National statistics, Ministry of Housing, communities & local government, 2019 data; 1 = most deprived, 10 = least deprived. [d] pupil premium: percentage of children receiving free school meals, as a measure of socioeconomic status

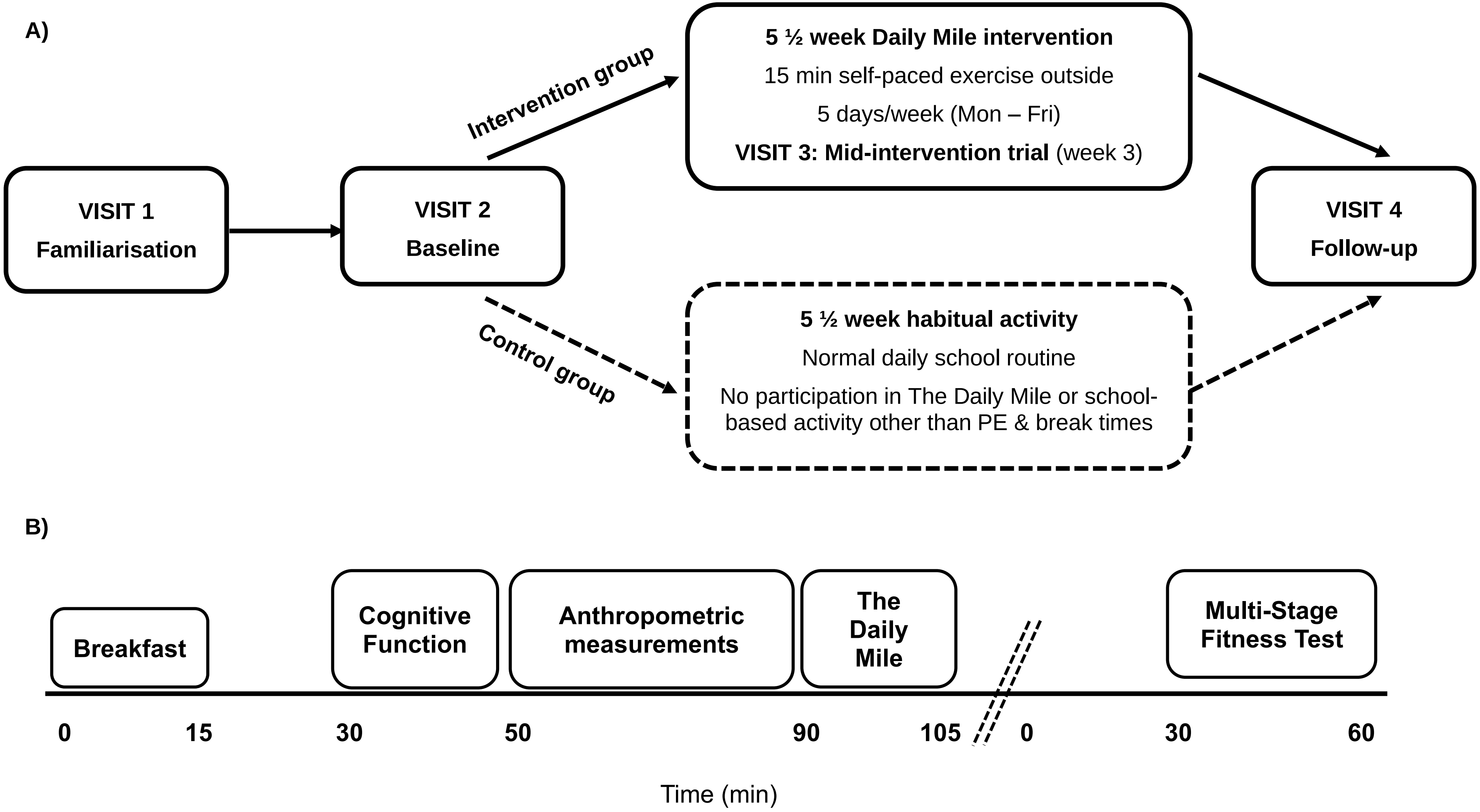

Figure 7.2. (A) Schematic representation of the overall study design. **(B)** Visual representation of the timeline of measurements during experimental visits two (baseline) and four (follow-up).

7.2.3. Experimental visits

7.2.3.1. Visit One: Familiarisation

During the familiarisation, participants were introduced to all procedures involved in the study. This included The Daily Mile and the cognitive function tests, which were practiced by participants twice in order to minimise any potential learning effects.

7.2.3.2. Visits Two and Three: Baseline and Follow-up Trials

Prior to the baseline and follow-up trials, participants followed pre-visit requirements regarding dietary intake, physical activity and caffeine consumption (section 3.4). Shortly following arrival, participants were provided with a standardised breakfast (section 3.5). Participants completed the cognitive function tests (which lasted ~ 10–15 min) 30 min following the start of breakfast. Following this, participants underwent anthropometric measurements of body mass, waist circumference, hip circumference and skinfolds. Precisely 90 min following breakfast (45 min following the cessation of cognitive function tests), participants completed The Daily Mile, which lasted 15 min. Moreover, participants completed the MSFT on a separate morning (< 48 h from the aforementioned measurements), to mitigate any detriment to physical performance that may have resulted due to fatigue from prior participation in The Daily Mile (Figure 7.2B).

7.2.4. The Daily Mile

Since its development, many schools have implemented a Daily Mile which focuses on getting children to cover one mile each day. More recently, however, there has been a shift in focus towards a Daily Mile which involves children exercising for 15 min each day, to align with the original design of The Daily Mile. A 15 min Daily Mile was thus utilised in this study so that the results would have practical implications for schools currently implementing The Daily Mile. The Daily Mile involved 15 min of informal, self-paced (walk, jog or run), outdoor physical activity around a pre-defined route (The Daily Mile, 2022a). The Daily Mile is designed to be completed during curriculum time (not tagged onto break, lunch or PE) and in almost all weathers, with participants wearing normal school uniform with appropriate footwear and outerwear (The Daily Mile, 2022c). The Daily Mie is intended as a daily activity, with each school teacher being responsible for administering it with their class (The Daily Mile, 2022c). The headteacher and the two class teachers of the participants within the intervention group were provided with information regarding the core principles of The Daily Mile (described above) and guidance regarding its implementation; teachers were also directed to The Daily Mile website (https://thedailymile.co.uk/) for further resources and support. Confirmation of full understanding of the Daily Mile intervention process was gained from teachers prior to commencing the intervention.

The fidelity of the intervention group to the five and a half-week Daily Mile intervention was assessed using teacher implementation logs. The class teachers of the two intervention groups completed a daily checklist indicating which days The Daily Mile was completed and which participants completed The Daily Mile on each occasion. If the class and/or a participant did not complete The Daily Mile on any given day, information regarding why was requested on the teacher implementation log. Fidelity (number of days completed / number of days available for implementation * 100; %) was recorded for each participant, as well as for the intervention group overall.

7.2.5. Control Group

During the five and a half-week intervention period, participants in the control group continued with their normal school routine. They did not participate in The Daily Mile, or in any other physical activity initiatives, during this time. No additional physical activity was undertaken during school hours, outside of normal physical education lessons and break/ lunchtime activities.

7.2.6. Experimental Procedures and Measurements

7.2.6.1. Anthropometric and Body Composition Measurements

Anthropometric measurements of height, body mass, waist circumference and hip circumference were conducted (section 3.7). Height and body mass were used to calculate BMI (section 3.7.3). Moreover, BMI z-scores were calculated using the LMS Growth Microsoft Excel add-in (Pan & Cole, 2011) and based on age and sex-specific British 1990 growth reference data (Cole et al., 1995; section 3.7.3). Waist and hip circumference were used to determine waist-to-hip ratio (section 3.7.4). Furthermore, skinfold measurements were taken from the triceps, subscapular, supraspinale and font thigh (section 3.7.5). The same researcher completed each participant's baseline and follow-up measurement, to minimise any inter-individual variability in measurement between researchers. Body mass (kg), BMI ($kg \cdot m^{-2}$), BMI z-score, waist circumference (cm), waist-to-hip ratio and sum of skinfolds (mm) were recorded at baseline for comparison to follow-up. Age, height and sitting height were used to calculate maturity offset at baseline, using methods described previously (Moore et al., 2015; section 3.7.2).

7.2.6.2. Cardiorespiratory Fitness

Cardiorespiratory fitness was assessed using the MSFT (Ramsbottom et al., 1988; section 3.8). Performance on the test, and thus cardiorespiratory fitness, was determined by the total distance covered (m) during the test.

7.2.6.3. Performance in The Daily Mile

Participants' average and peak heart rate during participation in The Daily Mile at baseline, mid-intervention (intervention group only) and follow-up trials was recorded (section 3.6.1). Subsequently, average and peak relative intensity ($\%HR_{max}$) during The Daily Mile was calculated, using maximum heart rate (HR_{max}) achieved during the MSFT. Additionally, participants' activity patterns during The Daily Mile at baseline, mid-intervention (intervention group only) and follow-up trials were measured using GPS (section 3.6.2). Specifically, total distance covered (m), distance covered within age-specific speed zones (m) and number of speed zone entries were recorded over the whole 15 min, and within each 5 min split of The Daily Mile.

7.2.6.4. Cognitive Function

The cognitive function test battery consisted of the Stroop test, Sternberg paradigm and the Flanker task, which were administered in line with the methods described in section 3.9.1. Twenty-eight laptops were used to enable the participants within each group to complete the tests simultaneously. Outcome measures for all tests were response time (ms) of correct responses (i.e., reaction time + movement time) and the percentage (%) of correct responses made.

7.2.7. Statistical Analysis

Initially, cognitive data were attended to in the open-source software, R (www.r-project.org; section 3.10). Statistical analyses were then performed using SPSS (Version 24; SPSS Inc., Chicago, IL., USA). Analysis of covariance (ANCOVA) was used for all outcome variables, to examine the between group (intervention vs. control) differences at follow-up, while controlling for the baseline score (covariate) of that outcome. The assumptions for an ANCOVA, such as normality, homogeneity and linearity, were tested and met prior to use. This approach is considered most appropriate and is recommended for experimental designs such as the one used in the present study (Hecksteden et al., 2018; Ritz, 2020). Cohen's d effect sizes were calculated, as recommended for quantifying the effectiveness of a pre-test post-test intervention (Dezron et al., 2005); effect sizes were interpreted as per convention: negligible effect (≥−0.15 and <.15), small effect (≥.15 and <.40), medium effect (≥.40 and <.75), large effect (≥.75 and <1.10), very large effect (≥1.10 and <1.45), and huge effect (>1.45). For each comparison, the mean difference and associated 95% confidence interval (CI) are presented. Additionally, the mean ± SD at follow-up for each group is presented, as well as the adjusted means and 95% CI, for all variables. Statistical significance was accepted as $p \leq 0.05$.

7.3. Results

7.3.1. Intervention Fidelity

All but four participants from the intervention group completed The Daily Mile every school day (5 days per week) for five and a half weeks, totalling 28 days of participation and 100% fidelity. The four participants that did not participate in all 28 days failed to do so due to being absent from school with illness. The number of days missed by these four participants ranged from 2–11 days and thus fidelity in these participants ranged from 61–93%. Average fidelity of the intervention group as a whole, including the participants who were not able to attend every session, was 27 ± 4 days, which is equal to 95 ± 13 %.

7.3.2. Differences in Body Composition

There was no statistically significant difference between the intervention and control group at follow-up in body mass, BMI z-score, waist circumference, waist-to-hip ratio or sum of skinfolds (all $p > 0.05$). There was a statistically significant difference in BMI between the intervention group and control group at follow-up ($F_{(1, 32)} = 6.5$, $p = 0.016$, d = 0.10; Figure 7.3). Specifically, BMI was lower in the intervention group (18.7 $kg \cdot m^{-2}$, 95% CI [18.5 $kg \cdot m^{-2}$, 18.8 $kg \cdot m^{-2}$]), compared to the control group (19.0 $kg \cdot m^{-2}$, 95% CI [18.8 $kg \cdot m^{-2}$, 19.1 $kg \cdot m^{-2}$]) at follow-up.

