Physical activity and cognition in children

Anneke van der Niet

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Moveo ergo sum

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General introduction

"When you play outside a lot, your brain can explore the world, what it's like"
(10 year old boy)

Just like this 10 year old boy mentions in response to a question "why do you think physical activity and brain function are related?", most individuals are aware of the fact that our physical activity and physical fitness are related to our brain fitness. Already the ancient Greek and Roman philosophers mentioned the link between the body and mind with "mens sana in corpora sano" (although this was mentioned in a slightly different context) (Tomporowski, Lambourne, & Okumura, 2011). Yet while the health benefits of physical activity on children's physical development have been studied extensively, only recently researchers have started to study the relationship between physical activity and children's cognitive abilities, and to explore the possible underlying processes that can explain these findings. In this thesis, the relationship between physical activity, physical fitness and cognition will be studied. In addition, a physical activity intervention program was developed and implemented during lunch recess at several primary schools, and effects of this increase in physical activity on physical fitness and cognition were investigated. This provides insight into the complex relationships between physical activity, physical fitness and cognition in children, as well as effects on physical fitness and cognition when physical activity is manipulated.

1.1 Theoretical background

Physical activity, physical fitness and cognitive performance

Humans are born to be physically active. Our bodies are designed to move. Physical activity comprises all bodily movement produced by the muscular system that increases energy expenditure above normal physiological demands (Ortega, Ruiz, Castillo, & Sjöström, 2008). From an evolutionary perspective, movement of the body is a central concept in the development of cognition (Llinas, 2001). Cognition is a very general term that reflects a number of underlying mental processes (Tomporowski, Davis, Miller, & Naglieri, 2008); e.g. perception, attention, executive functioning, intelligence, and academic achievement. It is through movement that we gradually come to understand, predict and anticipate the outcome of behavior. Physical activity and sensorimotor experience may thus be necessary for optimal neural development in children (Piaget, 1952). Young infants learn how to reach, sit, walk and run by experiencing and exploring a wide range of movements (Spencer et al., 2006). Most children have developed fundamental movement skills by the time they enter school at around age 4, which allows them to play physically active games with their peers. As children grow older, they will continue to explore by means of unstructured activities during free play time, and can develop and master more complicated movement skills during physical education or participation in organized sport and exercise. This will be beneficial for their general health and mental well-being. More specifically, involvement in repetitive and structured physical activity could increase children's physical fitness. Physical fitness is a set of attributes associated with the capacity to perform a variety of physical activities (Ortega et al., 2008), and consists of several dimensions like muscular strength, muscular endurance, speed, and cardiovascular endurance. While physical fitness has a strong genetic component, regular involvement in physical activity is essential for promoting physical fitness of children (Strong et al., 2005). It promotes development of the cardiovascular and musculoskeletal system. In addition, the physiological stress as a result of physical activity will be present in the brain, and can promote brain function. This has already been demonstrated in research on adults, which shows that physical activity enhances learning and memory (Hillman, Erickson, & Kramer, 2008), and might be even more important when the brain is still developing rapidly, as is the case in school aged children. The cognitive functions that show the largest benefits of physical activity are those that require extensive amount of cognitive control, i.e. executive functions. In this thesis, the focus is on these executive functions; the relationship with and the effects of physical activity and physical fitness on executive functions in children (Figure 1.1). In addition, academic achievement in children is studied, as the development of executive functions and academic achievement are closely related (Best, Miller, & Naglieri, 2011).

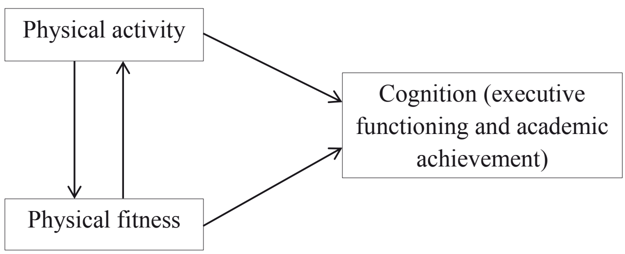

Figure 1.1. Hypothesized relations as examined in this thesis.

Executive functioning and academic achievement

As children develop, they become increasingly able to control their thoughts and actions, which has been associated with the development of executive functions (Friedman et al., 2008; Pennequin, Sorel, & Fontaine, 2010). Executive functions refer to various cognitive processes used to regulate goal directed interaction with the environment, especially in non-routine and unstructured situations (Banich, 2009). While executive functioning is an umbrella term that includes a wide range of skills and abilities, it is considered to include four core abilities; inhibition, working memory, cognitive flexibility, and strategic planning (Anderson, 2002; Miyake et al., 2000). Executive functions are essential for interaction in normal daily activities. Moreover, executive functions are related to creativity (Scibinetti, Tocci, & Pesce, 2011), and the emergence of theory of mind (Carlson, Moses, & Breton, 2002). Executive functions develop rapidly through childhood, and are clearly correlated with the maturation of the frontal lobes, in particular the prefrontal cortex; both psychological and neurobiological models of executive functions have suggested the close linkage between the development of executive functions and the refinement of prefrontal cortical circuitry (Best & Miller, 2010; Diamond, 2002). The prefrontal cortex shows several critical periods of development; during the first year of life, between 3 to 6 years, and during preadolescence, between 7 to 12 years of age (Anderson, 2002; Diamond, 2002). Therefore, it is likely that executive functioning might benefit from physical activity during the preadolescent years. This, in turn, might also be beneficial for academic achievement. Academic achievement is related to school performance, and is most often expressed as academic grade or score on standardized tests of mathematics, reading and spelling. Mathematics, reading and spelling are complex skills that require a child to effectively plan, update working memory, shift attention or inhibit impulsive behavior (Best et al., 2011). Executive functions are thus essential for academic achievement. In addition, the development of executive functioning goes together with the development of language (Ardila, 2013).

Language and executive functioning

As executive functioning is about the processes that control and regulate thought and action, language plays an important role in executive functioning processes. Inner speech (talking to oneself) seems crucial to apply and evaluate decisions, or to hold and manipulate information in mind. Indeed, language is seen as a cornerstone in the development of executive functioning (Ardila, 2008). Language is a complex social behaviour that includes multiple processes related to sensory, motor and cognitive skills (Jacob, 2013; Knudsen, 2004). Language development represents a powerful instrument to accumulate and transmit knowledge about the world, and is crucial for the initiation and maintenance of interpersonal relationships (Marton, Abramoff, & Rosenzweig, 2005). Children with developmental language disorders (DLD) are characterized by delayed language in the absence of a mental or physical handicap or a specific sensory or emotional cause (Bishop, 1992). The prevalence of language delay in children in the Netherlands has been estimated to be between 5 and 10% (Reep-Van den Berg, De Koning, De Ridder-Sluiter, Van der Lem, & Van der Maas, 1998), and is more likely to affect boys than girls. As language and executive functioning are intertwined, children with DLD also experience difficulties with executive functions (Henry, Messer, & Nash, 2012; Vugs, Hendriks, Cuperus, & Verhoeven, 2014). In addition, they show lower motor skill performance, which might be the result of a genetic risk or neurologic deficit, or of less or less varied physical activity, as communication difficulties will negatively influence social acceptance and participation in play activities. It is interesting to investigate the physical activity and physical fitness levels of children with DLD, as physical activity may be a tool to improve executive functioning in children with DLD. In this thesis, both typically developing children and children with DLD are included.

Previous research on physical activity and executive functioning

Within neuropsychology, which is the study of brain-behavior relationships, executive functioning is a relatively new term that was first mentioned as a subdomain of cognition by Luria in 1966 (Ardila, 2008). However, the idea that there was something like "higher" order cognition dates back from late 19th and early 20th century, when clinical investigators documented diverse behavioral disorders in cases of frontal pathology (e.g. the story of Phineas Gage) (Ardila, 2008). Based on adults with frontal injuries and experimental lesions studies, a basic understanding emerged on the role of executive functioning in adults. Neuropsychological tests were developed to detect deficiencies in normal brain function (Pennington & Ozonoff, 1996). Only in the late 1980s researchers started to focus on executive functioning development in children, at first in children with frontal lobe lesions (Espy & Kaufmann, 2002). From the mid-1990s, a growing body of research gradually emerged on executive functioning development in typically developing children, and on the beneficial effect of exercising the body on the performance capabilities of the brain. In the last decade, a few studies have shown a positive relationship between *physical fitness* and executive functioning in children; children with better performance on a physical fitness test also show better performance on tests measuring executive functioning (Buck, Hillman, & Castelli, 2008; Chaddock et al., 2010). In addition, neuroimaging studies on brain structure and function (e.g. EEG, fMRI) show that fitter children or more active children display larger volumes of specific regions of the basal ganglia and hippocampus, and show greater P3 amplitude during executive functioning tests than their less fit or active peers, indicating better working memory and inhibitory capacity (Chaddock et al., 2010; Kamijo, Takeda, & Hillman, 2011; Pontifex et al., 2011). Furthermore, a few studies have shown positive effects of *physical activity* on aspects of executive functioning performance in children, both immediately after exercise (acute effects) (Hillman et al., 2009) as well as effects resulting from multiple bouts of exercise (chronic effects) (Davis et al., 2011; Kamijo et al., 2011). Nevertheless, research on the effects of physical activity on executive functioning in children is still limited, and the mechanisms explaining the possible effects are subject of debate.

Neurobiological pathways

Regular aerobic exercise at a moderate to vigorous intensity appears specifically to enhance executive functioning, but involvement in cognitively engaging physical activity can stimulate executive functioning as well. Several mechanisms are mentioned to explain the relationship between physical activity and executive functions. They can broadly be categorized in physiological mechanisms and learning/developmental mechanisms. The physiological hypothesis states that aerobic exercise induces certain physiological changes in the brain as a result of increased physical fitness. Aerobic exercise places a demand on the body's cardiovascular system; there is an increase in the ability of the heart to deliver oxygen to the working muscles. However, aerobic exercise will also lead to an increased cerebral blood volume and will stimulate the release of neurotransmitters; both animal and human research show increased levels of neurotransmitters like brain-derived neurotrophic factor (BDNF) and other growth factors, that promote neurogenesis and synaptic plasticity (Hötting & Röder, 2013). In addition, research in humans shows increased regional cerebral blood volume in a specific area of the hippocampus involved in memory performance (Pereira et al., 2007). The beneficial effects of physical activity on cognition might thus be mediated by these physiological factors. Other mechanisms explaining the relationship between physical activity and cognition focus on the cognitive demands apparent in goal-directed exercise. When children are engaged in physical activities, these activities often take place in a complex and constantly changing environment.

The cognitive skills acquired during physically active free play and games will perhaps transfer to skills used during executive functioning tasks, or to skills apparent in words and mathematical operations. Also, learning new movements or being confronted with new situations as a result of making movements, require complex cognition (Best, 2010). This places a high demand on cognitive processes, including executive functions. Animal research suggest that environmental enrichment and complex learning tasks can promote the survival of new neurons (Kempermann et al., 2010), confirming the importance of cognitively engaging physical activity. The physiological and cognitive demand pathways might be additive, which would mean that a combination of both aerobic exercise and complex activity will lead to the biggest positive effects (Kempermann et al., 2010). Therefore, in the current study a combination of both exercises is included in the physical activity intervention program.

1.2 Objectives and outline of this thesis

The aims of this thesis are to 1) to examine the relationship between physical activity, physical fitness, executive functioning and academic achievement in primary school children aged 8-12 years, and 2) to study the effects of manipulating physical activity levels of children on physical fitness and executive functioning. Both typically developing children and children with DLD are examined.

In Chapter 2, relationships between physical fitness, executive functioning, and academic achievement are studied in typically developing children. More specifically, it is investigated if executive functioning has a mediating role within the relationship between physical fitness and academic achievement. While there are studies linking physical fitness to either executive functioning or academic achievement, it is valuable to investigate those relationships together. This is done by creating structural equation models, in which the relations between physical fitness, executive functioning and academic achievement are examined simultaneously. Physical fitness, executive functioning and academic achievement are factors that consist of several aspects that can be measured. Therefore, prior to the main analysis of the relationships between those three factors, it is necessary to perform confirmatory factor analysis to test whether the observed measures are good indicators of each factor. Measures of aerobic fitness are often used in studies relating physical fitness to cognition, however, in this study also strength components of physical fitness are included. Executive functioning and academic achievement are measured with neuropsychological tests and the child academic monitoring system.