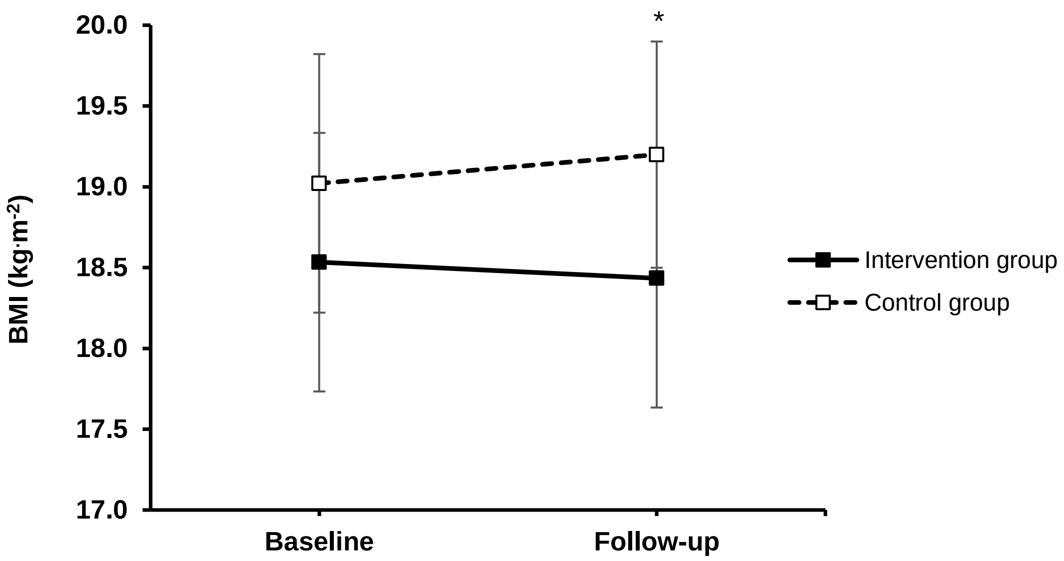

Figure 7.3. Mean (± SE) BMI ($kg \cdot m^{-2}$) at baseline and follow-up for the intervention group (solid line) and control group (dashed line). * Significant difference at follow-up, $p = 0.016$.

7.3.3. Differences in Multi-Stage Fitness Test Performance

There was no statistically significant difference between the intervention and control group at follow-up in distance covered on the MSFT (p = 0.249). However, there was a tendency for peak heart rate during the MSFT to be higher in the intervention group (205 beats·min^{-1}, [202 beats·min^{-1}, 208 beats·min^{-1}]), compared to the control group (201 beats·min^{-1}, [198 beats·min^{-1}, 203 beats·min^{-1}]), at follow-up ($F_{(1, 28)}$ = 4.2, p = 0.051, d = 0.73; Figure 7.4).

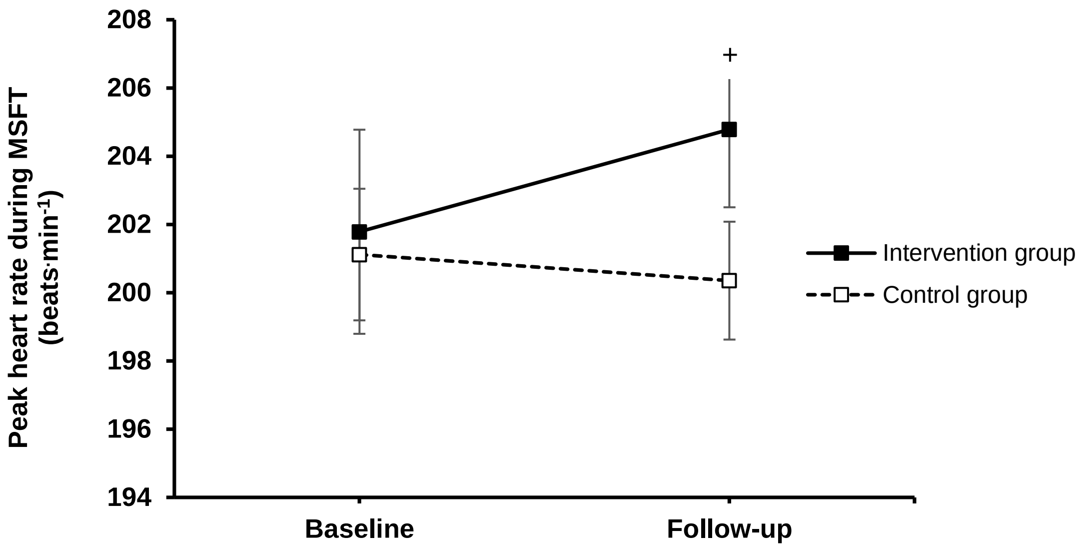

Figure 7.4. Mean (± SE) peak heart rate during the MSFT (beats.min^{-1}) at baseline and follow-up for the intervention group (solid line) and control group (dashed line). $^{+}$ Tendency for a difference at follow-up, p = 0.051.

Table 7.2. Baseline and follow-up results of anthropometric, cardiorespiratory fitness and performance outcomes, with data presented as mean ± SD. Follow-up and between-group differences adjusted for baseline results are also presented as mean ± 95% CI.

Outcome	**Intervention group**			**Control group**			**Adjusted Between-Group Difference Mean (95% CI)** [a b] ***[p value]***
	Baseline (Mean ± SD)	*Follow-Up (Mean ± SD)*	*Adjusted Follow-Up Mean (95% CI)* [a]	*Baseline (Mean ± SD)*	*Follow-Up (Mean ± SD)*	*Adjusted Follow-Up Mean (95% CI)* [a]	
Body mass (kg)	42.6 ± 8.7	42.9 ± 8.8	43.6 (43.2, 43.9)	43.7 ± 9.0	44.2 ± 9.3	43.6 (43.3, 43.9)	-0.0 (-0.4, 0.4) [p = 0.991]
BMI ($kg \cdot m^{-2}$)	18.5 ± 3.3	18.4 ± 3.3	18.7 (18.5, 18.8)	19.0 ± 2.9	19.2 ± 3.0	19.0 (18.8, 19.1)	-0.3 (-0.5, -0.1) **[p = 0.016]***
BMI z-score	0.38 ± 1.25	0.31 ± 1.26	0.39 (0.32, 0.45)	0.52 ± 1.06	0.54 ± 1.10	0.47 (0.41, 0.54)	-0.09 (-0.18, 0.01) [p = 0.067]
Waist circumference (cm)	65.8 ± 8.5	66.1 ± 8.2	66.6 (65.9, 67.3)	66.7 ± 7.9	66.5 ± 7.6	66.1 (65.4, 66.8)	0.5 (-0.5, 1.5) [p = 0.329]
Waist-to-hip ratio	0.81 ± 0.05	0.81 ± 0.05	0.81 (0.79, 0.83)	0.77 ± 0.13	0.80 ± 0.03	0.79 (0.78, 0.82)	0.02 (-0.01, 0.04) [p = 0.302]
Sum of skinfolds (mm)	50.8 ± 23.9	56.0 ± 33.0	60.7 (54.1, 67.4)	58.5 ± 23.1	61.5 ± 24.1	57.7 (51.7, 63.6)	3.1 (-5.9, 12.0) [p = 0.482]
Distance in MSFT (m)	800 ± 280	840 ± 310	860 (760, 960)	840 ± 440	800 ± 420	780 (680, 880)	80 (-59, 219) [p = 0.249]
Peak HR in MSFT ($beats \cdot min^{-1}$)	202 ± 11	205 ± 9	205 (202, 208)	201 ± 8	200 ± 7	201 (198, 203)	4 (-0, 8) **[p = 0.051]$^+$**

Abbreviations: SD; Standard Deviation. CI; Confidence Interval. BMI; Body Mass Index. MSFT; Multi-Stage Fitness Test. [a] Adjusted for baseline score. [b] Mean difference intervention group relative to control group. * Statistically significant difference between groups at follow-up, $p < 0.05$. $^+$ tendency for a difference at follow-up, $p < 0.10$.

7.3.4. Activity Patterns during The Daily Mile

Due to a technical issue with the GPS units, no activity pattern data was recorded at follow-up. Any differences in the activity patterns of participants in the intervention and control group during The Daily Mile post-intervention are thus unknown.

7.3.5. Heart Rate during The Daily Mile

There was a statistically significant difference in average heart rate during The Daily Mile ($F_{(1, 30)} = 4.8$, $p = 0.037$, d = 1.19; Figure 7.5) between the intervention and control group at follow-up, whereby the intervention group (166 beats·min^{-1}, [158 beats·min^{-1}, 175 beats·min^{-1}]) had a higher average heart rate compared to the control group (153 beats·min^{-1}, [145 beats·min^{-1}, 162 beats·min^{-1}]; Table 7.3). There was also a statistically significant difference in peak heart rate during The Daily Mile between the intervention and control group at follow-up ($F_{(1, 30)} = 6.7$, $p = 0.015$, d = 1.05, Figure 7.6), whereby the intervention group (194 beats·min^{-1}, [188 beats·min^{-1}, 200 beats·min^{-1}]) had a higher peak heart rate than the control group (183 beats·min^{-1}, [178 beats·min^{-1}, 189 beats·min^{-1}]; Table 7.3).

Table 7.3. Heart rate during participation in The Daily Mile at baseline, mid-intervention and follow-up. Data are mean ± SD (range).

Time	**Average HR** (beats·min^{-1})	**Average Relative Intensity** (%HRMax) [a]	**Peak HR** (beats·min^{-1})	**Peak Relative Intensity** (%HR_{max}) [a]
		Intervention group		
Baseline	158 ± 28 (103 – 186)	79 ± 15 (50 – 100)	185 ± 25 (120 – 209)	91 ± 13 (62 – 100)
Mid-intervention	160 ± 18 (117 – 183)	82 ± 9 (70 – 99)	193 ± 8 (179 – 205)	96 ± 4 (89 – 100)
Follow-up	166 ± 16 (140 – 192)	85 ± 8 (72 – 100)	193 ± 12 (174 – 214)	96 ± 4 (90 – 100)
		Control group		
Baseline	171 ± 10 (153 – 189)	86 ± 3 (79 – 91)	195 ± 6 (187 – 213)	98 ± 2 (91 – 100)
Follow-up	154 ± 16 (129 – 187)	77 ± 7 (66 – 88)	184 ± 10 (167 – 207)	92 ± 4 (84 – 97)
Adjusted Between-Group Difference [b] Mean (95% CI) [*p value]*	13 (1, 25) **[*p* = 0.037]***	9 (3, 15) **[*p* = 0.005]***	11 (2, 19) **[*p* = 0.015]***	4 (1, 8) **[*p* = 0.008]***

Abbreviations: HR; Heart Rate. HR_{max}; Maximum Heart Rate.

[a] Maximum Heart Rate achieved during the Multi-Stage Fitness Test.

[b] Mean difference intervention group relative to control group at follow-up, adjusted for baseline score

* Statistically significant difference between groups, $p < 0.05$.

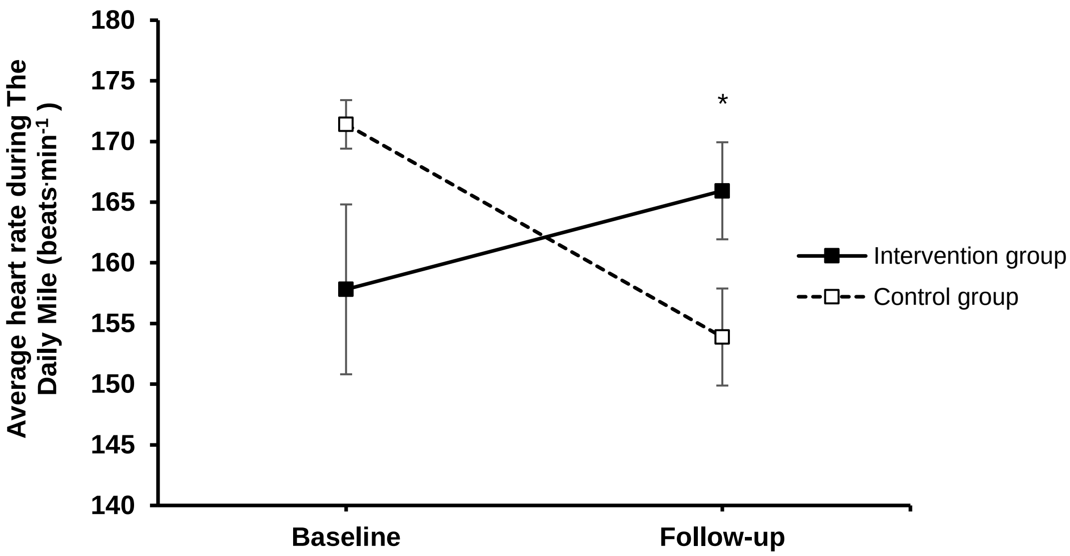

Figure 7.5. Mean (± SE) average heart rate (beats·min^{-1}) during The Daily Mile at baseline and follow-up for the intervention group (solid line) and control group (dashed line). * Significant difference at follow-up, $p = 0.037$.

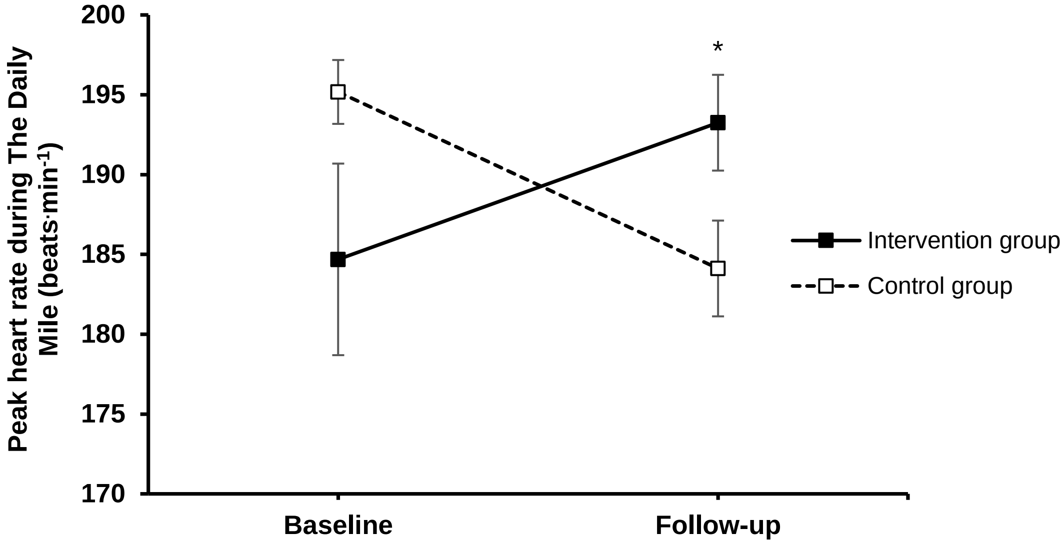

Figure 7.6. Mean (± SE) peak heart rate (beats·min^{-1}) during The Daily Mile at baseline and follow-up for the intervention group (solid line) and control group (dashed line). * Significant difference at follow-up, $p = 0.015$.

7.3.6. Differences in Cognitive Function

7.3.6.1. Stroop Test

Accuracy: At follow-up, there were no differences between the intervention and control group in accuracy on the simple or complex level of the Stroop test (both $p > 0.05$).

Response times: There were no differences between the intervention and control group at follow-up in response times on the simple or complex level of the Stroop test (both $p > 0.05$).

7.3.6.2. Sternberg Paradigm

Accuracy: At follow-up, there were no differences between the intervention and control group in accuracy on the one-item, three-item or five-item level of the test (all $p > 0.05$).

Response times: There were no differences at follow-up between the intervention and control group in response times on the one-item, three-item, or five-item level of the test (all $p > 0.05$).

7.3.6.3. Flanker Task

Accuracy: At follow-up, having controlled for baseline values, the intervention group (99% [96%, 100%]) tended to have higher accuracy compared to the control group (96% [94%, 98%]) on the congruent level of the Flanker test ($F_{(1, 31)}$ = 3.6, p = 0.068, d = 0.73; Figure 7.7). There were no differences in accuracy between the intervention and control group at follow-up on the incongruent level of the Flanker task (both $p > 0.05$).

Response times: The intervention group (602 ms [572 ms, 633 ms]) tended to respond faster than the control group (643 ms [613 ms, 674 ms]) on the congruent level of the Flanker task at follow-up ($F_{(1, 31)}$ = 3.7, p = 0.063, d = 0.47; Figure 7.8). There were no differences in response times between the intervention and control group at follow-up on the incongruent level of the Flanker task (both $p > 0.05$).

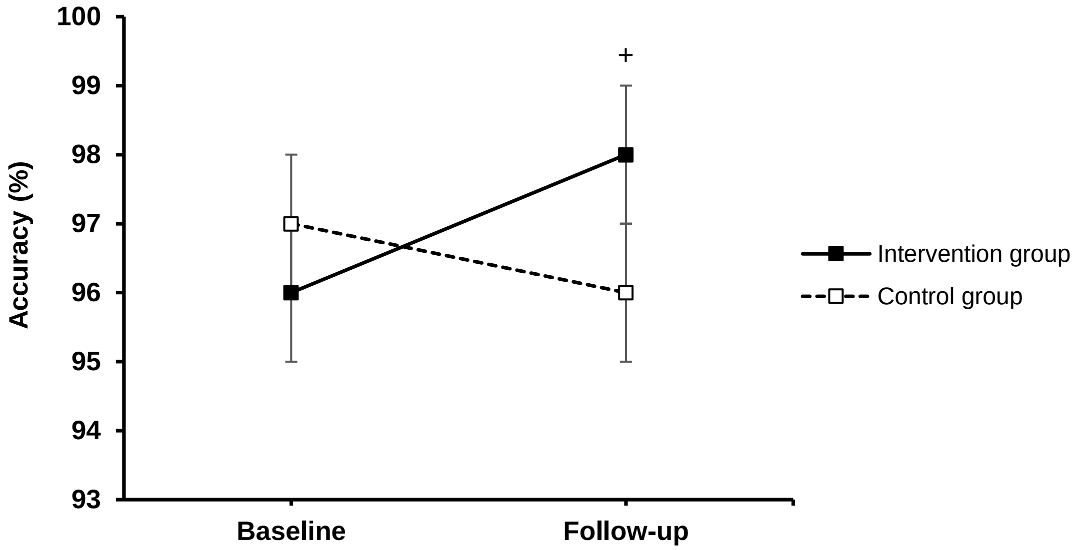

Figure 7.7. Mean (± SE) accuracy (%) on congruent level of Flanker task at baseline and follow-up for the intervention group (solid line) and control group (dashed line). $^{+}$ Tendency for a difference at follow-up, p = 0.068.

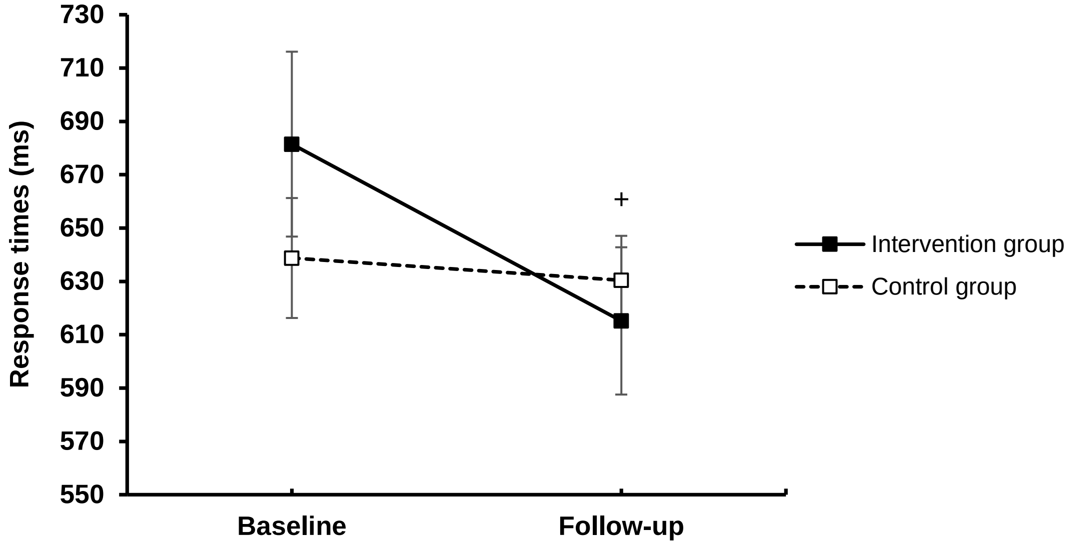

Figure 7.8. Mean (± SE) response time (ms) on congruent level of Flanker task at baseline and follow-up for the intervention group (solid line) and control group (dashed line). + Tendency for a difference at follow-up, p = 0.063.

Table 7.4. Baseline and follow-up results of cognitive function outcomes, with data presented as mean ± SD. Follow-up and between-group differences adjusted for baseline results are also presented as mean ± 95% CI.

Outcome	**Intervention**			**Control**			**Adjusted Between-Group Difference Mean (95% CI)** [a] **[*p value*]**
	Baseline (Mean ± SD)	*Follow-Up (Mean ± SD)*	*Adjusted Follow-Up Mean (95% CI)* [a]	*Baseline (Mean ± SD)*	*Follow-Up (Mean ± SD)*	*Adjusted Follow-Up Mean (95% CI)* [a]	
			Response Times (ms)				
Simple Stroop	964 ± 144	928 ± 219	917 (853, 982)	937 ± 127	892 ± 100	902 (839, 965)	15 (-75, 105) [*p* = 0.731]
Complex Stroop	1295 ± 288	1201 ± 249	1194 (1128, 1261)	1278 ± 191	1244 ± 213	1250 (1186, 1314)	-56 (-149, 36) [*p* = 0.225]
Sternberg One-Item	667 ± 152	607 ± 126	606 (557, 655)	664 ± 150	604 ± 118	605 (557, 653)	1 (-67, 70) [*p* = 0.967]
Sternberg Three-Item	806 ± 175	717 ± 103	724 (685, 763)	839 ± 147	778 ± 108	771 (732, 809)	-47 (-101, 8) [*p* = 0.092]
Sternberg Five-Item	906 ± 193	868 ± 137	886 (805, 968)	1014 ± 153	958 ± 193	941 (862, 1020)	-55 (-171, 61) [*p* = 0.343]
Congruent Flanker	681 ± 143	615 ± 114	602 (572, 633)	639 ± 93	630 ± 69	643 (613, 674)	-41 (-84, 2) **[*p* = 0.063]**[+]
Incongruent Flanker	712 ± 146	669 ± 121	669 (634, 703)	712 ± 137	690 ± 92	690 (656, 725)	-21 (-70, 27) [*p* = 0.337]
			Accuracy (%)				
Simple Stroop	98 ± 3	96 ± 5	96 (94, 98)	97 ± 4	99 ± 3	99 (97, 100)	-3 (-6, 0) [*p* = 0.074]
Complex Stroop	95 ± 5	94 ± 5	94 (91, 97)	91 ± 9	94 ± 7	95 (92, 98)	-1 (-5, 3) [*p* = 0.617]
Sternberg One-Item	97 ± 5	94 ± 9	94 (91, 97)	94 ± 6	98 ± 3	98 (95, 100)	-4 (-9, 0) [*p* = 0.074]
Sternberg Three-Item	95 ± 5	95 ± 6	95 (93, 98)	95 ± 5	97 ± 4	97 (94, 99)	-1 (-5, 2) [*p* = 0.414]

Sternberg Five-Item	90 ± 11	90 ± 11	90 (86, 94)	92 ± 9	90 ± 9	90 (86, 94)	0 (-5, 6) [*p* = 0.929]
Congruent Flanker	96 ± 5	98 ± 2	99 (96, 100)	97 ± 3	96 ± 6	96 (94, 98)	3 (0, 6) **[*p* = 0.068]+**
Incongruent Flanker	95 ± 6	96 ± 5	95 (92, 98)	93 ± 6	93 ± 9	94 (91, 97)	0 (0, 6) [*p* = 0.566]

Abbreviations: SD; Standard Deviation. CI; Confidence Interval.