The aim of Chapter 3 is to examine the relationships between objectively measured daily physical activity and performance on core aspects of executive functioning in typically developing children. Daily physical activity of children, which means the typical activity pattern of children in daily life, can be measured with an accelerometer that children wear all day long, for several days. This is important to investigate, as habitual physical activity of children consists of long periods of time spent sedentary, alternated with physical activity at low intensity, and short bursts of moderate to vigorous physical activity. Chapter 3 gives insight into the time spent in different intensity levels in children, which are then related separately to their performance on executive functioning measures.

Chapter 4 focuses on children with developmental language disorders. As communication is very important to get involved in activities that require social interaction, it might be expected that children with DLD show lower physical activity and physical fitness levels compared to typically developing children. Therefore, in this study physical activity and physical fitness levels of children with DLD are compared to those levels of typically developing children. In addition, physical activity is related to performance on the physical fitness measures in both groups of children. So far, no studies have evaluated the developmental profile of children with DLD across physical activity and physical fitness domains.

Chapters 5 and 6 describe the effects of a physical activity intervention program on physical fitness and executive functioning of respectively typically developing children and children with DLD. While the physical activity intervention program for typically developing children was provided twice a week during lunch recess, children with DLD followed the intervention program as part of the regular school day. In both instances, the physical activity program was run for 22 weeks. In these chapters, baseline and posttest scores on physical fitness and executive functioning of children in the intervention group are compared to those scores of children in a control group who did not follow the physical activity intervention program. Results can provide insight into effects of increased physical activity on physical fitness and executive functioning in children. The possible mechanisms explaining the relation between physical activity and executive functioning are also discussed. In addition, Chapter 6 explores whether physical activity offers an alternative way to improve executive functioning in children with DLD, who experience difficulties in both language and executive functioning performance.

Finally, a summary and general discussion are provided, in which the results of the studies in this thesis are discussed more generally in the light of the theory as described in this introduction. In addition, critical reflections are made on the theoretical background, and on the methods used in this study. Suggestions for further research are provided, in order to strengthen the importance of promoting children to be physically active. Children need to have the opportunity to explore the world through physical activity, because, just like the boy said, only then the brain can understand how it is to act in this complex world.

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2

Modeling relationships between physical fitness, executive functioning, and academic achievement in primary school children

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Abstract

Objectives: The relationship between physical fitness and academic achievement in children has received much attention, however, whether executive functioning plays a mediating role in this relationship is unclear. The aim of this study therefore was to investigate the relationships between physical fitness, executive functioning, and academic achievement, more specifically to test whether the relationship between physical fitness and academic achievement is direct or indirect, via executive functioning.

Design: Cross-sectional.

Method: This study examined 263 children (145 boys, 118 girls), aged 7 to 12 years, who performed tests on physical fitness, executive functioning, and academic achievement.

Results: In a structural equation model linking physical fitness to executive functioning and academic achievement there was a significant relationship between physical fitness and executive functioning (r = .43, R^2 = .19) and academic achievement (r = .33, R^2 = .11). Adding a relationship from executive functioning to academic achievement resulted in a non-significant direct link between physical fitness and academic achievement (r = -.08, R^2 = .006). However, a significant indirect relation through executive functioning persisted. The indirect relation between fitness and academic achievement (r = .41), was stronger than both the direct and total relation (r = .33).

Conclusion: Executive functioning thus served as a mediator in the relation between physical fitness and academic achievement. This highlights the importance of including executive functioning when studying the relationship between physical fitness and academic achievement in children.

2.1 Introduction

While researchers and health professionals notice that children are increasingly less fit, teachers are observing that there is a growing concentration deficit and reduced attention in children (Budde, Voelcker-Rehage, Pietraßyk-Kendziorra, Ribeiro, & Tidow, 2008). In this context it is interesting to look at the relation between physical fitness and performance in the classroom. Physical fitness (fitness) is a set of attributes associated with the capacity to perform physical activities (Ortega, Ruiz, Castillo, & Sjöström, 2008). It refers to the full range of physical qualities and can be subdivided into various aspects like aerobic endurance, muscle strength and body composition (Ruiz et al., 2006). In children, fitness has not only been related to performance on academic achievement, but also to other cognitive functions. Some studies have found a positive relationship between aerobic endurance and academic achievement (Castelli, Hillman, Buck, & Erwin, 2007; Chomitz et al., 2009; Eveland-Sayers, Farley, Fuller, Morgan, & Caputo, 2009), or between aerobic endurance and aspects of higher order cognitive functions, e.g. executive functioning (Buck, Hillman, & Castelli, 2008; Hillman, Buck, Themanson, Pontifex, & Castelli, 2009; Pontifex et al., 2011). Executive functioning encompasses a subset of cognitive operations used to effortfully guide behavior towards a goal (Banich, 2009), and includes abilities such as inhibition, filtering interference, flexibility of action and strategy development. Executive functioning develops throughout childhood and adolescence and has been linked to academic achievement (Bull & Scerif, 2001).

Neuropsychological research shows that performance in executive functioning is mediated by the development of the prefrontal cortex (Stuss, 1992). Children show substantial improvements in executive functioning when the frontal brain regions mature, with rapid development between ages 7 and 9 (Anderson, 2002; Best, Miller, & Jones, 2009). A foundational component of executive functioning is cognitive flexibility (also called set-shifting). Cognitive flexibility is the ability to alternate attention between two simultaneous goals (Arbuthnott & Frank, 2000). The ability to shift between two tasks starts in infancy but develops into more complex switching capacity throughout childhood and into adulthood (Diamond, 2002). It is usually tested in set-switching tasks, in which the participant is asked to switch between two stimuli or to sort cards according to rules that change along the way (Best et al., 2009). Successful task switching requires inhibitory control of the currently irrelevant task set (Arbuthnott & Frank, 2000), and is found to be of importance in environments in which attentional demands are constantly changing.

Another important executive function is response planning or problem solving, which refers to the processes that facilitate the selection of task appropriate responses (Asato, Sweeney, & Luna, 2006). The ability to plan is a critical part of goal-oriented behavior and enables a child to direct and evaluate his or her behavior when confronted with a novel situation (Best et al., 2009). Tasks testing this ability require the child to plan multiple steps in advance and evaluate this plan while performing the actions (Best et al., 2009). Response planning involves multiple cognitive processes like response inhibition and working memory, and therefore reflects essential elements of executive functioning (Asato et al., 2006).

Both cognitive flexibility and response planning are frequently linked to the development of academic achievement in children, especially mathematics and reading (Best, Miller, & Naglieri, 2011). It is thought that improvements in executive functioning facilitate improvements in academic achievement (Best et al., 2009), or that adequate executive functioning develops prior to behaviors affecting academic achievement (Blair & Razza, 2007). Indeed, the ability to shift attention is likely to be important for moving between tasks and has been found to be involved in mathematics (Bull, Espy, & Wiebe, 2008) and reading performance (Van der Sluis, De Jong, & Van der Leij, 2007). Likewise, the ability to plan in order to solve a problem seems to be fundamental for mathematic skills (Sikora, Haley, Edwards, & Butler, 2002).

The link between fitness and executive functioning or academic achievement in children seems to be most valid for the aerobic fitness component of physical fitness. Aerobic fitness refers to the overall capacity of the cardiovascular and respiratory system to use oxygen, and the ability to carry out prolonged strenuous exercise (Ortega et al., 2008). Castelli et al. (2007) examined the relation between academic achievement and various aspects of fitness, including aerobic fitness, muscle fitness, flexibility and body composition. They found that only aerobic fitness and BMI were related to performance on reading and mathematics. Other studies also found that more fit children, based on performance on aerobic fitness tests, had better scores on academic achievement tests (Chomitz et al., 2009) and executive functioning tasks (Buck et al., 2008) than their lower fit peers. Research on neuro-electric activation patterns of cognition in children showed that more fit children, with greater aerobic fitness based on directly measured maximal oxygen consumption, were more accurate on executive functioning tasks compared to their lower fit peers (Hillman et al., 2009; Pontifex et al., 2011). In addition to the aerobic fitness component, studies in older adults also showed a positive relation between muscle strength and performance on executive functioning tasks (Cassilhas et al., 2007; Liu-

Ambrose et al., 2010), but in children this possible relation is still unclear. Castelli et al. (2007) did not find a relation between muscle strength and academic achievement, however, in a study by Eveland-Sayers et al. (2009) a positive relationship was found between muscular fitness and mathematics scores. Also, Dwyer, Sallis, Blizzard, Lazarus and Dean (2001) found an association between muscle force, muscle power and academic achievement, specifically with sit-ups and standing long jump, measuring trunk strength and explosive leg power respectively.

One possible theory explaining the relationship between aerobic fitness and executive functioning or academic achievement is the physiological fitness hypothesis, also called the cardiovascular fitness hypothesis. It states that regular exercise (either aerobic or non-aerobic exercise like muscular resistance or games without an aerobic component) will induce short and long term changes in brain regions critical to learning and memory, as a result of increased cerebral blood flow (Etnier et al., 1997). Acute bouts of exercise will result in an increase in the release of neurotransmitters responsible for synaptic transmission and plasticity like growth factors and neurotrophins (Best, 2010). In the long term, chronic exercise not only results in increased brain neurotransmitters, it may also result in permanent structural changes in the brain like new neuronal and vascular architecture (Hillman, Erickson, & Kramer, 2008). While most support for the physical fitness hypothesis comes from non-human studies, more and more research on humans show similar results (Pereira et al., 2007).

Taken together, several studies have described the relationships between fitness, executive functioning, and academic achievement separately. However, it remains unclear how these factors relate when investigated together. The goal of this study was therefore to simultaneously examine the relations between fitness (including both aerobic fitness and strength components), executive functioning, and academic achievement. Prior to the main analysis of the relationships between the three latent factors fitness, executive functioning, and academic achievement, confirmatory factor analysis (CFA) was used to test whether the observed measures served as good indicators of each factor. Once the three factors fitness, executive functioning, and academic achievement were clearly defined by their respective indicators, the relationships between the three factors were analyzed by putting them together in a model using structural equation modeling (SEM). To confirm relations found in previous studies, it was first tested whether fitness was related to executive functioning and academic achievement. It was hypothesized that fitness would be positively related to both executive functioning and academic achievement.

Next, to address the main question, it was tested whether executive functioning plays a mediating role within the relation between fitness and academic achievement. That is, whether the relationship between fitness and academic achievement is direct or indirect. We hypothesized that executive functioning would serve as a mediator in the relation between fitness and academic achievement.

2.2 Method

Participants

Children from four primary schools in the northern Netherlands were recruited to participate in the study. In total, 263 typically developing children (145 boys, 118 girls) between the ages of 7 and 12 years old were included. Most of the children came from similar socioeconomic backgrounds; 12% of the children had a low or middle low socioeconomic status (SES) based on the education of the parents[1]. No statistical differences were found between boys and girls with respect to age, height, weight, Body Mass Index (BMI) and the percentage of children with normal weight and overweight/obese, as depicted in Table 2.1. In all instances, informed consent was obtained from the children's parents/guardians prior to participation. Student consent rate was 94%. All procedures were in accordance with and approved by the ethical committee of the Center for Human Movement Sciences of the University Medical Center Groningen, University of Groningen.

Table 2.1. Descriptive Statistics.

	All (n = 263)		Boys (n = 145)		Girls (n = 118)		
	Mean	SD	Mean	SD	Mean	SD	*p*-value
Age (year)	9.5	1.2	9.5	1.2	9.5	1.3	.99[b]
Height (cm)	142.8	10.0	142.8	9.1	142.8	11.0	.99[b]
Weight (kg)	35.2	9.4	34.9	9.0	35.7	9.8	.51[b]
BMI (kg/m^2)	17.1	2.9	16.9	2.9	17.4	3.0	.25[b]
% normal weight[a]	80		84		75		.06[c]
% overweight/obese[a]	20		16		25		

Note. [a] Calculated from cut-off criteria of Cole, Bellizzi, Flegal, and Dietz (2000). [b] Student's t-test. [c] Non parametric Chi square test.

1 Low SES: One of the parents has finished primary school at most, the other parent finished a maximum of two years of other education in addition to primary school. Middle low SES: One or both of the parents have at least finished primary school and a maximum of two years of other education.