[a] Adjusted for baseline score. * Statistically significant difference between groups, $p < 0.05$. + tendency for a difference at follow-up, $p < 0.10$.

7.4. Discussion

The present study examined the effects of chronic participation in The Daily Mile on a range of domains of cognitive function. The main findings are that there was a tendency for attention to be enhanced in the intervention group, compared to the control group, following five and a half weeks of participation in The Daily Mile. This study is also the first to explore whether changes to body composition and cardiorespiratory fitness occur with shorter (< 12 weeks) but more frequent (5 days per week) participation in The Daily Mile. The present study found that BMI was lower in the intervention group, compared to the control group, following participation in The Daily Mile. Additionally, both average and peak heart rate, and relative exercise intensity, were higher during The Daily Mile at follow-up in the intervention group, compared to the control group. There was no difference in cardiorespiratory fitness, however, between the intervention group and the control group at follow-up; suggesting that five and a half weeks of daily participation in The Daily Mile is not sufficient to enhance cardiorespiratory fitness.

Findings from the present study demonstrate that participation in The Daily Mile for five and a half weeks did not result in a significant change in cognitive function, but that it tended to improve attention performance. Specifically, the intervention group tended to have better performance on the congruent level of the Flanker task (41 ms faster per stimulus and 3% higher accuracy). Importantly, this improvement in response times was not at the expense of reduced accuracy, which indicates an actual improvement rather than a speed-accuracy trade off. Moreover, while only a tendency for enhanced attention was observed, a medium sized effect ($d = 0.47 – 0.73$) was evidenced. As there was a large participant drop out from the study due to the COVID-19 pandemic, the study was likely underpowered. It is thus possible that an adequately powered study, with a larger number of participants, may observe a significant effect to attention from five and a half weeks of The Daily Mile, however this theory warrants further investigation.

The tendency towards benefits to attention following participation in The Daily Mile could have important implications, given that attention is related to learning and academic performance (Diamond, 2013; Gathercole et al., 2003), and is closely linked to attainment in English, Mathematics and Science (St. Clair-Thompson & Gathercole, 2006). However, participation in The Daily Mile over five and a half weeks had no effect on inhibitory control or visual working memory. This may be due to the duration of the intervention, as enhancements to these cognitive domains are more consistently observed from longer (> 22 weeks) physical activity interventions (Hillman et al., 2014; Kamijo et al., 2011; van der Niet et al., 2016). Future research should explore whether significant effects to cognition occur from participation in a longer intervention (> 6 weeks) of The Daily Mile, as this is currently unknown.

In the present study, participation in The Daily Mile over five and a half weeks did not significantly affect cardiorespiratory fitness. However, there was a tendency (with medium sized effect [d = 0.73]) for peak heart rate during the MSFT at follow up to be higher in the intervention group, compared to the control group (mean difference = 4 beats·min^{-1} [0 beats·min^{-1}, 8 beats·min^{-1}]). Moreover, both average (mean difference = 13 beats·min^{-1} [1 beats·min^{-1}, 25 beats·min^{-1}]) and peak (mean difference = 11 beats·min^{-1} [2 beats·min^{-1}, 19 beats·min^{-1}]) heart rate during The Daily Mile were significantly higher in the intervention group compared to the control group at follow-up, with large-to-very large effect (d = 1.05 – 1.19). This suggests that whilst the control group exercised at a moderate-to-vigorous intensity, the intervention group exercised at a vigorous-to-maximal intensity (ACSM, 2014). Participation in The Daily Mile intervention thus resulted in children investing increased effort in the activity and exercising at a higher relative intensity during The Daily Mile. Over time, this regular, effortful, high intensity participation in The Daily Mile is likely to result in improvements to cardiorespiratory fitness (Sun et al., 2013), particularly as vigorous physical activity provides the greatest time investment returns for both fitness and adiposity in children (Collings et al., 2017). This is supported by research which observed enhanced cardiorespiratory fitness following participation in The Daily Mile over 12 weeks (Brustio et al., 2019; de Jonge et al., 2020), 24 weeks (Brustio et al., 2020; Marchant et al., 2020) and 28 weeks (Chesham et al., 2018).

Importantly, based on a large-scale study of European normative values in children, participants in the present study had higher cardiorespiratory fitness (girls = 80th percentile, boys = 70th percentile), compared to other children of the same age and sex (Tomkinson et al., 2018). This high baseline fitness within the study sample would make it less likely that a change in fitness could be observed following a short-term increase in physical activity (i.e., five and a half weeks participation in The Daily Mile). It is possible that greater benefits to cardiorespiratory fitness would be observed in children with 'normal' and lower levels of fitness. The present study provides novel evidence that participation in the Daily Mile for five and a half weeks is not sufficient to enhance cardiorespiratory fitness but will elicit increased effort and relative exercise intensity during participation. Future research should continue to investigate, with a sample representative of the wider population, the duration of participation in The Daily Mile required to improve cardiorespiratory fitness.

Future research that explores whether any changes in cognition are related to changes in cardiorespiratory fitness would also be valuable, as there is a strong association between cardiorespiratory fitness and cognition (e.g., Chaddock et al., 2011b; Páez-Maldonado et al., 2020; Williams et al., 2020). Furthermore, there is emerging evidence that cardiorespiratory fitness influences the acute physical activity-cognition relationship (e.g., Cooper et al., 2018; Hogan et al., 2013; Williams et al., 2020), though cardiorespiratory fitness did not influence the effect of an acute bout of The Daily Mile on children's attention, inhibitory control, working memory or cognitive flexibility (Chapter VI). Nevertheless, the present study is the first to examine the effects of chronic participation in The Daily Mile on cognition and thus provides novel evidence that participation over five and a half weeks results in a tendency for enhanced attention.

It was also the intended purpose of this study to examine participants' activity patterns during The Daily Mile at baseline, mid-intervention (intervention group only) and follow-up.

However, unfortunately due to a technical issue with the GPS units, no data was recorded at follow-up. This information would have been valuable in determining whether there were any differences in physical activity performance between the intervention group and control group following the five and a half-week intervention (i.e., in absolute intensity). Moreover, if there were any differences, the baseline, mid-intervention and follow-up data could have been compared to explore when these changes appear (e.g., at three weeks or five and a half weeks). However, as previously discussed, both average and peak heart rate during The Daily Mile were significantly higher in the intervention group, compared to the control group, at follow-up, suggesting differences in physical activity intensity as a result of the intervention. It would thus be valuable for future research to explore whether these differences extend to additional measures of performance and absolute intensity, such as distance covered and activity patterns (similar to those assessed in Chapter V).

Data from the present study demonstrate that there were no significant differences in waist circumference, waist-to-hip ratio, BMI z-score, or sum of skinfolds between the intervention group and control group at follow-up. However, BMI was significantly lower in the intervention group, compared to the control group, at follow-up (mean difference = -0.3 $kg{\cdot}m^{-2}$, [-0.5 $kg{\cdot}m^{-2}$, -0.1 $kg{\cdot}m^{-2}$]). Interestingly, two recent studies on The Daily Mile found no effect on BMI from 12 weeks (Brustio et al., 2019) or 24 weeks (Brustio et al., 2020) of participation. However, The Daily Mile in these studies was implemented on only two (Brustio et al., 2020) and three (Brustio et al., 2019) days per week, suggesting that a high frequency of implementation, such as that used in the present study (5 days per week), may be important for improvements in BMI. Moreover, BMI z-score was lower in the intervention group, compared to the control group, at follow-up (mean difference = -0.09 [-0.18, 0.01]; p = 0.067). While this could be interpreted as a trend, the effect size was small (d = 0.16). It's likely that the study was underpowered due to the large participant drop out and with a larger number of participants, a significant effect and/or greater effect size may be observed. However, a longer duration of participation in The Daily Mile may be needed to significantly effect BMI z-score.

Breheny et al. (2020) found that participation in The Daily Mile benefited BMI z-score, whereby participation for four months attenuated the increase in BMI z-scores reported in children over this time. However, Breheny et al. (2020) reported that BMI z-scores were significantly lower only in girls in the intervention group, compared to the control group, following 12 months of participation. The change in BMI z-score in the intervention group (-0.07) in the present study would not be considered clinically important (-0.125) for obesity prevention (Kolsgaard et al., 2011). However, the sample in the present study had lower rates of overweight and obesity (23 %) compared to typical children of this age (50 %) (Public Health England, 2022), which makes it less likely to see a significant change in body composition. Thus, larger and more diverse effects to body composition from The Daily Mile may be observed in a sample that is more representative of the wider population. Furthermore, greater effects to body composition may also be observed from participation in The Daily Mile over a longer duration and in particular once changes to cardiorespiratory fitness appear, as seen in the study by Chesham et al. (2018), where changes in fitness (~40 m increase in shuttle run distance) predicted changes in adiposity (1.4 mm reduction in sum of skinfolds) from 28 weeks of participation in The Daily Mile. Nevertheless, the findings of the present study demonstrate, for the first time, that participation in The Daily Mile for five and a half weeks reduced BMI. The Daily Mile intervention may, therefore, be a useful component within the multifaceted measures designed to help tackle the obesity pandemic (Nishtar et al., 2016).

As discussed a large number of participants (n = 27) dropped out of the study prior to the follow-up trial; this was due to COVID-19 and the bubble isolation protocol in place at the time of data collection. Data imputation is an approach sometimes used to reduce the bias that can be caused by removing participant data when aspects (e.g., variables or time points) are missing (Sterne et al., 2009). However, the approach was considered inappropriate for this study because data from a whole school class was lost and these participants were part of the intervention group. Moreover, there are several limitations of imputation (Sterne et al., 2009) including the possibility of computational problems.

The present study has a number of strengths, such as being the first study to examine the effect of chronic participation in The Daily Mile on children's cognition. Moreover, despite being a field-based study, the experimental design was highly controlled; participants practiced the cognitive function tests twice to mitigate any potential learning effects, dietary intake prior to the baseline trial was replicated prior to the follow-up trial (with a standardised breakfast provided during the intervention trials), and participants were recruited from one school to prevent any between-school variance that may have impacted outcome measures. The study is not, however, without limitations. For logistical reasons, physical activity outside of school during the intervention period was not measured or controlled. Moreover, there was a significant difference in age at baseline between the intervention and control group, which occurred due to the large participant drop out resulting from COVID-19 (and the isolation period for one of the classes taking part in the study). However, although age has been shown to influence some of the variables measured in the study (e.g., waist-to-hip ratio and cognitive function), this is primarily when children (pre-pubertal) are compared to adolescents (pubertal–post-pubertal), with minimal differences between children aged 9–11 years, as used in the present study.