Measures

Physical fitness. Participants' fitness was measured with four tests from the European physical fitness test battery (EUROFIT) (Adam, Klissouras, Ravazzolo, Renson, & Tuxworth, 1988). These tests were the standing broad jump (SBJ, in cm), sit-ups (SUP, number in 30 seconds), the 10x5 meter shuttle run (10x5m SR, in seconds) and the 20-meter shuttle run (20m SR, in stages). All tests were administered by trained examiners. The shuttle run test was measured during a normal physical education lesson, while the remaining three tests were completed in circuit form in a random order during another physical education lesson. For a subsample of the data (n = 83) an analysis of covariance (ANCOVA) was performed, to evaluate if there would be a testing order effect. Three ANCOVA's were performed, one for the standing broad jump, one for the 10x5m shuttle run, and one for the sit-ups, with testing order (1, 2 or 3) as independent variable, and age and gender as control variables. Examination of the results showed that there was no effect of testing order on the performances ($p > .05$).

It was hypothesized that the four measures reflect both a strength and aerobic component of fitness. In the SBJ test children were asked to jump as far as possible with two feet from a standing position, as a measure of explosive leg strength. Trunk strength was measured with the SUP test, in which children have to perform as many sit-ups as possible within 30 seconds. In the 10x5m SR test children were asked to run 5 meters 10 times, covering a distance of 50 meters in total, to measure their running speed and agility. In the 20m SR test children run back and forth between two lines 20 meters apart, pacing their run to audio signals that progressively increase in difficulty. Results are expressed as the last completed stage. The test measures cardiorespiratory endurance. The test-retest reliability, ranging from .62 to .97, and construct validity of the four tests for children are adequate (Léger, Mercier, Gadoury, & Lambert, 1988; Van Mechelen, Van Lier, Hlobil, Crolla, & Kemper, 1991).

Executive functioning. All children were tested individually on their problem solving skills using the Tower of London test, and cognitive flexibility was measured using the Trailmaking test. Both tests were administered by trained examiners. The Tower of London (ToL, Shallice, 1982) is thought to examine the ability to plan and sequence a behavior towards a goal (Banich, 2009; Unterrainer et al., 2004). In the ToL task a child is presented with three colored balls that need to be moved between three pegs of differing heights in order to reproduce a depicted target pattern in a prescribed number of moves (Baker, Segalowitz, & Ferlisi, 2001). The child must create a strategy and keep in mind the target pattern while evaluating their progress after each move. A total of 12 problems has to be solved that vary in difficulty by the number of required moves. Points are assigned when a child solves the problem, with a maximum of three points for each problem. The ToL has been tested and validated for use with children (Anderson, Anderson, & Lajoie, 1996). The Trailmaking test (TMT) is a visual task in which children are asked to connect circles in numerical order (trail A), and in alternating between both numerical and alphabetical order (trail B), by drawing a line from one point to the next as quickly as possible (Reitan, 1971; Reitan & Wolfson, 2004). To obtain an accurate measure of cognitive flexibility, the time to complete trail A is subtracted from the time to complete trail B (Strauss, Sherman, & Spreen, 2006). The TMT has been used and validated in children from age 7 (Anderson, 1998; Strauss et al., 2006).

Academic achievement. To assess the children's academic achievement, the child academic monitoring system was used (Cito). This system is used by Dutch schools to measure and monitor the progress in academic achievement at least twice a year. Standardized test scores on mathematics, reading and spelling were used. The math test consists of different parts measuring number sense and computation, algebraic, and measurement skills (Janssen, Verhelst, Engelen, & Scheltens, 2010). The test intends to measure whether the child is able to execute math and to use strategies to solve math problems. Reading abilities are assessed by having children read a text for themselves on which they have to answer several questions. In this case not only reading skills are measured, but also understanding, interpretation and reflection skills (Feenstra, Kamphuis, Kleintjes, & Krom, 2010; Weekers, Groenen, Kleintjes, & Feenstra, 2011). To assess spelling skills the child has to write down words that are read out aloud by the teacher and pick the wrongly spelled word out of a list of four words (De Wijs, Kamphuis, Kleintjes, & Tomesen, 2010). The reliability of all tests ranges from .87 to .96, the content validity and construct validity were good (De Wijs et al., 2010; Feenstra et al., 2010; Janssen et al., 2010; Weekers et al., 2011).

Statistical analysis and modeling

Initial data analyses were performed using SPSS 20.0 for Windows (statistical significance was set at .05). Descriptive statistics were used to describe participants' characteristics and performance on fitness, executive functioning, and academic achievement measures. An independent Student's *t*-test was used to test the effect of gender on the measured variables. A multivariate analysis of covariance (MANCOVA) was performed on a subsample of the data (n = 61) to find out if there were differences on the scores on the fitness, executive functioning and academic achievement measures between children with a low or middle low SES (n = 28) and children with a regular SES. Three MANCOVA's were performed on 1) four fitness measures, 2) two executive functioning measures, and 3) three academic achievement measures. To examine the relations between fitness, executive functioning, and academic achievement, models were constructed in LISREL modeling (Jöreskog & Sörbom, 2007), using PRELIS.

Confirmatory factor analysis was performed to test whether the observed measures served as good indicators for the latent factors fitness, executive functioning, and academic achievement. Next, two models were designed using structural equation modeling, in which it was investigated if the complete model fitted the empirical data. In the first model, fitness loaded directly to both executive functioning and academic achievement, with a covariance between executive functioning and academic achievement. In the second model a path was added from executive functioning to academic achievement. In this model, academic achievement was both directly and indirectly linked to fitness. In addition to this, age and gender were added as a factor to both models, loading directly on the three factors fitness, executive functioning, and academic achievement, to see whether the models would change when taking these confounding factors into account. Maximum Likelihood estimation was used in all models to calculate the covariance matrix from the raw data. To investigate the mediating role of executive functioning in the second model, the total and indirect effects were obtained from the LISREL output, using raw correlations to give a measure of the effect size. The indirect effect of physical fitness on academic achievement via executive functioning is the product of the direct relations, while the total effect is the sum of all direct and indirect relations.

Goodness of fit. For all CFA and SEM models, standardized solutions were used that reflect correlations (r) between indicators and latent variables. R^2 values indicate how well the latent variable explains the variance in the observed variable, or in the case of structural relations the variance in another latent variable. A stepwise approach was used to drop relationships that were not significant (t-value smaller than -1.96) from the model. Several goodness of fit measures were used to describe the final model; χ^2 statistic, the root mean square error of approximation (RMSEA), and the non-normed fit index (NNFI). The χ^2 statistic is a measure of overall fit of the model to the data. A small χ^2 corresponds to a good fit and a large χ^2 to a bad fit between the sample correlation matrix and the fitted correlation matrix (Jöreskog, 1993). In addition, a good model fit will result in a non-significant p-value

(p > .05). The RMSEA is a measure of the error of approximation and shows how well the model, with unknown, but optimally chosen parameter values fit the population matrix. Values below .08 are indicative of acceptable fit (Hooper, Coughlan, & Mullen, 2008). The NNFI value is based on the χ^2 distribution and ranges between 0 to values greater than 1, with values greater than .95 indicating a good fit (Hooper et al., 2008).

2.3 Results

Descriptive statistics

Only children with measures on all variables were included in the analysis, and cases with extreme outliers (n = 1) were excluded, resulting in 243 cases (134 boys, 109 girls). Table 2.2 shows the correlations between the variables and participants' performance on fitness, executive functioning, and academic achievement measures.

Table 2.2. Correlations between the variables used in the analysis with mean and SD for each variable.

	20m SR[a]	**10x5m SR[b]**	**SUP[a]**	**SBJ[a]**	**ToL[a]**	**TMT[b]**	**Maths[a]**	**Read[a]**	**Spell[a]**
20m SR	1.0								
10x5m SR	-.55**	1.0							
SUP	.41**	-.33**	1.0						
SBJ	.46**	-.52**	.39**	1.0					
ToL	.06	-.09	.00	.20	1.0				
TMT	-.15*	.20**	-.13*	-.21**	-.16**	1.0			
Maths	.28**	-.22**	.15*	.32**	.25**	-.46**	1.0		
Reading	.15*	-.12	.08	.18**	.25**	-.39**	.76**	1.0	
Spelling	.16*	-.19**	.06	.24**	.21**	-.44**	.78**	.74**	1.0
Mean	4.5	23.3	16	134.4	27.7	79.4	83.3	29.9	131.4
(SD)	(1.9)	(2.4)	(5.0)	(20.7)	(3.2)	(40.6)	(22.1)	(20.2)	(11.4)

Note. [a] A higher score indicates a better performance. [b] A lower score indicates a better performance. 20m SR = 20-meter shuttle run. 10x5m SR = 10x5 meter shuttle run. SUP = sit-ups. SBJ = standing broad jump. ToL = Tower of London. TMT = Trailmaking test. Maths = mathematics. Read = reading. Spell = spelling.
* p < .05 ** p < .01

A Student's t-test revealed that boys performed significantly better on all fitness tests: 20-meter shuttle run test, 10x5 meter shuttle run, standing broad jump, and sit-ups (p < .05). No differences between boys and girls were found on measures of executive functioning and academic achievement. Results of the MANCOVA indicated that there were no differences on fitness, executive functioning and academic achievement scores between children with a low or middle low SES and children with a regular SES ($p > .05$).

Confirmatory factor analysis

One model was constructed to test if the four measured variables, 20m SR, 10x5m SR, SUP and SBJ provided good measures of fitness. The model provided a good fit with the data, as reflected in the fit indices (χ^2 (2) = 5.17, p = 0.075, RMSEA = 0.077, NNFI = 0.97). The latent factors executive functioning and academic achievement were specified according to their described indicators ToL and TMT (executive functioning), and mathematics, reading and spelling (academic achievement). This model also provided a good fit with the data (χ^2 (4) = 2.05, p = 0.730, RMSEA = 0.000, NNFI = 1.01). Table 2.3 shows the standardized parameter estimates for the CFA models. All correlations explained a small to large amount of the item variance (R^2 ranged from 0.09 to 0.81).

Table 2.3. Standardized parameter estimates for the CFA models fitness and executive functioning (EF)/academic achievement (AA).

Item	Physical Fitness	R^2	Executive Functioning	Academic Achievement	R^2
Fitness					
20m SR	0.72	0.52			
10x5m SR	-0.74	0.55			
SUP	0.52	0.27			
SBJ	0.68	0.46			
EF/AA					
ToL			-0.29		0.09
TMT			0.53		0.28
Mathematics				0.90	0.81
Spelling				0.87	0.75
Reading				0.84	0.71

Note. 20m SR = 20-meter shuttle run. 10x5m SR = 10x5 meter shuttle run. SUP = sit-ups. SBJ = standing broad jump. ToL = Tower of London. TMT = Trailmaking test.

Structural equation modeling

In all models, fitness was defined as the exogenous latent variable related to the endogenous variables executive functioning and academic achievement. For all models, executive functioning was scaled to 1 to compensate for the high difference in scale between the ToL and TMT. Furthermore, as the CFA revealed the covariance between executive functioning and academic achievement was high, in Model 1 we set the error covariance between these factors free.

Model 1, in which fitness was related to both executive functioning and academic achievement, provided a good fit with the data (χ^2 (24) = 34.86, p = 0.071, RMSEA = 0.040, NNFI = 0.98).

Adding age to the first model did not provide a good fit with the data on all fit indices (χ^2 (30) = 75.39, p = 0.00, RMSEA = 0.076, NNFI = 0.95). Adding gender to the first model did not provide a good fit with the data on all fit indices either (χ^2 (30) = 49.91, p = 0.013, RMSEA = 0.046, NNFI = 0.98). We thus continued interpreting Model 1 without these confounding factors.

Model 1 showed there is a stronger relationship between fitness and executive functioning (r = .43, R^2 = .19) than fitness and academic achievement (r = .33, R^2 = .11). This means fitness explains 19% of the variance in executive functioning, and 11% of the variance in academic achievement.

To test the main question whether the relation between fitness and academic achievement was a direct or indirect path, thus indicating if executive functioning serves as a mediator in this relationship, a second model was tested. In Model 2 fitness was related to both academic achievement and executive functioning, and an extra relation was added from executive functioning to academic achievement (Figure 2.1). The goodness of fit indices were the same as Model 1, indicating that Model 2 has a good fit with the data (χ^2 (24) = 34.86, p = 0.071, RMSEA = 0.040, NNFI = 0.98).