7.5. Conclusion

The present study is the first to demonstrate that participation in The Daily Mile for five and a half weeks tends to improve attention. Additionally, the findings demonstrate that BMI was reduced, and that participants chose to exercise at a higher relative exercise intensity during The Daily Mile, following daily participation in The Daily Mile for five and a half weeks. Cardiorespiratory fitness, and other aspects of cognitive function and body composition were not improved by the intervention. As this is the first study to investigate the effects of chronic participation in The Daily Mile on cognition, future work should continue to examine the effects to various aspects of cognition from longer durations of intervention. It would also be valuable to explore the effect of participation over a longer period (e.g., 6–12 weeks) on body composition and cardiorespiratory fitness, and to explore the effect of participation in The Daily

Mile intervention on activity patterns (e.g., absolute intensity, distance covered, speed) during participation in The Daily Mile.

7.6. Practical Recommendations

The Daily Mile should be implemented every day, and throughout the school year. This will promote achievement of in-school daily physical activity targets and provide the best chance for gaining improvements to cognitive function, body composition and cardiorespiratory fitness from participation. The initiative should, however, be implemented alongside other formal and informal opportunities for physical activity in school across the school day, and not as an alternative to physical education or break time.

Chapter VIII

General Discussion

8.1 Summary of key findings

The studies presented within this thesis have examined some of the moderating variables in the acute physical activity-cognitive function relationship in young people, with a focus on physical activity duration and The Daily Mile as an ecologically valid form of school-based physical activity. Furthermore, this thesis has provided a holistic evaluation of The Daily Mile, not only in terms of the activity patterns of children participating and the acute effects to cognitive function, but also on enjoyment of those participating and longer-term effects to cognition, body composition and cardiorespiratory fitness. The main findings are summarised below:

Chapter IV

- Both 30 min and 60 min of high-intensity intermittent running enhanced post-activity cognitive function, compared to resting.
- Specifically, 30 min of high-intensity intermittent running enhanced attention and information processing immediately and 45 min following the activity, as well as inhibitory control 45 min following the activity, compared to resting. Whereas, 60 min of high-intensity intermittent running enhanced working memory immediately following the activity, compared to resting.
- When comparing activity duration, 30 min compared to 60 min of high-intensity intermittent running was more beneficial to both immediate cognitive function (information processing, inhibitory control) and delayed (45 min post-activity) cognitive function (information processing, attention, inhibitory control, working memory).
- The positive effects of high-intensity intermittent running on cognitive function were primarily evidenced through a reduction in response times. Effects to accuracy were limited and presented as maintained, compared to reduced, accuracy.

Chapter V

- On average, the total distance covered during The Daily Mile was 2511 m (~1.5 miles).
- Average heart rate was 163 ± 27 beats·min^{-1} and the relative physical activity intensity was 81 ± 13% of age-predicted HR_{max}, meaning The Daily Mile elicited a moderate-to-vigorous intensity physical activity.
- The mean number of speed zone entries for each participant was 646 (a high number of entries demonstrating that participants frequently changed pace), suggesting that all children were to some extent intermittent in their activity patterns during The Daily Mile.
- Participants covered the greatest distance, and were also most intermittent, during the first 5 min of The Daily Mile, compared to the later stages.
- Boys' average heart rate, peak heart rate and their relative physical activity intensity was higher than in girls. Moreover, boys ran further and faster compared to girls, and boys' activity was also more intermittent.
- In contrast, although the absolute dose of activity was different between fitness levels (as fitter children ran further and faster), the relative dose (average heart rate) did not differ between low and high fit children, suggesting a potentially similar and positive health benefit for children of all fitness levels participating in The Daily Mile.

Chapter VI

- The Daily Mile did not acutely significantly affect cognitive function, compared to rest.
- However, accuracy in tasks of inhibitory control and visual working memory tended to improve immediately following The Daily Mile.
- High-fit children demonstrated superior cognition compared to low-fit children; this was evidenced through faster response times on the simple and complex levels of the cognitive function tests.
- Moreover, boys demonstrated faster response times on the simple levels of tests, compared to girls.

- Children enjoyed the social context and self-paced nature of The Daily Mile and perceived benefits to health and learning from participation; however, children enjoy variety in physical activity opportunities, and a few desired a competitive element to be incorporated within The Daily Mile.

Chapter VII

- There was a tendency for attention to be enhanced in the intervention group, compared to the control group, following five and a half weeks of participation in The Daily Mile.
- BMI scores were lower in the intervention group, compared to the control group, following participation in The Daily Mile. However, there were no significant differences in other domains of cognitive function (e.g., inhibitory control, working memory), body composition or cardiorespiratory fitness between the groups at follow-up.
- Nevertheless, both average and peak heart rate, and relative exercise intensity, were higher during The Daily Mile at follow-up in the intervention group, compared to the control group. This suggests that regular participation in The Daily Mile leads to an increase in relative physical activity intensity when participating in The Daily Mile.

8.2 Moderating Variables in the Acute Physical Activity-Cognition Relationship

8.2.1 Physical Activity Characteristics

This thesis contributes to knowledge regarding the physical activity characteristics which moderate the effect of physical activity on cognitive function in young people. Whilst initially this thesis focused on physical activity duration, information regarding other moderating variables (such as intensity and modality) were reported and, as such, enhanced understanding of these moderating variables, can be gained from the findings of this thesis (Figure 8.1). Therefore, the findings of this thesis have contributed to the physical activity-cognition relationship theory.

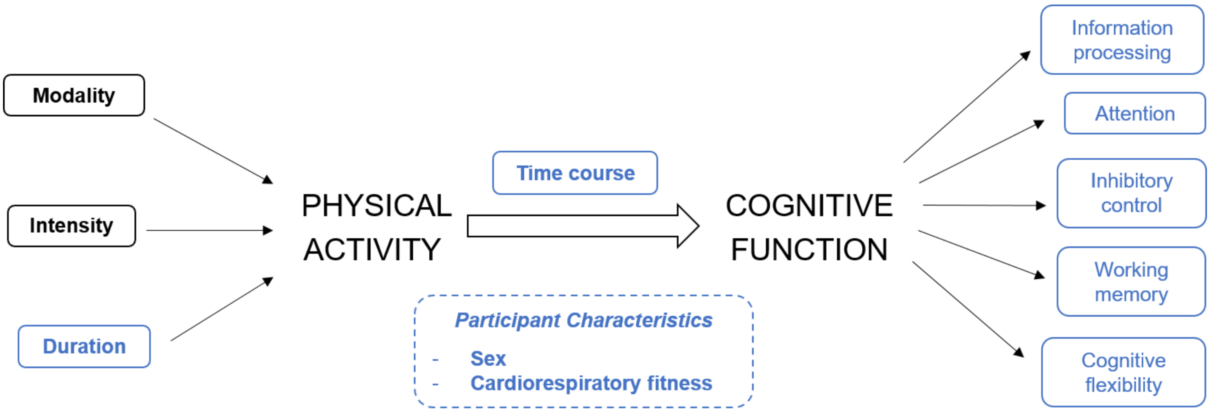

Figure 8.1. The physical activity-cognition relationship, including the cognitive domains (right) alongside the key moderating variables: physical activity characteristics (left), timing of cognitive testing (top), and participant characteristics (bottom) shown in bold. Variables explored within this thesis are highlighted in blue. Schematic adapted from Williams et al. (2019).

Chapter IV presented the first within-subjects dose-response study to directly compare the effects of differing durations of physical activity on cognition in young people. The results demonstrate that whilst both 30 min and 60 min of activity is beneficial to subsequent cognition, 30 mins is more favourable in that it leads to both immediate and delayed effects across cognitive domains. The finding that 30 min of activity enhanced cognitive function, despite previous research reporting no effects to cognition from this duration of physical activity (van den Berg et al., 2018), is likely due to the modality and intensity utilised. High-intensity intermittent running is an enjoyable (Malik et al., 2017) and ecologically valid (Howe et al., 2010) physical activity for young people, which has been shown to enhance cognition in young people (Cooper et al., 2016, 2018) and be favourable compared to continuous physical activity (Lambrick et al., 2016) and moderate-intensity intermittent activity (Lind et al., 2019). The findings of this thesis support the cognitive enhancing effects of high intensity intermittent activity in young people.

Furthermore, data from Chapter V of this thesis shows that during The Daily Mile participants engage in moderate-to-high intensity intermittent running; and data from Chapter VI demonstrates that participation in The Daily Mile for 20 min tends to improve cognition. Therefore, it is possible that 30 min of physical activity is required to enhance subsequent cognition, whilst 20 min is not of a sufficient duration to elicit statistically significant effects. However, there is some evidence to suggest that improvements to cognition can be gained from shorter durations of exercise (Budde et al., 2008, 2010; Salerno et al., 2020), though not from dose-response studies. Salerno et al. (2020), for example, compared 10, 20 and 30 min of walking to seated rest of the same duration. The results revealed that walking anywhere from 10 to 30 min can enhance cognition. However, as with the study by van den Berg et al. (2018), a between-subjects design was used to compare the physical activity durations. Moreover, the study was conducted on adult women and so the findings may not be translatable to young people. Additional research is needed to further examine the dose-response nature of physical activity duration on subsequent cognition in young people, and ultimately to determine the minimum duration of physical activity that enhances subsequent cognition, which is likely to be of interest to school policy makers and young people. It must be noted however that the other moderating variables in Figure 8.1 will also influence the subsequent effects on cognition. Nevertheless, the findings of this thesis demonstrate, for the first time, that a shorter duration (30 min vs 60 min) of physical activity is favourable for post-activity cognitive function. These findings have notable practical implications; not only do they endorse the implementation of high-intensity intermittent running in schools, but they also guide implementation by informing that only 30 min of high-intensity intermittent running is needed for significant enhancements to cognition. This information will be particularly valuable to policy makers, school-board members and school staff, who are keen to support young people's learning through physical activity, but frequently cite time constraints as a barrier hindering its implementation in schools (McMullen et al., 2014; Naylor et al., 2015; van den Berg et al., 2017).

8.2.2 Timing of Cognitive Testing

Within this thesis, cognitive function was measured both immediately and 45 min following the cessation of physical activity (Chapter IV & VI; Figure 8.1); the findings of these studies thus expand on the currently limited research which has measured cognition at more than one time point following the cessation of physical activity (see section 2.4.3.2). Data from

Chapter VI demonstrate that inhibitory control and visual working memory tend to improve immediately following physical activity, and data from Chapter IV show that there is a significant improvement in attention and information processing immediately following physical activity. These findings are the first to demonstrate that there are immediate positive effects to attention and information processing from 30 min of high-intensity intermittent running, with previous research utilising different types of physical activity (e.g., Ellemberg & St.-Louis-Deschênes, 2010; Etnier et al., 2014; Tine & Butler, 2012) and/or measuring different cognitive domains (e.g., Caterino & Polak, 1999; Etnier et al., 2014). Moreover, while the findings of Chapter VI demonstrate that no effects to cognition are observed 45 min following 20 min of moderate-to-high intensity intermittent activity (The Daily Mile), the findings of Chapter IV indicate that enhancements to attention, information processing and inhibitory control are present 45 min following 30 min high-intensity intermittent running. Moreover, enhancements to high-order cognitive domains (e.g., inhibitory control) were evident 45 min, and not immediately, following high-intensity intermittent running. Overall, the findings of this thesis suggest that benefits to cognition from physical activity are observed both immediately and 45 min following physical activity. However, for enhancements at 45 min post-activity, physical activity needed to be high intensity and 30 min in duration. These findings will help to develop evidence-based recommendations regarding the implementation of physical activity in school; this includes guiding the timing of implementation of physical activity throughout the school day to support and sustain cognitive benefits in young people.