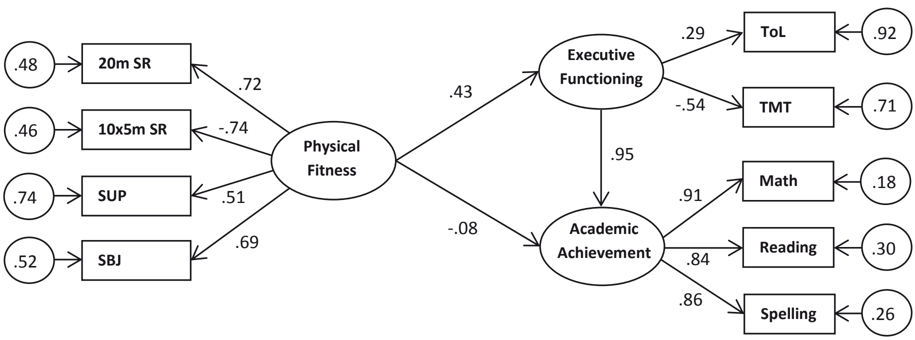

Figure 2.1. The estimated structural Model 2 (the direct and indirect effect of physical fitness on academic achievement). 20mSR = 20-meter shuttle run. 10x5m SR = 10x5 meter shuttle run. SUP = sit-ups. SBJ = standing broad jump. ToL = Tower of London. TMT = Trailmaking test. Math = mathematics.

Adding age to Model 2 did not provide a good fit with the data (χ^2 (30) = 75.39, p = 0.00, RMSEA = 0.076, NNFI = 0.95). Adding gender to Model 2 did not provide a good fit with the data either (χ^2 (30) = 49.91, p = 0.013, RMSEA = 0.046, NNFI = 0.98). We thus continued interpreting Model 2 without these confounding factors.

Model 2 showed that the (direct) link between fitness and academic achievement was not significant (t = -.38, r = -.08, which is an explained variance of only 0.64%), indicating that this relation does not exist in the population. The relationship between fitness and executive functioning persisted (r = .43, R^2 = .19), and executive functioning was strongly related to academic achievement (r = .95, R^2 = .90).

To investigate the mediating role of executive functioning in the relation between physical fitness and academic achievement, the total and indirect effects of the model were obtained from the LISREL output. The total effect was .33 (p < .01), while the indirect effect was .41 (p < .05). The indirect effect (r = .41) is thus stronger than the total effect (r = .33), as well as the direct effect found in Model 1 (r = .33), confirming the mediating role of executive functioning in Model 2.

Finally, as we found statistically significant differences between boys and girls on all physical fitness measures, multi-group moderation analysis was conducted to determine whether the structural relations would change as a result of these differences in fitness. Results showed that the structural relations between fitness, executive functioning and academic achievement did not significantly differ between boys and girls when gender differences in fitness were taken into account.

2.4 Discussion

The relationship between fitness and academic achievement in children have been increasingly studied over the last decades, resulting in evidence of a relationship between fitness and academic achievement (Castelli et al., 2007). Also, there is increasing evidence of a relation between fitness and executive functioning (Buck et al., 2008). However, to our knowledge this is the first study to examine the associations between fitness, executive functioning, and academic achievement simultaneously in a sample of primary school children. We hypothesized that fitness would be positively related to both executive functioning and academic achievement, and attempted to investigate whether executive functioning was a mediator in the relation between fitness and academic achievement.

CFA showed that the four measured fitness variables used in this study (20m SR, 10x5m SR, SUP and SBJ) were good indicators of the latent variable fitness. CFA also showed that the ToL and TMT significantly loaded on the latent variable executive functioning, and that mathematics, reading, and spelling loaded significantly on the latent variable academic achievement. SEM showed that fitness was significantly related to both executive functioning and academic achievement, and more strongly related to executive functioning than academic achievement (Model 1). Furthermore, SEM showed that the direct link between fitness and academic achievement disappeared when a relationship was added from executive functioning to academic achievement (Model 2), confirming the hypothesis that executive functioning serves as a mediator in the relationship between fitness and academic achievement.

Findings from the SEM confirm the strong relations between fitness and executive functioning or fitness and academic achievement found in other studies (e.g. Castelli et al., 2007; Chomitz et al., 2009), and extends our current knowledge on these relations by showing that fitness was more strongly related to executive functioning (r = .43, R^2 = .19) than academic achievement (r = .33, R^2 = .11). The significant relationship between fitness and executive functioning is in agreement with the existing evidence of the physical fitness hypothesis, which states that executive functioning can be improved by gains in aerobic fitness by means of increased blood flow and brain neurotransmitters. However, this might not only be the case for aerobic fitness; gains in muscle strength may have an effect as well, suggesting that more mechanisms could be involved in explaining the potential benefit of fitness on executive functioning. In a study by Cassilhas et al. (2007) the benefits of strength training on executive functioning in the elderly are explained by increased concentrations of insulin-like growth factor I, which promotes neuronal growth and survival and improves executive functioning. Whether this same mechanism applies to executive functioning benefits of strength gains in children is not yet known.

Physical fitness is thus related to both executive functioning and academic achievement, however, as previous studies suggest a relation between executive functioning and academic achievement (e.g. Best et al., 2011), this relation was added in Model 2. Findings from this model showed that executive functioning was a mediator in the relationship between fitness and academic achievement. The direct link in Model 2 was non-significant, meaning that the direct relationship between fitness and academic achievement is negligible when a mediating relation between executive functioning and academic achievement is taken into account. Moreover, the indirect relation between fitness and academic achievement (r = .41), was stronger than the direct and total relation (r = .33). This raises the question whether adequate executive functioning might be a prerequisite for using fitness to improve academic achievement. The cognitive capacities involved in executive functioning might be foundational for academic achievement. As Bull et al. (2008) suggest, executive functioning skills provide children with building blocks for the development of mathematics and reading. To improve school performance, targeting executive functioning can then be crucial (Best et al., 2011), as some studies on preschoolers have already shown (Blair & Razza, 2007; Welsh, Nix, Blair, Bierman, & Nelson, 2010). Research aiming to improve academic achievement by increasing fitness must therefore not forget to include executive functioning, as it might be that executive functioning will improve prior to improvements in academic achievement.

Despite the contribution of the current study to extend the knowledge on the relationships between fitness, executive functioning, and academic achievement, it is worth mentioning several points to consider in future studies. We used a cross-sectional design, which did not allow us to draw firm conclusions about the causality of the relationships we found. It would be interesting to explore whether the findings can be replicated in longitudinal studies. For example, the addition of age and gender in the models in this cross-sectional study did not provide a good fit with the data. Therefore, the role of age and gender in the relations between fitness, executive functioning, and academic achievement requires further explanation, as this might be different when looking at the development of these relations in a longitudinal design. Also, it would be interesting to explore the relations in children from a low socioeconomic status or in children from special populations. For example, there is evidence of a relationship between motor performance and executive functioning (Hartman, Houwen, Scherder, & Visscher, 2010) and motor performance and academic achievement (Vuijk, Hartman, Mombarg, Scherder, & Visscher, 2011) in children with learning or intellectual disabilities. However, whether fitness is also related to executive functioning and academic achievement in these cognitively vulnerable populations requires further investigation. Finally, the positive relations between fitness and both executive functioning and academic achievement highlight the importance of children being physically active, which can be achieved during the school day, in physical education classes or recess, free play time after school or involvement in organized sports. Moreover, special fitness programs could be developed for children to stimulate academic achievement. Interventions focusing on increasing fitness in children should include activities targeting aerobic fitness and strength, and research focusing on the effects of these interventions should incorporate both academic achievement and executive function measurements.

In conclusion, the present study confirms the associations between physical fitness, executive functioning, and academic achievement in primary school children. In the sample of primary school children, physical fitness was represented by four measured variables reflecting both a strength and aerobic component of fitness. Moreover, the study shows that executive functioning is a mediator in the relationship between physical fitness and academic achievement, thus making executive functioning an important aspect to examine in future research.

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3

Associations between daily physical activity and executive functioning in primary school-aged children

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Abstract

Objectives: While there is some evidence that aerobic fitness is positively associated with executive functioning in children, evidence for a relation between children's daily physical activity (PA) and their executive functioning is limited. The objective was to examine associations between objectively measured daily PA (total volume, sedentary behavior, moderate to vigorous physical activity (MVPA)) and executive functioning in children.

Design: Cross-sectional.

Methods: Eighty primary school children (36 boys, 44 girls) aged 8-12 years old participated in the study. Physical activity (PA) was measured using accelerometers. Executive functions measured included inhibition (Stroop test), working memory (Visual Memory Span test), cognitive flexibility (Trailmaking test), and planning (Tower of London: ToL). Total volume of PA, time spent in sedentary behavior and MVPA were calculated and related to performance on executive functioning.

Results: More time spent in sedentary behavior was related to worse inhibition (r = -0.24). A higher total volume of PA was associated with better planning ability, as reflected by both a higher score on the ToL (r = 0.24) and a shorter total execution time (r = -0.29). Also, a significant moderate correlation was found between time spent in MVPA and the total execution time of the ToL (r = -0.29).

Conclusion: Children should limit time spent in sedentary behavior, and increasing their total PA. Total volume of PA, which consisted mostly of light intensity PA, is related to executive functioning. This opens up new possibilities to explore both the quantity and quality of PA in relation to cognition in children.

3.1 Introduction

The relationship between exercise and cognition in children has been frequently studied. A meta-analytic review by Sibley and Etnier (2003) showed that physical activity (PA) was significantly related to improved cognition in school-aged children. Besides, some studies show that fitter children, with greater aerobic fitness based on directly measured oxygen consumption, perform better or more accurately on executive functioning tasks compared to their lower fit peers (Buck, Hillman, & Castelli, 2008; Pontifex et al., 2011). Executive functions encompass a subset of cognitive operations used to effortfully guide behavior towards a goal (Banich, 2009), and include a wide range of abilities of which inhibition, working memory, cognitive flexibility, and planning are mentioned as core executive functions (Anderson, 2002; Miyake et al., 2000). Executive functions develop as a child's brain matures, and play an important role in the cognitive, behavioral, and social-emotional development of children (Anderson, 2002). It is suggested that development can be facilitated by activities that challenge executive functioning (Diamond & Lee, 2011). Regular involvement in PA in early childhood is thought to be one of the activities that can stimulate the development of executive functions (Best, 2010). PA is defined as all bodily movement produced by the muscular system that increases energy expenditure above normal physiological demands (Ortega, Ruiz, Castillo, & Sjöström, 2008), while sedentary behavior is marked by low energy expenditure.

There is some evidence from intervention studies showing that engaging in moderate to vigorous physical activity (MVPA) can lead to improvements in certain aspects of executive functioning in children (Davis et al., 2011; Fisher et al., 2011). However, in these studies children's PA behavior is stimulated beyond their normal PA. It remains unclear if children's habitual PA, which is the typical activity pattern of children in daily life including their sedentary behavior, is related to performance on executive functioning. PA and sedentary behavior might be independently related to executive functioning. Aerobic exercise can lead to both neurochemical and morphological changes in brain regions associated with executive functioning (Best, 2010). Additionally, the cognitive demands of children's PA have the potential to influence executive functioning in several ways (Best, 2010). Group games can challenge inhibition skills and working memory, or require the child to shift attention or act according to a plan. In contrast, sedentary behavior would not be expected to stimulate executive functioning in these ways, and has been shown to be associated with EF problems (Riggs, Huh, Chou, Spruijt-Metz, & Pentz, 2012). We thus believe that PA (even at low intensity) is inherently more demanding on EF than sedentary behavior.

In a systematic review by Keeley and Fox (2009), no studies were found that examined the links between daily PA and executive functioning in typically developing children. A study in boys with Attention Deficit Hyperactivity Disorder (ADHD) showed that the time spent in MVPA was a significant predictor of planning ability (Gapin & Etnier, 2010). A recent study on daily PA in adolescent males showed that higher MVPA was associated with better executive attention performance (Booth et al., 2013). However, total volume of PA, which mainly consisted of light PA, was a predictor of lower executive functioning performance. In both studies, the link between sedentary behavior and executive functioning was not examined. However, as research on PA of children in Europe showed high levels of sedentary behavior (Verloigne et al., 2012), studying this association is needed.

The purpose of this study therefore was to examine the relationships between objectively measured daily PA and core aspects of executive functioning in primary school children, i.e. their inhibition, working memory, cognitive flexibility, and planning skills. In particular, we studied how the total volume of PA, MVPA and sedentary behavior were related to executive functioning. It was hypothesized that the total volume of PA and MVPA would be positively associated with performance on executive functioning measures, and that sedentary behavior would be linked to poor performance on executive functioning measures.