8.2.3. Cardiorespiratory Fitness

The findings of this thesis demonstrate that higher cardiorespiratory fitness is associated with superior cognition in young people, when compared to their lower fit counterparts. In Chapter VI, higher fit boys and girls presented faster response times on simple and complex levels of cognitive function tests, demonstrating superior information processing, attention, inhibitory control, working memory and cognitive flexibility. These findings suggest that chronic participation in physical activity, which enhances cardiorespiratory fitness, results in superior cognitive function, which is supported by the literature (Hillman et al., 2011; Ludyga et al., 2020). However, the findings of this thesis also extend the literature by demonstrating that the associations between higher cardiorespiratory fitness and faster response times in inhibitory control and working memory tasks are present in children, with this only being evidenced in adolescents previously (e.g., Westfall et al., 2018; Williams et al., 2020).

While there was a clear association between cardiorespiratory fitness and cognition, the findings of this thesis (Chapter VI) suggest that cardiorespiratory fitness does not moderate the acute effect of physical activity on cognitive function. Similar findings have been reported previously (Crova et al., 2014; Ludyga et al., 2016), including in a study which utilised The Daily Mile (Booth et al., 2020). However, these findings are in contrast to the wider physical-activity cognition literature, which suggests that young people with higher cardiorespiratory fitness gain greater cognitive benefits from acute physical activity (Cooper et al., 2018; Hogan et al., 2013; 2015; Jäger et al., 2015; Williams et al., 2020). As discussed within this thesis, there are several variables which may moderate the acute physical activity-cognition relationship (Figure 8.1) and although they can act independently and thus must be first examined in isolation, the variables may also interact to influence the relationship. Cardiorespiratory fitness may, for example, have a greater or lesser impact depending on the characteristics of the physical activity. The interaction of these variables may thus explain the heterogeneity in the findings in this area. Future research which examines the interaction between cardiorespiratory fitness and physical activity characteristics would thus be valuable. For example, future research could examine the moderating role of cardiorespiratory fitness on the acute effect of different durations of physical activity (of the same modality and intensity) on cognition.

Furthermore, research suggests that chronic physical activity interventions which improve cardiorespiratory fitness enhance cognitive function in young people (Xue et al., 2019). Chapter VII of this thesis demonstrated that cardiorespiratory fitness was not improved from chronic (5.5 weeks) participation in The Daily Mile; this may therefore explain why cognitive function was not significantly improved from chronic participation in The Daily Mile.

8.3. An evaluation of The Daily Mile

8.3.1. Activity Patterns during Participation in The Daily Mile

Chapter V of this thesis presented the first study to quantify the activity patterns alongside the physiological responses of children during The Daily Mile. The findings demonstrate that children engaged in moderate-to-high intensity, intermittent physical activity. The Daily Mile thus mimics the typical activity patterns of young people (Armstrong & Welsman, 2006; Howe et al., 2010), which they find enjoyable (Malik et al., 2017, 2019). Moreover, these findings demonstrate that The Daily Mile is positively contributing ≥ 50 % towards the in school daily target of 30 min moderate-to-vigorous physical activity. If The Daily Mile is implemented alongside, and not in replacement of, break times and physical education, as advised (The Daily Mile, 2022c), young people should meet this physical activity target, making The Daily Mile a worthwhile addition to school-based approaches aimed at increasing physical activity levels in young people. Habitual MVPA has numerous benefits in young people; MVPA is positively associated with physical, psychological and social indicators of health, with regular participation during childhood linked to reduced adiposity, enhanced bone health, and favourable cardiovascular and metabolic disease risk profiles (Department of Health, 2011; Hills et al., 2015; Poitras et al., 2016). Participation in MVPA is also linked to improved psychological wellbeing and reduced symptoms of anxiety and depression (Department of Health, 2011; Hills et al., 2015; Poitras et al., 2016); it is reported to be a positive predictor of 'flourishing' mental health in young people (Bélanger et al., 2019). Moreover, longitudinal data shows that increased MVPA at aged 7 is associated with fewer peer problems in both boys and girls at age 11; with each additional 15 min of engagement in MVPA, a decrease in peer problems is observed (Ahn et al., 2017). Furthermore, while boys presented a higher relative physical activity intensity than girls during The Daily Mile, there was a similar relative intensity between children of all fitness levels (Chapter VI). The Daily Mile is thus an advantageous intervention as children of all fitness levels are able to participate and receive similar benefits from participation, as the relative, compared to the absolute dose of physical activity is more likely to determine the physiological responses (Mann et al., 2013).

Unfortunately, this thesis was not able to report children's activity patterns during chronic participation in The Daily Mile due to a technical issue with the GPS systems (Chapter VII). However, heart rate data presented in Chapter VII shows that both average and peak heart rate during The Daily Mile were significantly higher in the intervention group, compared to the control group, following chronic (5.5 weeks) participation in The Daily Mile. Participants engaged, on average, at a moderate-to-vigorous intensity at baseline (79 ± 15% HR max), in line with the findings of Chapter V, and while activity intensity remained the same in the control group, it increased to vigorous intensity (85 ± 8% HR max) in the intervention group at follow up. These novel findings suggest that regularly participating in The Daily Mile increases relative physical activity intensity when participating in The Daily Mile. These findings are likely due to the self-paced nature of The Daily Mile, which enables participants to alter their walking/running speed, and thus physical activity intensity, as they improve with repeated participation. This progression in performance is not possible in many other school-based physical activity interventions, which tend to be more structured in pace and intensity (e.g., Howie et al., 2014; Ma et al., 2015; Vazou & Smiley-Oyen, 2014). Therefore, young people should continue to receive benefits from chronic participation in The Daily Mile and not experience the plateau that can occur in structured activities where there is no room for progression.

8.3.2. Effects on Cognitive Function

The findings from this thesis on The Daily Mile suggest that acute participation in The Daily Mile tends to improve inhibitory control and visual working memory (Chapter VI), and that daily participation over five and a half weeks tends to improve attention (Chapter VII). Chapter VII presents the first study to examine the chronic effects of The Daily Mile on cognition. However, of the two studies which have examined the acute effects to cognition, Morris et al. (2019) reported no effects, while Booth et al. (2020) reported positive effects to inhibitory control and verbal working memory. The heterogeneity in the evidence so far may be due to the different timing of post-activity cognitive testing as Booth et al. (2020) measured cognition up to 20 min following The Daily Mile, and 10–20 min following activity has previously been suggested as the time at which the greatest effects are observed (Chang et al., 2012). However, research in this area is within its infancy and additional research which measures the acute effects of The Daily Mile on a range of domains and at multiple time points is needed. Moreover, while participation for five and a half weeks tended to improve attention (with medium sized effect [d = 0.47 – 0.73]), there were no effects to inhibitory control or working memory. There was a large participant drop out (due to the COVID-19 pandemic) from the study presented in Chapter VII and it was likely underpowered. It's possible that an adequately powered study, with a larger number of participants, may find a significant effect to attention from five and a half weeks of The Daily Mile, however this theory warrants further investigation. Participation in The Daily Mile over a longer intervention period (> 6 weeks) may elicit significant positive effects to cognition, as enhancements to cognition are more consistently observed from longer (> 22 weeks) physical activity interventions (Hillman et al., 2014; Kamijo et al., 2011; van der Niet et al., 2016). This is supported by the findings of Chapter V, which showed that The Daily Mile elicited moderate-to-vigorous intensity activity, and time spent in moderate-to-vigorous intensity physical activity is positively associated with attention capacity in young people (Vanhelst et al., 2016). This is promising as The Daily Mile is designed to be implemented across the school year, throughout primary school. Importantly, the findings from Chapter VII demonstrate that there is high fidelity to the intervention (95%). However, one way to optimise the cognitive benefits from The Daily Mile might be to include cognitively engaging activities (Gu et al., 2019; Jäger et al., 2014; Vazou & Smiley-Oyen, 2014). Nevertheless, the findings from this thesis are pertinent, given that attention is related to learning *(*Diamond, 2013; Gathercole et al., 2003)*,* and linked to attainment in English, Mathematics and Science (St. Clair-Thompson & Gathercole, 2006). Therefore, the findings tentatively support the use of The Daily Mile within curriculum time, in addition to break time, physical education and other formal and informal opportunities for physical activity, to promote enhanced cognitive function in young people.

8.3.3. Effects on Body Composition

Data from Chapter VII of this thesis demonstrate that BMI was significantly lower in the intervention group, compared to the control group, following five and a half weeks of participation in The Daily Mile. These findings contrast with meta-analyses that suggested that there is no improvement in young people's BMI from school-based physical interventions lasting ≤ 6 months (Harris et al., 2009) and that longer-term school-based physical interventions (ranging from 12 to 72 months) are needed to promote reductions in BMI in young people (Mei et al., 2016). The findings of this thesis are also in contrast to two recent studies on The Daily Mile which found no effect on BMI from 12 weeks (Brustio et al., 2019) or 24 weeks (Brustio et al., 2020) of participation, though participants completed The Daily Mile two (Brustio et al., 2020) and three (Brustio et al., 2019) days per week in these studies; suggesting that daily (5 days per week) participation may be necessary for improvements in BMI.

Data from Chapter VII also showed that BMI z-score was lower in the intervention group, compared to the control group following five and a half weeks of The Daily Mile, however this effect was not significant ($p = 0.067$). While this could be interpreted as a trend, the effect size was small (d = 0.16) and it is likely that the study was underpowered due to the large participant drop out. With a larger number of participants, a significant effect and/or greater effect size may be observed, however this requires further investigation. Moreover, participants in this study were classified as normal weight, meaning there was limited potential for five and a half weeks of The Daily Mile to change body composition. Given the rising prevalence of overweight and obesity during childhood (Ogden et al., 2016), future research should examine the potential for The Daily Mile to improve the body composition of children categorised as overweight/obese.

Furthermore, whilst the findings from Chapter VII suggested that there was no change in adiposity (sum of skinfolds) from five and a half weeks of The Daily Mile, improvements in adiposity have been observed from 28 weeks of participation in The Daily Mile (Chesham et al., 2018), suggesting that a longer intervention duration may be needed for improvements to occur. Overall, the findings of this thesis demonstrate that participation in The Daily Mile for five and a half weeks can positively affect some aspects of body composition (BMI), whilst not affecting other aspects of body composition (waist circumference, waist-to-hip ratio, sum of skinfolds).

8.3.4. Effects on Cardiorespiratory Fitness

Cardiorespiratory fitness did not moderate the acute effects of The Daily Mile on cognitive function (Chapter VI), and there was no effect of five and a half weeks of participation in The Daily Mile on cardiorespiratory fitness (Chapter VII). However, there was a tendency (with medium-sized effect [d = 0.7]) for peak heart rate during the MSFT to be higher in the intervention group, compared to the control group following five and a half weeks of participation in The Daily Mile (Chapter VII). Additionally, both average and peak heart rate during The Daily Mile were significantly higher in the intervention group, compared to the control group, following the five and a half-week intervention (with large-to-very large effect [d = 1.05-1.19]; Chapter VII). Therefore, participation in The Daily Mile intervention led to children investing more effort in the activity and exercising at a higher relative intensity during The Daily Mile. Over time, this regular, effortful, high intensity participation in The Daily Mile is likely to result in improvements to cardiorespiratory fitness (Sun et al., 2013), particularly as vigorous physical activity provides the greatest time investment returns for both fitness and adiposity in children (Collings et al., 2017) and Chapter V demonstrated that children engaged in vigorous intensity activity during The Daily Mile. Moreover, this is consonance with the literature which reports enhanced cardiorespiratory fitness following participation in The Daily Mile for 12 weeks (Brustio et al., 2019; de Jonge et al., 2020), 24 weeks (Brustio et al., 2020; Marchant et al., 2020) and 32 weeks (Chesham et al., 2018). Future research could consider whether improvements to cardiorespiratory fitness occur before 12 weeks and whether any changes to cardiorespiratory fitness are associated with changes in cognition, given the fitness-cognition relationship demonstrated in Chapter VI and the wider literature (Kamijo et al., 2011; Ludyga et al., 2020; Xue et al., 2019). Additional research could also examine whether any changes to cardiorespiratory fitness are associated with changes in body composition, as

Chesham et al. (2018) reported that change in distance covered in the 20 m shuttle run test predicted change in sum of skinfolds following 28 weeks of participation in The Daily Mile.

8.3.5. Enjoyment of, & Fidelity to, The Daily Mile

Data from Chapter VI of this thesis show that, over five and half weeks, there was 95% fidelity to The Daily Mile. This suggests that fidelity to the intervention is high, which is in line with the findings of a study which implemented The Daily Mile for 12 weeks (Harris et al., 2019). Enjoyment of physical activity is a major factor influencing fidelity and adherence to an intervention (Nasuti & Rhodes, 2013; Sebire et al., 2013). Chapter VI presents the first study to examine children's enjoyment of The Daily Mile and found that levels of enjoyment were high. There were many factors which contributed to this enjoyment, including the fun and supportive social context, the autonomy-promoting self-paced nature, and the fact that The Daily Mile provides an opportunity for regular physical activity (Chapter VI). Children also perceived to gain cognitive benefits from participation in The Daily Mile, including improved concentration and learning (Chapter VI), which is in line with the finding that children tended to have superior inhibitory control and working memory following acute participation in The Daily Mile (Chapter VI), both of which are fundamental to concentration and learning (Borella et al., 2010; Diamond, 2013; Gathercole et al., 2003).

The fact that children enjoyed The Daily Mile will not only promote effortful engagement in and adherence to intervention (Nasuti & Rhodes, 2013; Sebire et al., 2013), it will also promote school-level adherence through positively influencing teachers' perceptions of the intervention, the importance they place on its administration (McMullen et al., 2014) and the level of support that they provide towards its continued implementation (Chalkley et al., 2018). Therefore, the findings of this thesis suggest that adherence and long-term engagement in The Daily Mile is likely, which has not been the case with many other school-based physical activity interventions (Durlak & DuPre, 2008; Glasgow & Emmons, 2007). Moreover, enjoyment of a physical activity leads to intrinsic motivation for physical activity, which in turn promotes positive perceptions of physical activity more generally (Ntoumanis, 2001; Standage et al., 2005). This has previously been reported in a qualitative study on The Daily Mile, where regular engagement led to an improved attitude towards physical activity (Marchant et al., 2020). Enjoyment, and intrinsic motivation, also promote higher effort in physical activity (Ye, 2021) and a greater willingness to try challenging physical activities (Standage et al., 2005). Furthermore, children's enjoyment of physical activity has been shown to predict cardiorespiratory fitness improvements from participation (Elbe et al., 2017), and physical activity-induced positive affect has been shown to partially mediate enhancements to verbal working memory following physical activity (Booth et al., 2020). The findings of this thesis thus suggest that, through promoting enjoyment, engagement in The Daily Mile will result in children being more habitually active through long-term participation in both The Daily Mile and a range of other activities (Kalaja et al., 2010; Sebire et al., 2013), which in turn with lead to children being healthier (Elbe et al., 2017), with superior cognitive performance (Vanhelst et al., 2016).

The findings from Chapter IV also revealed, however, that a few children felt bored during The Daily Mile due to its repetitive nature and it was suggested that incorporating other activities and/or a competitive element would help to negate this. Importantly, while all children expressed a desire for variety in the physical activity they engage in at school, most children enjoyed the non-competitive nature of The Daily Mile (Chapter VI). Nevertheless, these findings highlight the importance of implementing The Daily Mile during lesson time in addition to, and not in replacement of, breaktime or physical education, as has been reported in some studies (Malden & Doi, 2019; Marchant et al., 2020), as this will ensure there is adequate variety of physical activity and opportunity for competition for children at school.

Moreover, teachers report that their participation in The Daily Mile motivates children and increases physical activity levels, as children compete with them (Malden & Doi, 2019). Teachers could thus seek out children who desire competition and participate in The Daily Mile with them. This will help to sustain engagement and enjoyment in competitive children and will allow other children to enjoy a non-competitive Daily Mile, which is not possible when incentive or reward-based systems are implemented, as has been reported in some schools (Malden & Doi, 2019). Additionally, incorporating discretionary goal setting which enables self-competition may help to sustain the engagement of all children, as has been suggested by some teachers implementing The Daily Mile (Marchant et al., 2020). Future research could consider, however, whether incorporating some cognitively engaging activities into The Daily Mile may help to sustain enjoyment in all children, without compromising the core components that make The Daily Mile so successful.

8.4. Strengths and Limitations

The work presented in this thesis has a number of strengths. Firstly, the studies took an ecologically valid approach to paediatric exercise research through the utilisation of physical activity that school children find enjoyable and typically engage in, and by conducting all measurements on-site within schools. Moreover, appropriate and valid field-based measurements were utilised (e.g., MSFT) and the studies adopted a high level of control over potential confounding variables (e.g., dietary intake controlled using standardised breakfast). Additionally, the studies presented within this thesis controlled, or at least reported, data regarding the main moderating variables (physical activity characteristics, participant characteristics, timing of cognitive testing) in the physical activity-cognition relationship; this has provided transparency of research methods and has supported the inference of findings and comparison of findings with the wider literature.

The work presented within this thesis is not, however, without limitations. One of the main limitations is the smaller than intended sample size for Chapter VII, which occurred due to last minute dropouts due to isolation of a class bubble resulting from the COVID-19 pandemic. Nonetheless, every effort was made to retain as many participants as possible in the study and to ensure that the intervention was completed, with follow-up measures obtained. Moreover, the objective to measure children's activity patterns from chronic participation in The Daily Mile was unfortunately not achieved due to technical issues with the GPS units. This information would elucidate whether (and when) any changes to physical activity performance occur from repeated participation in The Daily Mile, which is needed to better understand the impact of The Daily Mile on cardiorespiratory fitness, health and cognitive performance, and to determine the appropriateness of long-term implementation.

Furthermore, due to the diverse and complex nature of the physical activity-cognition relationship, it was not feasible to measure all possible impacting factors in the studies presented within this thesis. For example, according to a recent report, sleep quality and sleep efficiency may play mediating roles in the physical activity-inhibitory control relationship in young adults (Li et al., 2021). It would thus be valuable for future research to measure this variable when examining the effects of physical activity on cognitive function in youth.

8.5. Conclusions and Practical Applications

From the studies presented within this thesis, several patterns have emerged relating to the moderating variables in the acute physical activity-cognition relationship and the effectiveness of The Daily Mile as a school-based physical activity intervention. Specifically, these are:

- *Duration is a significant moderator in the physical activity-cognition relationship*, with participation in 30 min, compared to 60 min, of high-intensity intermittent activity resulting in greater enhancements to young people's cognitive function.
- *Higher cardiorespiratory fitness is associated with superior cognitive function in young people*. However, neither sex nor cardiorespiratory fitness moderate the acute effects of The Daily Mile on cognition.
- *The Daily Mile is a worthwhile intervention* as it is an enjoyable and inclusive (children of all fitness levels can participate and experience similar relative 'dose' from participation) physical activity that presents high levels of adherence. Additionally, it contributes to physical activity targets, enables progression in physical activity performance (increase in physical activity intensity over time), improves body composition, and tends to acutely and chronically enhance some aspects of cognitive function.
- *There are limitations to The Daily Mile* such as the tendency for it to become boring for some children over time, and the fact that no effects to adiposity (waist-to-hip ratio,

skinfolds) or cardiorespiratory fitness were observed from participation over five and a half weeks.

- *The Daily Mile should be implemented as part of a comprehensive whole school approach to physical activity.* The initiative should be implemented alongside other formal and informal opportunities for physical activity in school across the school day, and not as an alternative to physical education or break time.

8.5.1. Recommendations for Optimising the Benefits Gained from The Daily Mile

- *Anything is better than nothing*. Even if only 5 min is available on any given day, it is still worthwhile implementing The Daily Mile as children covered the greatest distance and were most intermittent during this time (Chapter V), so benefits from participation are likely and the activity will contribute towards MVPA targets.
- *Keep children informed*. Teachers/school staff should inform children of how much time is left during participation in The Daily Mile, particularly when in the last 5 min as children increase the distance they cover in high-speed zones and become more intermittent in the last 5 min (Chapter V), suggesting that they invest additional effort in the activity when provided with this information.
- *Balance engagement between the sexes*. Differences in activity patterns and relative physical activity intensity is observed between boys and girls (Chapter V) and although sex does not moderate the effect of an acute bout of The Daily Mile on cognition (Chapter VI), the differences in activity patterns may lead to differences in long term impact of The Daily Mile on body composition, cardiorespiratory fitness and cognitive function. Teachers/school staff can support an increase in girl's physical activity through verbal encouragement (Harris et al., 2019) and through their own personal engagement (Marchant et al., 2020). It is paramount, however, that the core components of The Daily Mile (e.g., simple, social nature) which are important for enjoyment and fundamental to its popularity and success as a school-based intervention (Harris et al., 2020; Ryde et al., 2018) and not changed in this process.

- *Implement every day, and throughout the school year.* This will promote achievement of in-school daily physical activity targets and provide the best chance for gaining improvements to cognitive function, body composition and cardiorespiratory fitness from participation.

8.6. Directions for Future Research

To advance the knowledge regarding the physical activity-cognition relationship in young people, and the impact of The Daily Mile on young people, the following suggestions are recommended for future research:

- Research should continue to examine the moderating variables in the physical activity-cognition relationship, at first in isolation and subsequently the nature in which they interact. Moreover, where this is not the main aim of the research, the potential moderating variables should be controlled, and at least reported to allow synthesis and interpretation of the literature as a whole.
- Further examinations of the effect of chronic participation of > 6 weeks in The Daily Mile on cognitive function, as this is currently unknown and will elucidate the potential impact of this school-based initiative on young people's subsequent learning and academic performance.
- Investigation into the potential moderating role of participant sex and cardiorespiratory fitness on the chronic effects of The Daily Mile on body composition, cardiorespiratory fitness and cognitive function, as this is not yet known. These investigations will illuminate any inequalities that may be exacerbated by The Daily Mile and will help to inform on how to diminish/eliminate these if present.
- The participants in the studies presented within this thesis had higher cardiorespiratory fitness and lower rates of overweight and obesity compared to other young people of the same age and sex (Public Health England, 2022; Tomkinson et al., 2018). Additional research with diverse samples which vary with regards to cardiorespiratory

fitness, sex, socioeconomic status, and cognitive performance (e.g., special educational needs, ADHD) would be valuable.

- Future research could compare the effects of The Daily Mile to cognitively engaging physical activity and/or explore the effect of a ‘Daily Mile’ which involves a cognitively engaging element on participant enjoyment, as well as physical and cognitive outcomes.

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Appendix A
Participant information

The Daily Mile: Effects to Children's Brain Function

Research suggests that participation in exercise has a positive effect on health and cognitive function in children, adolescents and adults. Therefore, daily physical activity is key in keeping us healthy, as well as in optimising learning, development and academic achievement.

School-based interventions like 'The Daily Mile' aim to get children involved in exercise. The Daily Mile involves children going outdoors for 15 minutes (~ 1 mile) each day and exercising at their own pace (e.g. walk/jog/run), usually around the school playground or sports pitch. The Daily Mile is gaining popularity and a large amount of funding has been given to support its use in schools across the UK.

Currently, however, surprising little is known regarding the effects of The Daily Mile on children's health and performance. This includes an absence of high-quality research on the effects of The Daily Mile on the brain function of school children.

Therefore, the aim of the present study is to explore the effect of The Daily Mile on brain function in primary school children aged 8-11 years old.

What does the study involve?