3.2 Methods

A total of 80 typically developing children (36 boys, 44 girls) aged 8-12 years participated in this study. Children were recruited from three primary schools in the northern part of The Netherlands. Most children came from similar socioeconomic backgrounds: 82% of the children had an average socioeconomic status (SES) based on the education of the parents. No statistical differences were found between boys and girls with respect to chronological age, height or weight, as depicted in Table 3.1. Statistical differences were found between boys and girls on Body Mass Index (BMI) and the percentage of children with normal weight and overweight/obese ($p < .05$), with girls showing significantly higher BMI and a higher percentage in the category overweight/obese than boys (Table 3.1). In all instances, informed consent was obtained from the children's parents/guardians prior to participation. All procedures were in accordance with and approved by the ethical committee of the Center for Human Movement Sciences of the University Medical Center Groningen, University of Groningen.

Table 3.1. Descriptive statistics for the total sample and for boys and girls separately.

	All (n = 80)		Boys (n = 36)		Girls (n = 44)		
	Mean	SD	Mean	SD	Mean	SD	*p*-value
Age (year)	8.9	1.0	8.8	0.8	9.0	1.2	.54[b]
Height (cm)	142.6	9.3	142.9	7.8	142.4	10.4	.80[b]
Weight (kg)	36.0	9.2	34.0	6.1	37.5	10.9	.09[b]
BMI (kg/m^2)	17.5	2.8	16.6	2.3	18.2	3.0	<.05[b]
% Normal Weight[a]	77		89		68		.03[c]
% Overweight/Obese[a]	23		11		32		

Note. [a] Calculated from cut-off criteria of Cole, Bellizzi, Flegal, and Dietz (2000). [b] Student's t-test. [c] Non-parametric Chi square test.

PA was measured with a hip mounted accelerometer (ActiGraph GT3x+, Pensacola, FL, USA), for seven consecutive days (Trost, Pate, Freedson, Sallis, & Taylor, 2000). This device measures acceleration in three directions and records with a frequency of 100 Hz. Children were asked to wear the accelerometer every day during waking hours, except during swimming or bathing, or in certain other cases when the accelerometer could be damaged (self-defensive or contact sports). Data were collected from October through February.

Data were analyzed using data analysis software ActiLife6 (ActiGraph, ActiLife version 6.7.1). A recording epoch of 10 s was used. Data recorded on the first afternoon were discarded in order to minimize any influence of changes in behavior as a result of wearing the device. All accelerometer data were visually reviewed to check the quality of the data. When data were below a valid activity floor of 10 counts/min for 20 consecutive minutes, data were flagged as non-wear period and excluded from analysis. Children had to provide a minimum of 3 weekdays and 1 weekend day of at least 9 hours of wear time each day. Data from only the vertical axis were used and evaluated for the volume of PA (mean counts/min), and time spent at different intensity levels, using the cut-off points of Pulsford et al. (2011): sedentary: <100 counts/min, corresponding to activities such as lying and sitting; moderate: >2240 and ≤3840 counts/min, reflecting brisk walking;

vigorous: ≥3841 counts/min, which is best represented by an activity like jogging. Daily accumulation of MVPA was assessed by summing the time spent in moderate and vigorous PA. MVPA was taken as a measure of high intensity activity.

Inhibition involves the ability to control attention and behavior on the task at hand, while suppressing attention to other stimuli (Diamond, 2013). Inhibition skills were tested with the Golden version of the Stroop test (Buck et al., 2008), in which the child has to complete three reading conditions in 45 seconds each. In the first condition (Word card), the child has to read out aloud words written in black ink (e.g. green, yellow). In the second condition (Color card) the child has to name the colors of colored rectangles. In the last condition (Color-Word card), the child is presented with words written in different colors of ink, and is asked to name the color of the ink instead of reading the word (e.g. green written in blue ink). In all three conditions, the number of correctly mentioned items is scored. In order to get a measure of their inhibition skills, a ratio score (I_R) was calculated by dividing the score of the third condition by the score of the second condition; I_R = CW/C for number of items scored. This is a method to assess the resistance to interference, independently of the child's ability to read or name colors (Lansbergen, Kenemans, & Van Engeland, 2007). A higher ratio score indicates a better ability to resist interference. The Golden version has been used in children from age 5. Test-retest reliability coefficients of the three separate cards are high ($r > 0.80$) (Neyens & Aldenkamp, 1997; Strauss, Sherman, & Spreen, 2006).

Working memory involves the ability to hold and manipulate information in the mind (Diamond, 2013), which was assessed with the Visual Memory Span (VMS) test, a part of the Wechsler Memory Scale revised (Wechsler, 1987). In the VMS test a child has to replicate a sequence of movements of the examiner who is pointing at colored squares on a paper, in a predefined order. The tests starts with two sequences and increases to seven sequences that the child has to copy in reverse (backward) order, with two attempts at each level, resulting in a maximum of 12 attempts. The test discontinues when the child is unable to repeat two sequences of the same length. Each correct trial is awarded with one point. The maximum score for the VMS test is 12 points, with a higher score indicating better performance. The VMS test has been used in children from age 6. Reliability of working memory tests similar to the one adopted here, ranges from 0.70 to 0.90 (Strauss et al., 2006).

Cognitive flexibility, which is the ability to change attention and switch rapidly between response sets (Anderson, 2002), was measured using the Trailmaking test

(TMT). This is a paper and pencil task containing two parts. In trail A the child is asked to connect circles in numerical order, while in trail B the child has to alternate between both numerical and alphabetical order, by drawing a line from one point to the next as quickly as possible (Reitan, 1971). To obtain an accurate measure of cognitive flexibility, the time to complete trail A is subtracted from the time to complete trail B (Strauss et al., 2006). The TMT has been used and validated in children from age 7, and shows low (Trails A, $r = 0.33$) to moderate (Trails B, $r = 0.56$) test-retest reliability (Neyens & Aldenkamp, 1997; Strauss et al., 2006).

Planning ability was measured using the Tower of London (ToL) test (Shallice, 1982). In the ToL a child has to move three colored balls between three pegs of differing heights in order to reproduce a depicted target pattern from a fixed start state. This implies that the child creates a strategy to solve the problem and keeps in mind the target pattern while evaluating the progress after each move. A total of 12 problems have to be solved that vary in difficulty by the number of required moves, starting with two and increasing to five moves. Only one ball can be moved at a time, and cannot be moved when another ball is lying on top of it. Besides, the longest peg can carry three balls, the middle peg two and the shortest peg one ball. A problem is solved correctly when the target pattern is achieved in the prescribed number of moves. The child has three attempts to solve each problem and receives points accordingly: three points when the problem has been solved in one attempt, two if two attempts were necessary and one if the child needed three attempts to solve the problem. No points are given if the child does not succeed to solve the problem in three attempts. The ToL score is the sum of points of all 12 problems, resulting in a maximum score of 36. In addition, decision time and execution time were scored to investigate the processes underlying ToL performance. Decision time is the time between the presentation of the problem and the initiation of the first move of a trial (ball leaves peg), while execution time is the time between the first move and the completion of the trial (regardless of the (in)correctness of the moves) (Anderson, Anderson, & Lajoie, 1996). The sum of the decision times of the first trial of all 12 problems was used as total decision time score, and the sum of the execution times of the first trial of all 12 problems was used as total execution time. The ToL has been tested and validated for use with children from age 7 (Anderson et al., 1996).

Data analyses were performed using SPSS 20.0 for Windows (IBM Corp., Armonk, NY, USA). In nine cases, data for ToL execution time was missing. These data were replaced by the regression means of the missing value analysis of SPSS (standard error of the estimate = 0.13). Pearson's partial correlation coefficients (r) between the PA variables and executive functioning measures were calculated, adjusting for gender, age, SES and total wear time. For the Stroop ratio score, the correlation was also adjusted for the score on condition one (Word card), to control for the reading proficiency of the child. Cohen's conventions to interpret the strength of the correlations were used, with a correlation of 0.1 representing a small association, 0.3 as moderate, and 0.5 or larger representing a strong association (Cohen, 1992). P-values < .05 were regarded as significant.

3.3 Results

Three children were excluded from the analyses as their MVPA measure was more than 3 standard deviations above the median, bringing the total sample to 77. Table 3.2 shows the results on the PA variables and performance on executive functioning measures for all participants. A Student's t-test revealed that boys spent significantly more time (52 ± 14 min/day) at a moderate to vigorous intensity level than girls (37 ± 14 min/day). No significant differences between boys and girls were found on the other PA measures, and on performance of all executive function measures.

Table 3.2. Results for the physical activity and executive functioning measures for the total sample.

	Mean	SD	Range
Physical Activity			
Total PA (counts/min)	526	127.9	237.3 – 812.5
Sedentary behavior (min/day)	366	70.0	222.0 – 570.8
MVPA (min/day)	43	15.8	11.0 – 80.2
Executive Functioning			
Stroop (ratio)	0.65	0.11	0.40 – 0.90
VMS (points)	6.8	1.6	2 – 10
TMT (s)	83.2	40.5	23 – 245
ToL (points)	27.5	3.2	19 – 35
ToL dec time (s)	58.1	37.8	21.7 – 288.9
ToL exe time (s)	135.7	49.5	76.0 – 368.5

Note. n = 77. [a] Student's t-test. dec time = total decision time. exe time = total execution time. MVPA = moderate to vigorous physical activity. PA = physical activity. Stroop = Stroop color word test. TMT = Trailmaking test. ToL = Tower of London. VMS = Visual memory span test.

Table 3.3 shows the correlations between the various PA measures and scores on the measures of executive functioning for all participants. A small negative correlation was found between the time spent in sedentary behavior and the Stroop ratio score (r = -0.24), indicating that children who spent a lot of time sedentary showed worse performance on this inhibition task. Significant small to moderate correlations were found between the total volume of PA and both ToL score (r = 0.24) and the total execution time of the ToL (r = -0.29), indicating that the more active the child, the better his or her performance on solving ToL problems, as well as the faster the child can solve ToL problems once the trial has been initiated. Also, a significant small to moderate correlation was found between time spent in MVPA and the total execution time of the ToL (r = -0.29), indicating that the more time a child is active at moderate to vigorous intensities, the faster the child can solve ToL problems once the trial has been initiated. The other correlation coefficients did not reach significance.

Table 3.3. Correlations between physical activity measures and measures of executive functioning for all participants.

	Stroop[a]	VMS[a]	TMT[b]	ToL[a]	ToL dec time[a]	ToL exe time[b]
Total PA	0.11 ns	0.04 ns	-0.04 ns	0.24* p = .04	0.11 ns	-0.29* p = .01
Sedentary behavior	-0.24* p = .04	-0.04 ns	0.06 ns	-0.17 ns	-0.12 ns	0.21 ns
MVPA	-0.09 ns	0.08 ns	0.01 ns	0.22 ns	0.03 ns	-0.29* p = .01

Note. n = 77. [a] A higher score indicates a better performance. [b] A lower score indicates a better performance. dec time = total decision time. exe time = total execution time. MVPA = moderate to vigorous physical activity. ns = non-significant. PA = physical activity. Stroop = Stroop color word test. TMT = Trailmaking test. ToL = Tower of London. VMS = Visual memory span test.
* Significant r-value, $p < .05$

3.4 Discussion

The aim of this study was to relate daily PA in typically developing children to performance on a wide executive functioning array of tasks. We found positive relations between total volume of PA and planning performance on the ToL. In addition, a negative relation was found between sedentary behavior and inhibition as measured with the Stroop test, indicating that the more time children spent in sedentary behavior, the worse their performance on this inhibition task. To our knowledge, this is the first study that shows that sedentary behavior was negatively related to performance on an executive functioning task. There is some evidence of training studies showing that challenging, yet sedentary games could improve inhibition and working memory in children with ADHD (Best, 2010; Klingberg et al., 2005). The negative relation found in the present study suggests that the daily sedentary behavior of the current sample of typically developing children - which mainly consisted of watching TV, reading or playing on the computer - is not challenging enough to stimulate their inhibition skills. To improve executive functioning, there should be an increment in task difficulty, which might be lacking during most of the time children spent sedentary (Diamond & Lee, 2011).

The positive relation found between total volume of PA and planning performance is in line with findings from a study by Gapin and Etnier (2010), who showed that PA was positively related to performance on the ToL in boys with ADHD. Moreover, our study showed that MVPA was related to faster execution times on the ToL, which was also found by Gapin and Etnier (2010). A faster execution time indicates that, once the trial has been initiated, the child is faster in solving the problem. This can be the result of a better ability to monitor the process while moving the balls, suggesting that the task has been planned adequately in advance (Unterrainer et al., 2004). The ToL is a measure of planning and problem solving skills, but also includes abilities such as inhibition and working memory, as the child has to plan the appropriate response and inhibit task irrelevant responses. This is why Diamond (2013) calls planning a higher order executive functioning task. Perhaps the relationship between PA and executive functioning is most notable in skills that require these higher order executive functions.

Another important finding of this study was the positive relation between the total volume of PA and planning skills. This is in contrast to the finding of Booth et al. (2013), who found that total volume of PA led to lower prediction of executive function performance in adolescent children. In our study, as well as the study by Booth et al. (2013), the total volume of PA consisted mainly of light intensity exercise, suggesting that it is important to investigate what children do when they exercise at a light intensity. Children are often engaged in physically and socially playful activities of low intensity that place a demand on their executive functioning. PA of children is thus often an inherently cognitive process, stimulating executive functioning directly. The degree of cognitive engagement varies between activities and across ages (Best, 2010), which implies that the relative contribution of PA in the development of executive functioning might change as a result of experience.

A strength of the present study was that PA was measured with accelerometers, which gives an accurate reflection of what children normally do. However, when measuring PA with accelerometers, it is still not possible to capture all activities, e.g. cycling and swimming, which can lead to an underestimation of the measured PA. Besides, accelerometry does not provide information on the specific types of PA or sedentary behavior of children, which is an important area for further investigation. Also, while this study used multiple measures for executive functioning, examining the assessment procedure over sessions would strengthen the reliability, as well as including more indices of each executive functioning. Nevertheless, this study reveals independent and opposing relationships between sedentary and active behavior and some important executive functioning in children, which supports interventions to decrease sedentary time.

3.5 Conclusion

Children should try to limit their time spent in sedentary behavior, while increasing their overall PA as well as the time spent in MVPA. More research is needed to study whether sedentary behavior counteracts the positive relation between MVPA and executive functioning. Also, getting more insight into both the quantity and quality of PA in children is needed to identify whether certain types of PA are more strongly related to executive functioning than others.

Practical implications

- Children's daily PA gives a reflection of the activity pattern of children during everyday life, including time spent in sedentary behavior.

- More time spent in sedentary behavior is associated with worse performance on inhibitory control in children.

- Children should be challenged to be more physically active, either in low or high intensity activities, as this is positively associated to their planning performance.

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4

Relationship between physical activity and physical fitness in school-aged children with developmental language disorders

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Abstract

Children with developmental language disorders (DLD) often experience difficulty in understanding and engaging in interactive behavior with other children, which may lead to reduced daily physical activity and fitness levels. The present study evaluated the physical activity and physical fitness levels of 8 to 11 year old children with DLD (n = 27) and compared this to typically developing (TD) age and gender matched controls (n = 27). In addition, it was investigated whether interrelationships existed between physical activity and physical fitness in children with DLD and in TD children. Physical activity was measured using accelerometers. Physical fitness was measured using five tests of the Eurofit test battery (standing broad jump (SBJ), sit-ups (SUP), handgrip (HG), 10x5 m shuttle run (10x5m SR), and the 20m shuttle run test (20m SR)). Physical activity of children with DLD did not significantly differ from TD children. Physical fitness of children with DLD was significantly lower on the SBJ, SUP, HG and 10x5m SR than TD controls, while no significant difference was found on the 20m SR. Strong significant relationships were found between physical activity variables and sedentary behavior and some physical fitness measures (SBJ and SUP) in children with DLD, while in TD children a strong significant relationship was found between time spent in moderate to vigorous physical activity and performance on the SBJ. This study reveals important differences in fitness between children with DLD and TD children, which should be taken into account when creating physical activity interventions. Special attention has to be paid to children with DLD who show low physical activity and low physical fitness performance.

4.1 Introduction

Language is a complex social behavior that requires a combination of motor and perceptual processes (Jacob, 2013). Language competency is important for the application of social communication skills and the initiation and maintenance of interpersonal relationships (Marton, Abramoff, & Rosenzweig, 2005), as well as for inner speech and thought. Children with developmental language disorders (DLD) are characterized by delayed language in the absence of a mental or physical handicap or a specific sensory or emotional cause (Bishop, 1992). Due to this language delay, children with DLD face major challenges during their development and are at risk for behavioral and social difficulties (Lindsay, Dockrell, & Strand, 2007). The prevalence of language delay in children in the Netherlands has been estimated to be between 5 and 10% (Reep-Van den Berg, De Koning, De Ridder-Sluiter, Van der Lem, & Van der Maas, 1998), and is more likely to affect boys than girls. Individuals with DLD show nonverbal intelligence quotients in the average range. However, DLD are not limited to language, but co-occur with other disorders such as Attention Deficit Hyperactivity Disorder (Ullman & Pierpont, 2005). Furthermore, there is increasing evidence that children with DLD also have difficulties with nonlinguistic tasks like nonverbal executive functions (Henry, Messer, & Nash, 2012) and motor skills (Visscher, Houwen, Scherder, Moolenaar, & Hartman, 2007; Webster et al., 2006). This might be explained by a common genetic risk or by neurologic deficits (Bishop, 2002; Diamond, 2000), but also by environmental factors, as communication difficulties negatively influence social acceptance and participation in play activities and organized sport (Fujiki, Brinton, Hart, & Fitzgerald, 1999; Laws, Bates, Feuerstein, Mason-Apps, & White, 2012). Children with communication problems are therefore more likely to avoid activities that involve social interaction, which may result in less or less variable physical activity and consequently lower physical fitness levels.

Physical activity is defined as all bodily movement produced by the muscular system that increases energy expenditure above normal physiological demands (Ortega, Ruiz, Castillo, & Sjöström, 2008), while physically inactive or sedentary behavior is marked by low energy expenditure. Physical activity can vary in type, duration and intensity (light, moderate, vigorous). Physical fitness is a set of attributes associated with the capacity to perform a variety of physical activities (Chaddock, Pontifex, Hillman, & Kramer, 2011; Ortega et al., 2008). Physical fitness consists of several dimensions of which muscular strength, muscular endurance, speed and cardiovascular endurance are the most important.

Physical fitness and physical activity have been related to general health and mental well-being in children (Ortega et al., 2008; Strong et al., 2005). Besides, it is suggested that being physically active is important for the cardiovascular fitness of children (Andersen, Riddoch, Kriemler, & Hills, 2011; Strong et al., 2005). For example, it has been found that typically developing (TD) children aged 7-10 years who showed high levels and intensity of physical activity had less risk to develop overweight or obesity and performed better on an aerobic fitness test (Hussey, Bell, Bennett, O'Dwyer, & Gormley, 2007).

To date, no studies have investigated the daily physical activity behavior of children with DLD. In addition, there is little information on the physical fitness levels of these children. An observational study on playground behavior showed that children with DLD aged 7-11 years were less active than their TD peers (Fujiki, Brinton, Isaacson, & Summers, 2001). They also showed that children with DLD spent significantly more time isolated from peers, and that children with DLD were not able to compensate for their language difficulties by engaging in nonverbal games. Furthermore, it is possible that withdrawal from physical activity opportunities as a consequence of language and possible comorbid motor impairment, will result in fewer opportunities to improve existing and develop new physical abilities. This can affect functioning in daily life, and may result in decreased physical fitness levels in DLD children compared to their TD peers (see also Golubović, Maksimović, Golubović, & Glumbić, 2012; Hands & Larkin, 2006). In a study on sensorimotor function, it was found that children with mild DLD performed significantly worse on a vertical jump test compared to TD peers, probably due to a deficient ability to coordinate the leg muscles (Müürsepp, Aibast, Gapeyeva, & Pääsuke, 2014). However, children with mild DLD showed similar performance on a handgrip strength test compared to TD peers (Müürsepp et al., 2014). This test measures static force generation capacity. No other physical fitness measures were analyzed in the study by Müürsepp et al. (2014). In addition, it remains unclear how the fitness performances are related to physical activity behavior of children with DLD.

So far, no studies have evaluated the developmental profiles of children with DLD across physical activity and physical fitness domains. The aim of the current study was to evaluate physical activity and physical fitness of children with DLD and compare these results to age and gender matched TD children. In addition, we investigated whether interrelationships exist between physical activity and physical fitness of children with DLD and TD children. It was hypothesized that children with DLD would be less physically active and less physically fit than their TD peers. Furthermore, it was hypothesized that more active children in both groups would have higher scores on physical fitness measures.

4.2 Materials and methods

Participants

A total of 36 children with DLD (26 boys, 10 girls) between 8 and 11 years old were recruited for this study. All children had been diagnosed as language-impaired, with both severe receptive and expressive deficits, and received special education for children with DLD in the northern Netherlands. Three children were excluded from analyses because they were categorized as having impaired hearing (loss of > 35dB), and six children were excluded as they had an IQ below 80. This resulted in a sample of 27 children (18 boys, 9 girls), of which 9 children were diagnosed with Attention Deficit Hyperactivity Disorder or Attention Deficit Disorder. Table 4.1 shows the scores on two subtests of the CELF-4-NL (Clinical Evaluation of Language Fundamentals-4th edition-NL) (Kort, Schittekatte, & Compaan, 2008) and the PPVT-3-NL (Peabody Picture Vocabulary Test-3rd edition-NL) (Schlichting, 2005), for all participants and boys and girls separately. No statistical differences were found between boys and girls on non-verbal intelligence quotient (IQ) and scores on the CELF-4-NL subtests and PPVT-3-NL (Table 4.1).

Table 4.1. Descriptive statistics for the total sample of children with DLD and for boys and girls separately.

	All (n = 27)		Boys (n = 18)		Girls (n = 9)		
	Mean	SD	Mean	SD	Mean	SD	*p*-value
Nonverbal IQ	94.7	9.4	95.1	8.8	93.9	10.9	.77[a]
CELF-4 language structure	63.6	9.1	62.7	7.0	65.6	13.2	.57[a]
CELF-4 language content	74.8	11.7	75.9	11.1	72.7	13.2	.51[a]
PPVT-receptive	87.1	10.9	85.8	8.7	89.7	14.7	.40[a]

Note. [a] Student's t-test. IQ = Intelligence Quotient. CELF-4 = Clinical Evaluation of Language Fundamentals 4. PPVT = Peabody Picture Vocabulary Test.

An age (as closely as possible) and gender matched control group of TD children was used to compare performance on physical activity and physical fitness measures to those of the children with DLD. None of the TD children had a history of language disorders. TD children from three primary schools in the same region were recruited, who were participants in a larger study in which physical fitness and physical activity was assessed.

No statistical differences were found between children with DLD and TD children with respect to age, height, weight, Body Mass Index (BMI) or the percentage of children with normal weight and overweight/obese, as depicted in Table 4.2. In all instances, informed consent was obtained from the children's parents/guardians prior to participation. All procedures were in accordance with and approved by the ethical committee of the Center for Human Movement Sciences of the University Medical Center Groningen, University of Groningen.

Table 4.2. Descriptive statistics for children with DLD and TD children.

	DLD (n = 27)		TD (n = 27)		
	Mean	**SD**	**Mean**	**SD**	***p*-value**
Age (year)	8.6	0.8	8.6	0.8	.87[b]
Height (cm)	137.4	7.4	140.3	7.1	.15[b]
Weight (kg)	32.6	7.1	34.0	6.9	.47[b]
BMI (kg/m^2)	17.1	2.5	17.2	2.7	.94[b]
% normal weight[a]	77		78		.94[c]
% overweight/obese[a]	23		22		

Note. [a] Calculated from cut-off criteria of Cole, Bellizzi, Flegal, and Dietz (2000). [b] Student's t-test. [c] Non parametric Chi square test.