- Your child will complete a familiarisation session (visit 1), as well as two pre-intervention (visit 2 & 3) and post-intervention (visit 4 & 5) measurement sessions.
- The familiarisation visit will include body composition measurements (e.g. height) and practice attempts at three brain function tests (which measure attention, memory & inhibitory control). Your child will also have a go at The Daily Mile, to familiarise themselves with this exercise.
- The first pre- and post-intervention visits will involve your child completing the cognitive function tests, body composition measurements and a 'Bleep' test to measure fitness.
- The second pre- and post-intervention visits will involve your child completing The Daily Mile.
- Your child will be randomly assigned to either The Daily Mile intervention group or the control group. Children in The Daily Mile intervention group will complete The Daily Mile in school 4-5 days per week for 5 weeks, under the guidance of their teacher. Children in the control group will continue with their normal daily school routine for the 5 weeks. The pre- and post-intervention visits will occur before and after this 5 week period.
- On two occasions during the 5 weeks, children in The Daily Mile intervention group will wear a heart rate monitor and a GPS unit while completing The Daily Mile, to measure their activity (e.g. distance covered and speed).

COVID Provision:

The health and safety of our participants and research team are primary concerns. Therefore, the following COVID specific considerations will be implemented for the duration of this study;

- **Documentations:** Transmission rates via paper surfaces are low, however, wherever possible documentation will be provided electronically.
- **Personal Protective Equipment (PPE):** Face masks, face shields and gloves will be worn by all members of the research team throughout.
- **Physical contact:** If a member of the research team is required to take the measurement of a participant (e.g. height), they will position themselves with their chest towards the participants back (i.e. no face-to-face contact).
- **Brain Function Tests:** A member of the research team will position themselves at the front of the class, complying with social distancing requirements, and will provide the students with instructions on the cognitive tests.
- **Food preparation:** Strict food hygiene protocols will be followed by research team members and PPE (face masks, face shields and gloves) will be worn at all times during food preparation and serving.
- **The 'Bleep' Test:** This will be completed outside and social distancing requirements will be adhered to for the duration of the test (i.e. participants will run in lanes 2 m apart).
- **The Daily Mile:** The Daily Mile will be completed outside. Social distancing measures will be maintained throughout. Participants will fit the GPS vest and heart rate monitor themselves, following instructions on appropriate placement and fit. If a member of the research team is required to assist a participant, they will position themselves with their chest towards the participants back (i.e. no face-to-face contact) and will wear PPE (face mask, face shield and gloves). Participants will place their GPS vest and heart rate monitor strap directly into a designated sealable waste bag ready for washing. GPS and heart rate monitors will be disinfected and washed after each use.

What is required prior to the main trials?

- Children must not participate in exercise that results in heavy breathing for 24 hours before all visits (exercise at school is ok).
- On the morning of all visits children are to not have breakfast, as this will be provided on arrival at school.
- Caffeinated drinks should not be consumed 24 hours before all visits.

* Parent/Guardian/Carers will be reminded of these requirements two days before each session.

Important Notes:

- While your child's school has agreed to take part in this study, it is **NOT** compulsory your child takes part.
- Your child's school has agreed to participate in this project, thus taking time off normal lessons to participate has been cleared with the school.
- Your child can withdraw at any time without having to provide a reason.
- If at any point your child does decide to withdraw from the study their data will be destroyed.
- As a token of appreciation for the time and effort invested by the school staff and children, the school will receive sports equipment to the value of £10 per child who participates in the study.
- All staff involved in the study undertake training in the measures involved and undergo a DBS check to clear them to work with children.
- Your child will be supervised on all occasions and will only leave the testing session once they feel comfortable to do so.
- All information will be stored anonymously and your child's individual data will not be reported in the findings of the study.
- The study has been approved by Nottingham Trent University's Ethical Advisory Committee.

What to do next?

If you are willing for your child/dependent to participate in this study **please (parent/guardian) complete the enclosed consent form and health screen questionnaire and return them to your child/dependent's school as soon as possible.**

Contact Details:

If you have any questions you wish to ask, please do not hesitate in contacting Miss Lorna Hatch (lorna.hatch@ntu.ac.uk), Dr. Simon Cooper (simon.cooper@ntu.ac.uk or tel. 0115 848 8059), Dr. Caroline Sunderland (caroline.sunderland@ntu.ac.uk or tel. 0115 848 6379) or Professor Mary Nevil (mary.nevill@ntu.ac.uk or tel. 0115 848 3918).

We each look forward to meeting and working alongside you and your child and encourage you to contact us should you have any questions.

Thank you for taking the time to read the information relating to our study.

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Appendix B

Parent/Guardian Statement of Consent for Child/Dependent to Participate in the Investigation Entitled:

The Daily Mile: Effects to Children's Brain Function

1) I, *[name of parent/guardian]* agree for my child/dependent, *[name of participant] to* partake as a participant in the above study.

2) I understand from the participant information sheet, which I have read in full, that this will involve my child/dependent completing a familiarisation session, pre-and post-intervention visits and The Daily Mile. This is in order to determine the effect of this kind of exercise on primary school children's brain function. My child/dependent will undergo health measures, including a fitness test and cognitive function tests.

3) I also understand that the risks and side effects which may result from my child/dependent's participation are as follows: maximal exercise may cause delayed onset muscle soreness and the high intensity exercise may result in risks to health and in extreme cases can be a cause of sudden death. However, in active individuals the risks are minimal and all individuals who wish to take part in this study will complete a health history questionnaire beforehand which will be thoroughly checked by the lead investigator.

4) I confirm that the study has been explained to my child/dependent and that I and my child/dependent have had the opportunity to ask questions about the study. Where we have asked questions, these have been answered to our satisfaction.

5) I undertake to abide by University regulations and the advice of researchers regarding safety.

6) I am aware that I can withdraw my consent for my child/dependent to participate in the procedure at any time and for any reason, without having to explain my withdrawal and their personal data will be destroyed.

7) I understand that any personal information regarding my child/dependent, gained through their participation in this study, will be treated as confidential and only handled by individuals relevant to the performance of the study and the storing of information thereafter. Where information concerning my child/dependent appears within published material, their identity will be kept anonymous.

8) I confirm that I have had the University's policy relating to the storage and subsequent destruction of sensitive information explained to me. I understand that sensitive information provided through my child/dependent's participation in this study, in the form of health screens, questionnaires and cognitive function test data will be handled in accordance with this policy.

9) I confirm that I have completed the health questionnaire and know of no reason, medical or otherwise that would prevent my child/dependent from partaking in this research.

10) I confirm that I understand the COVID-19 precautions that will be implemented in this study and that I and my child/dependent have had the opportunity to ask questions about these precautions. Where we have asked questions, these have been answered to our satisfaction.

To be completed by parent/guardian/care-giver:

Parent/Guardian signature: Date:

Independent witness signature: Date:

Primary Researcher signature: Date:

<u>Appendix C</u>

Participant Assent Form

The Daily Mile Study

- I have read the participant information sheet and understand what I am being asked to do in this study.
- I have talked about this with my parent/guardian/care-giver and they agree that I can take part in the study.
- The purpose and details of the study have been explained to me and I understand that the study involves:

- Completing a 'bleep test' and The Daily Mile
- Consuming breakfast (cornflakes with milk and toast with margarine)
- Completing computerised brain function tests (short computer tests)
- Having measures taken (including height and weight)

- I have had a chance to ask any questions about taking part in the study.
- I understand that there are some risks of taking part in this study but these risks have been minimised and I am not worried about taking part.
- I understand the COVID-19 precautions that will be implemented for this study
- I have been told that I can stop taking part at any time if I change my mind and that I will not have to provide a reason for this.
- If I am worried or want to stop taking part I just have to talk to Lorna Hatch (lorna.hatch@ntu.ac.uk). I can also ask my parent/guardian/care-giver to talk to Lorna Hatch (lorna.hatch@ntu.ac.uk) if I am worried but do not want to say so myself.

I agree to take part in this study

Name of participant: ……………………………………………………………

Signature of participant: ……………………………………………………………

Signature of Researcher: ………………………………………………......................

Date: ……………………………………………………………

Appendix D
Health Screen Questionnaire

To be completed by parent/guardian/care-giver on behalf of your child/dependent

Name of child ....……………

Please complete this brief questionnaire to confirm fitness of your child/dependent to participate:

1. **At present,** do you have any health problem for which you are:

(a) on medication, prescribed or otherwise — Yes ☐ No ☐

(b) attending your general practitioner — Yes ☐ No ☐

(c) on a hospital waiting list — Yes ☐ No ☐

2. **In the past two years,** have you had any illness which required you to:

(a) consult your GP — Yes ☐ No ☐

(b) attend a hospital outpatient department — Yes ☐ No ☐

(c) be admitted to hospital — Yes ☐ No ☐

3. **Have you ever** had any of the following?

(a) Convulsions/epilepsy — Yes ☐ No ☐

(b) Asthma — Yes ☐ No ☐

(c) Eczema — Yes ☐ No ☐

(d) Diabetes — Yes ☐ No ☐

(e) A blood disorder — Yes ☐ No ☐

(f) Head injury — Yes ☐ No ☐

(g) Digestive problems — Yes ☐ No ☐

(h) Heart problems — Yes ☐ No ☐

(i) Problems with bones or joints — Yes ☐ No ☐

(j) Disturbance of balance / coordination — Yes ☐ No ☐

(k) Numbness in hands or feet — Yes ☐ No ☐

(l) Disturbance of vision — Yes ☐ No ☐

(m) Ear / hearing problems — Yes ☐ No ☐

(n) Thyroid problems — Yes ☐ No ☐

(o) Kidney or liver problems — Yes ☐ No ☐

(p) Allergy to nuts, alcohol etc. — Yes ☐ No ☐

(q) Any problems affecting your nose e.g. recurrent nose bleeds — Yes ☐ No ☐

(r) Any nasal fracture or deviated nasal septum — Yes ☐ No ☐

4. **Has any,** otherwise healthy, member of your family under the age of 50 died suddenly during or soon after exercise? Yes ☐ No ☐

5. Have you had a cold, flu or any flu like symptoms in the last month? Yes ☐ No ☐

If YES to any question, please describe briefly if you wish (e.g. to confirm problem was/is short-lived, insignificant or well controlled.)

....
....
....

6. Has your child ever been diagnosed with Coronavirus (COVID-19)? Yes ☐ No ☐

If you answered **<u>YES</u>** to question 8, please answer the following questions.

(a) How was this diagnosis confirmed? . . . .

(b) Was your child hospitalised? Yes ☐ No ☐

(c) What was the date of your child's diagnosis? . . . .

(d) What was the duration of your child's illness? . . . .

(e) Is you child currently free from COVID-19 symptoms (unexplained fever, dry continuous cough, sudden loss of taste or smell)?

Yes ☐ No ☐

7. Does your child/dependent have any dietary requirements we need to be aware of?

The breakfast being provided consists of cornflakes with semi-skimmed milk and white bread toasted with flora margarine

Yes ☐ No ☐

If YES, please describe briefly the dietary requirements of your child/dependent:

....
....
....

Please complete the below contact details so that a member of our research team is able to contact you in the event of an emergency:

Name of parent/guardian/care-giver: ________________________

Relationship to child/dependent: ________________________

Contact Telephone Number: __________________________

Questions (***** = priority questions)	**Probes**
***1.** Today you did the Daily Mile. What was your experience of the Daily Mile?	Outside 20 min Choose to walk/jog/run With friends, all about fun
***2.** Did you enjoy doing the Daily Mile or did you not enjoy the Daily Mile?	Did enjoy? Can you give me any examples (e.g.) Didn't enjoy? e.g.
3. How would everyone feel if your school started doing the Daily Mile every day?	Same activity, outside Most days During lesson School uniform (vs. sports kit)
4. If not the Daily Mile, what other type of exercise would you enjoy doing the most in school?	Modality + intensity Duration + time of day + frequency Environment Social context (inv./teams; competitive/ for fun)
5. Tell me a little bit about….how you feel about exercise?	Like? Can you give me any examples (e.g.) Dislike? e.g.
6. How would you all feel if your school started doing more exercise with you each day?	Like? Can you give me any examples (e.g.) Dislike? e.g.