Instruments

Accelerometer. To measure physical activity, an accelerometer (ActiGraph GT3x+, Pensacola, FL, USA) was worn on an adjustable elastic belt around the waist, for seven consecutive days (Trost, Pate, Freedson, Sallis, & Taylor, 2000). The device measures acceleration in three directions and records with a frequency of 100 Hz. Children were instructed to wear the accelerometer the whole day, and only remove the device when going to bed, swimming or bathing, or during other activities that could damage the device. Only data from the vertical axis were used for the analysis. All data were analyzed using the data analysis software ActiLife6 (ActiGraph, ActiLife version 6.7.1). A recording epoch of 10 s was used, as the activity patterns of children are highly variable. Data were visually reviewed to check the quality of the data. When data were below a valid activity floor of 10 counts/min for 20 consecutive minutes, data were flagged as non-wear period and excluded from analysis. Criteria for a valid recording were a minimum of 4 days (including 1 weekend day), of 9 hours of wear time per day. Remaining data were evaluated for the total volume of physical activity (mean counts/min), and time spent at different intensity levels, using the cut-off points of Pulsford et al. (2011): sedentary: <100 counts/min, corresponding to activities such as lying and sitting; moderate: >2240 and ≤3840 counts/min, reflecting brisk walking; vigorous: ≥3841 counts/min, which is best represented by an activity like jogging. Daily accumulation of moderate to vigorous (MVPA) physical activity was assessed by summing the time spent in moderate and vigorous physical activity. MVPA was taken as a measure of high intensity activity.

Physical fitness test. Participants' fitness was measured with five tests from the European physical fitness test battery (EUROFIT) (Adam, Klissouras, Ravazzolo, Renson, & Tuxworth, 1988). The tests were the standing broad jump (SBJ, in cm), the number of sit-ups in 30 seconds (SUP, total number in 30s), the handgrip test (HG, in kg), the 10x5m shuttle run (10x5m SR, in s), and the 20m shuttle run test (20m SR, in stages). In the SBJ children are asked to jump as far as possible with two feet from a standing position, measuring explosive leg strength. In the SUP test children have to perform as many sit-ups in 30 seconds, as a measure of their abdominal muscular power and endurance. Isometric strength of the hand and forearm was measured with the HG test, in which the child has to squeeze a handgrip dynamometer for several seconds. The 10x5m SR is a measure of speed and agility. In this test children are asked to cover a distance of 5 meters, 10 times, by running back and forth between two lines. The 20m SR measures cardiovascular endurance. In this test children run back and forth between two lines 20 meters apart, on the pace of a beep that increases in difficulty. The 20m SR test was assessed during a regular physical education class, while the remaining four tests were assessed in a circuit form during another regular physical education class. All tests were administered by trained examiners. The test-retest reliability, ranging from .62 to .97, and construct validity of the five tests for children are adequate (Léger, Mercier, Gadoury, & Lambert, 1988; Van Mechelen, Van Lier, Hlobil, Crolla, & Kemper, 1991).

Data analysis

Data analyses were performed using SPSS 20.0 for Windows (IBM Corp., Armonk, NY, USA). Descriptive statistics were used to describe characteristics of children with DLD and TD children for both physical activity and physical fitness measures. To test for differences on physical activity and physical fitness measures between children with DLD and TD children, Student's tests were used. Pearson's partial correlation analyses were used to examine relationships between the physical activity and physical fitness variables, controlling for age, gender and total wear time. Cohen's conventions to interpret the strength of the correlations were used, with a correlation of .10 representing a small relationship, a correlation of .30 as moderate, and a correlation of .50 or larger representing a strong relationship (Cohen, 1992). *P*-values < .05 were regarded as significant.

4.3 Results

One child was excluded because the MVPA measure was more than 3 standard deviations above the median. A total of 26 children with DLD (17 boys, 9 girls) were included in the analyses, as well as their age and gender matched TD controls. A Student's t-test revealed no differences on physical activity variables between children with DLD and children with DLD and an additional diagnoses of ADHD ($p > .05$). Besides, no significant correlations were found between scores on the two subtests of the CELF-4-NL and the PPVT-3-NL and any of the physical activity and physical fitness measures in children with DLD. Table 4.3 shows the results on the physical activity and physical fitness variables for children with DLD and TD children. A Student's t-test revealed no differences between children with DLD and TD children on the total volume of physical activity, time spent in sedentary behavior and time spent in MVPA. Also, no differences were found between children with DLD and TD children on the 20m SR test. Significant differences were found on the other physical fitness measures, with TD children performing significantly better than children with DLD on the SBJ, SUP, HG and 10x5m SR test ($p < .05$).

Table 4.3. Results for the physical fitness and physical activity measures of children with DLD and TD children.

	DLD (n = 26)		TD (n = 26)		
	Mean	**SD**	**Mean**	**SD**	***p*-value[a]**
Physical Activity					
Total volume (counts/min)	560.5	138.3	555.5	110.2	.90
Sedentary behavior (min/day)	340.5	62.4	349.1	55.2	.65
MVPA (min/day)	50.1	19.4	46.4	15.0	.51
Physical Fitness					
SBJ (cm)	114.8	25.7	132.9	15.7	<.05
SUP (number)	10	6.2	16	3.3	<.001
HG (kg)	14.3	4.8	17.0	3.8	<.05
10x5m SR (s)	25.8	2.5	22.7	1.9	<.001
20m SR (stages)	3.6	1.9	4.3	1.8	.23

Note. [a] Student's t-test. DLD = Developmental language disorders. TD = Typically developing. MVPA = moderate to vigorous physical activity. SBJ = Standing broad jump. SUP = Sit-ups. HG = Handgrip. 10x5m SR = 10x5m shuttle run. 20m SR = 20m shuttle run.

Table 4.4 shows the correlations between the three PA measures and scores on the five physical fitness variables for children with DLD and TD children. In children with DLD strong significant positive correlations were found between the total volume of physical activity and performance on the SBJ (r = .79) and SUP (r = .71), indicating that the more active the child, the better the performance on these fitness measures. Significant strong negative correlations were found between the time spent in sedentary behavior and both SBJ and SUP performance (r = -.68 and r = -.66 respectively) in children with DLD. This indicates that when time spent in sedentary behavior increases, performance on the SBJ and SUP decreases. Moreover, strong significant positive correlations were found between the time spent in MVPA and performance on the SBJ (r = .72) and SUP (r = .67) in children with DLD. This means that the more time a child is active at moderate to vigorous intensities, the better the performance on the SBJ and SUP. No other significant correlations were found between physical activity and physical fitness in children with DLD. In TD children, a strong significant relationship was found between time spent in moderate to vigorous physical activity and performance on the SBJ (r = .51). No other significant correlation coefficients were found between physical activity and performance on physical fitness measures in TD children.

Table 4.4. Correlations between physical fitness and physical activity measures of children with DLD and TD children.

		Physical Activity		
Physical Fitness		**Total volume**	**Sed**	**MVPA**
SBJ	DLD	.79*	-.68*	.72*
	TD	.35	-.17	.51*
SUP	DLD	.71*	-.66*	.67*
	TD	.24	-.10	.37
HG	DLD	.44	-.22	.47
	TD	.09	-.06	.05
10x5m SR	DLD	-.09	-.09	-.18
	TD	-.31	-.03	-.42
20m SR	DLD	.31	-.14	.44
	TD	.12	.37	.33

Note. N = 26. DLD = Developmental language disorders. TD = Typically developing. Sed = sedentary behavior. MVPA = moderate to vigorous physical activity. SBJ = Standing broad jump. SUP = Sit-ups. HG = Handgrip. 10x5m SR = 10x5m shuttle run. 20m SR = 20m shuttle run.
*Significant r-value, $p < .05$

4.4 Discussion

The aim of this study was to provide a comprehensive evaluation of the physical activity and physical fitness level of children with DLD in comparison to age and gender matched TD peers, and to examine the possible relationships between physical activity and physical fitness measures in both groups of children. Physical activity of children with DLD did not significantly differ compared to their TD peers. In contrast, children with DLD had significantly lower performance on four measures of physical fitness (SBJ, SUP, HG, 10x5m SR, which measures explosive leg strength, abdominal strength and endurance, isometric hand strength, and speed and agility, respectively) compared to their TD peers. No difference between children with DLD and TD children was found on performance on the 20m SR test, which measures cardiovascular endurance. In addition, the results in children with DLD revealed strong negative relationships between sedentary behavior and two physical fitness measures of strength (SBJ and SUP), and strong positive relationships between the total volume of physical activity and MVPA and these two physical fitness measures. In TD children, a significant relationship was found between time spent in moderate to vigorous physical activity and performance on the SBJ.

No significant differences were found between children with DLD and TD peers on the physical activity variables. This is in contrast to our hypothesis, and to findings from Fujiki et al. (2001), in which it was shown that children with DLD were less physically active than their TD peers. However, in their observational study, children with DLD were attending regular education, and therefore playground behavior during recess of children with DLD interacting with TD peers was analyzed. In the current study, all children with DLD were within a specialized school setting, with no interaction with TD children during school hours. This might have had a positive effect on the physical activity behavior of children during school hours, as they could interact with peers that show similar problems, which will likely limit withdrawal from physical activity. However, the current study also incorporated physical activity outside school hours. Apparently, the language impairments did not negatively affect the overall physical activity behavior in this sample of children with DLD.

Even though the performance difference on the 20m SR test failed to reach significance, children with DLD performed worse on the other physical fitness measures compared to their TD peers. Several factors may account for the observed differences on physical fitness measures between children with DLD and TD children. Physical fitness performance of children is determined by genetic potential, maturation and long-term physical activity patterns. Assuming that children with DLD show typical maturation, the lower physical fitness of children with DLD at school age might be the result of years of less or less varied physical activity and play during preschool years (Dwyer, Baur, & Hardy, 2009). According to the developmental skill-learning gap hypothesis (Wall, 2004), this would mean that when children grow older, the gap between children with DLD and TD children widens, as TD children will participate in increasingly more challenging and complicated physical activity settings, while children with DLD possibly miss the necessary practice and in turn fall even further behind their age-group peers. Without a carefully designed physical activity program, it will be difficult for them to catch up during school age years (Golubović et al., 2012).

This study revealed strong relationships between physical activity variables and SBJ and SUP performance in children with DLD. It is interesting to discuss possible mechanisms underlying the present findings concerning the relatively high correlations in children with DLD, while in TD children only one significant relation was found, between time spent in moderate to vigorous physical activity and performance on the SBJ. Performance on the SBJ and SUP require a high degree of motor competence. As previous studies showed that there is an interrelation between physical fitness, physical activity and motor competence in children (Haga, 2008; Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2006), motor competence level might have moderated the relationship between physical activity and physical fitness in our sample of children with DLD. In addition, more time spent in sedentary behavior was negatively related to performance on SBJ and SUP, suggesting that inactivity might negatively impact physical fitness by restricting the opportunities for developing adequate motor competence. In contrast, no such relationships were found in TD children. Perhaps their motor skills are at adequate levels that will not interfere with the physical fitness measures.

Children with DLD thus showed comparable physical activity in terms of amount and intensity compared to TD children. In addition, it seems important for children with DLD to be physically active, as this was strongly related to performances reflecting explosive leg strength and abdominal muscle strength. However, one can argue that while the amount and intensity of the physical activity behavior was statistically at the same level across groups, there might be a difference in the type of activities that children with DLD and TD children were involved in, both during and outside school hours. This has for example been argued in studies on children with cerebral palsy (Majnemer et al., 2008), and children with autistic disorder (Ziviani, Rodger, & Peters, 2005). The majority of physical activity of children involves social interplay that becomes more complex over time (Dwyer et al., 2009). This requires communication and understanding, which is difficult for children with DLD, probably resulting in withdrawal and more solitary and less varied activities. Furthermore, physical activity of children mainly consists of high intensity bursts of anaerobic exercise, such as jumping and sprint running (Strong et al., 2005; Tomkinson, 2007). The lower scores of children with DLD on the physical fitness measures compared to TD children, might indicate that they are possibly less involved in these kind of activities. It would therefore be interesting to investigate what kind of activities children with DLD are involved in, in addition to how much they do. This would be valuable information to address in future studies, and could be a starting point to develop specific physical activity programs.

The strengths of this study are the objective measures of physical activity and physical fitness in both children with DLD and TD children. Nevertheless, it is worth mentioning several points to consider in future studies. Because of the cross-sectional design of this study, the direction of the relationship between physical activity and physical fitness cannot be determined. It should also be noted that children with DLD showed very diverse scores on physical activity and physical fitness measures, as reflected by the high standard deviations. The heterogeneity of school-aged children with DLD, both in the type of language disorders as well in the presence of comorbidities, has been found in several studies (Webster et al., 2006), and is perhaps even a characteristic of this group. Despite these limitations, this study contributes to the sparse literature available about the physical activity and physical fitness of children with DLD.

4.5 Conclusions

This study shows that children with DLD show similar physical activity levels compared to TD peers. However, their physical fitness performance is significantly lower. In addition, physical activity in children with DLD is related to performance on the standing broad jump and sit-ups, which reflect leg and abdominal muscle strength and endurance. Given the heterogeneity of children with DLD, children with low physical activity or low physical fitness should be identified and enrolled in training programs. These training programs should aim at improving physical fitness by means of a carefully targeted physical activity program.

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5

Effects of a physical activity intervention during recess on children's physical fitness and executive functioning

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Abstract

The objective of this study was to analyze the effects of a physical activity program including both aerobic exercise and cognitively engaging physical activities on children's physical fitness and executive functions. Children from three primary schools (aged 8-12 years) were recruited. A quasi-experimental design was used. Children in the intervention group (n = 53; 19 boys, 34 girls) participated in a 22 week physical activity program for 30 minutes during lunch recess, twice a week. Children in the control group (n = 52; 32 boys, 20 girls) followed their normal lunch routine. Aerobic fitness, speed and agility, and muscle strength were assessed using the Eurofit test battery. Executive functions were assessed using tasks measuring inhibition (Stroop test), working memory (Visual Memory Span test, Digit Span test), cognitive flexibility (Trailmaking test), and planning (Tower of London). Children in the intervention group showed significantly greater improvement than children in the control group on the Stroop test and Digit Span test, reflecting enhanced inhibition and verbal working memory skills respectively. No differences were found on any of the physical fitness variables. A physical activity program including aerobic exercise and cognitively engaging physical activities can enhance aspects of executive functioning in primary school children.

5.1 Introduction

Research indicates that development of children's executive functions might benefit from increased physical activity (Barenberg, Berse, & Dutke, 2011; Best, 2010). However, the specific characteristics of exercise that will be most beneficial for children's executive functions remains a topic of debate (Tomporowski, McCullick, Pendleton, & Pesce, 2015). Executive functions is an umbrella term that refers to the cognitive processes responsible for purposeful and goal-directed behavior (Banich, 2009), and include a wide range of abilities of which inhibition, working memory, cognitive flexibility, and planning are mentioned as core executive functions (Anderson, 2002; Miyake et al., 2000). Executive functions develop as a child's brain matures, with accelerated development between 7 and 9 years of age, and have been positively linked to academic achievement (Van der Niet, Hartman, Smith, & Visscher, 2014). It is suggested that regular aerobic exercise at moderate to vigorous intensities can induce neurochemical and morphological changes in brain areas associated with executive functioning (Best, 2010). In addition, cognitive demands inherent in most physical activity and play during childhood might directly impact the development of executive functions (Best, 2010).

Results from meta-analytic studies in children show positive relations between physical activity and executive functions (Sibley & Etnier, 2003), as well as improved executive functioning with acute exercise (Verburgh, Königs, Scherder, & Oosterlaan, 2014). Studies on the effects of chronic exercise aiming to improve executive functions are scarce, and show mixed results. For example, Davis et al. (2011) found an increase in planning skills in overweight children following a 13 week aerobic exercise program after school. However, Fisher et al. (2011) failed to find positive effects of a 10 week increased physical education intervention on cognition. In addition, two studies found that a nine month physical activity program after school designed to improve cardiorespiratory fitness, led to improvements in working memory performance (Kamijo et al., 2011), as well as inhibition and cognitive flexibility (Hillman et al., 2014) in preadolescent children. Both studies showed that in addition to improvements on executive functions, children in the intervention group also demonstrated greater improvement on aerobic fitness compared to the control group, suggesting a mediating role of aerobic fitness. In a study by Crova et al. (2014), overweight children showed higher improvement in inhibitory ability than overweight controls and lean peers following a six month enhanced physical education program. Interestingly, their intervention consisted of object control skills in tennis, which were assumed to be cognitively challenging. Aerobic fitness did not mediate the effects, suggesting that the cognitive challenges inherent in open skill tasks might have led to improved inhibitory ability.

It thus seems that additional aerobic training or cognitively engaging physical activity can lead to improvements on executive functioning in children. This suggests that including both aspects in a physical activity program will likely be most beneficial. Therefore, the current intervention focused on improving executive functioning by providing a physical activity program that included both aerobic exercise at moderate to vigorous intensities, and cognitively engaging physical activities. It was expected that including complex play settings like team games would create situations to effectively train executive functions (Best, 2010). The aim was to examine the effects of this program on the physical fitness of children (including aerobic fitness and strength components), and their performance on a broad range of executive functions. The physical activity program was run during lunch recess, facilitating implementation of the program within the time constraints of the school program. It was hypothesized that children in the intervention group would show greater improvements on physical fitness and executive functions after the intervention than their control peers who didn't participate in the program.

5.2 Methods

Participants

A total of 112 typically developing children (56 boys, 56 girls) aged 8-12 years participated in this study. Children were recruited from three primary schools in the northern part of The Netherlands. A quasi-experimental design was used; based on parental consent children were allocated to either the intervention or control group. Seven children were excluded from analysis as a result of missing data due to moving school during the intervention period. The final sample consisted of 105 children, of which 53 children (19 boys, 34 girls) participated in the intervention group (Table 5.1). Most children came from similar socioeconomic backgrounds: 82% of the children had an average socioeconomic status (SES) based on the education of the parents. The intervention and control group differed in gender ratio, with more girls in the intervention group, and more boys in the control group. There were no significant differences between both groups in terms of age, height, weight, BMI and the percentage of children with normal weight and overweight/

obese. Informed consent was obtained from the children's parents/guardians prior to participation. All procedures were in accordance with and approved by the ethical committee of the Center for Human Movement Sciences of the University Medical Center Groningen, University of Groningen.

Table 5.1. Descriptive statistics for children in the intervention and control group at baseline.

	Intervention group	Control group	*p*-value
N	53	52	
Boys	19	32	.01[b]*
Girls	34	20	
Age (year)	8.8 (0.8)	8.9 (1.2)	.52[c]
Height (cm)	141.5 (7.6)	142.5 (9.5)	.55[c]
Weight (kg)	35.0 (6.8)	33.9 (7.1)	.42[c]
BMI (kg/m^2)	17.4 (2.5)	16.6 (2.2)	.08[c]
% normal weight[a]	74	85	.17[b]
% overweight/obese[a]	26	15	

Note. Values are expressed as means (SD). [a] Calculated from cut-off criteria of Cole, Bellizzi, Flegal, and Dietz (2000).
[b] Non parametric Chi square test. [c] Student's t-test.
* $p < .05$

Study design

All children followed their normal daily school routine, including two physical education lessons per week. The intervention group received additional physical activity programmed on two non-physical education days. Children in the intervention group followed the physical activity program during lunch recess, and had their lunch at school. Children in the control group had lunch as they normally did, either at home or at school. Physical fitness and executive functions were assessed at baseline and posttest. All children were tested individually by trained examiners, who were unaware of the child's experimental group. One week after the baseline tests, the physical activity intervention program started. Children needed to participate in 80% of the program to be included in the intervention group.

Training program

The intervention primarily focused on increasing physical activity during lunch time at school. The emphasis was on intensity and enjoyment, in order to make sure children would continue participation in the program. A 22 week, twice a week physical activity program was designed. The intervention was run in the games room within the school, making it easy to implement. Activities were selected based on intensity, cognitive effort, and practical feasibility. The program consisted of activities at moderate to vigorous intensity, such as running games and circuit training, in which children were executing exercises like sit-ups, push-ups or rope skipping. In addition, activities requiring cognitive effort were included, such as tag games and modified football games, as well as relay games with letters that had to be spelled into a word. Each session lasted approximately 30 minutes and consisted of a warming up (5 minutes), a core activity (20 minutes), and a cooling down (5 minutes), in which both aerobic exercise and cognitively engaging activities were included. The intensity of the intervention was controlled by measuring heart rate of all participants during three randomly selected sessions, using a Team 2 Polar system (Polar Vantage). During core activities, mean heart rate was 149.2 (±15.5) bpm. Based on their maximum heart rate, this intensity ranged from 57 to 88 % of the maximum, which represents moderate to vigorous physical activity. The intervention was provided by student physical education teachers.

Measures of physical fitness

Physical fitness was assessed using four tests from the European physical fitness test battery (EUROFIT) (Adam, Klissouras, Ravazzolo, Renson, & Tuxworth, 1988). The tests included were the standing broad jump (SBJ, in cm), sit-ups (SUP, number in 30 seconds), the 10x5 meter shuttle run (10x5m SR, in seconds) and the 20-meter shuttle run (20m SR, in stages). Explosive leg strength was measured with the SBJ. In this test, the child is asked to jump as far as possible with two feet from a standing position. In the SUP, children have to perform as many sit-ups in 30 s, as a measure of trunk strength and endurance. Running speed and agility were measured using the 10x5m SR, in which the child is asked to cover a distance of 50 meters in total by running 10 times 5 meters back and forth between two lines. The 20m SR test measures cardiovascular endurance. In this test children run back and forth between two lines 20m apart, pacing their run to audio signals that progressively increase in difficulty. The 20m SR test was measured during a normal physical education lesson, while the remaining three tests were completed in circuit form in a random order during another physical education lesson. The test-retest reliability, ranging from .62 to .97, and construct validity of the four tests for children are adequate (Léger, Mercier, Gadoury, & Lambert, 1988; Van Mechelen, Van Lier, Hlobil, Crolla, & Kemper, 1991).

Executive functions measures

Inhibition, which is the ability to control attention and behavior while suppressing distracting stimuli (Diamond, 2013), was tested with the Golden version of the Stroop test. In this test, the child has to complete three reading conditions in 45 seconds each, by reading out aloud words written in black ink (Word card), the colors of colored rectangles (Color card) or the color of the ink in which words are written (Color-Word card) (e.g. the word 'green' written in blue ink). In all three conditions, the number of correctly mentioned items is scored. Inhibition was measured by a ratio score (I_R), calculated by dividing the score obtained for the third card by the score for the second card; $I_R = CW/C$ for number of correctly items scored. This is a method to assess inhibition ability, independently of the child's ability to read or name colors (Lansbergen, Kenemans, & Van Engeland, 2007). A higher ratio score indicates better ability to inhibit distractions. The Golden version has been used in children from age 5. Test-retest reliability coefficients of the three separate cards are high ($r > .80$) (Strauss, Sherman, & Spreen, 2006).

Visuo-spatial working memory was assessed with the Visual Memory Span (VMS) test, and verbal working memory using the Digit Span (DS) test. Both tests are part of the Wechsler Memory Scale revised (Wechsler, 1987), and measure the ability to hold and manipulate information in mind (Diamond, 2013). In the VMS test a child has to replicate in reverse (backward) order a sequence of movements made by the examiner pointing in a predefined order at colored squares on a paper. The test starts with two sequences and increases to seven sequences, with two attempts at each level, resulting in a maximum of 12 attempts. The test discontinues when the child is unable to repeat two sequences of the same length. In the digit span (DS) test the child has to repeat in backward order a sequence of spoken digits that are read aloud by the examiner. The test starts with two sequences and increases to eight sequences, with three attempts at each level, resulting in a maximum of 21 attempts. The test is discontinued when the child is unable to repeat two attempts of the same length. In both tests, each correct trial is awarded with one point. The maximum score for the VMS test is 12 points, for the DS 21 points, with higher scores indicating better performance. VMS and DS tests have been used in children from age 6, and show reliability ranging from .70 to .90 (Strauss et al., 2006).

Cognitive flexibility was assessed using the Trailmaking test (TMT), a paper and pencil task in which children are asked to connect circles in numerical order (trail A), and alternating between both numerical and alphabetical order (trail B), by drawing a line from one point to the next as quickly as possible (Reitan, 1971). To obtain an accurate measure of cognitive flexibility, which is the ability to shift attention between stimuli (Anderson, 2002), the time to complete trail A is subtracted from the time to complete trail B (Strauss et al., 2006). The TMT has been used and validated in children from age 7 (Strauss et al., 2006).

The Tower of London (ToL, Shallice, 1982) examines the ability to plan and sequence a behavior towards a goal. In this task a child has to move three colored balls between three pegs of differing heights in order to reproduce a depicted target pattern from a fixed start state, in a prescribed number of moves (Baker, Segalowitz, & Ferlisi, 2001). This implies that the child creates a strategy and keeps in mind the target pattern while evaluating their progress after each move. A total of 12 problems have to be solved that vary in difficulty according to the number of required moves, starting with two and increasing to five moves. The child has three attempts to solve each problem. Points are assigned when a child solves the problem, with a maximum of three points for each problem, resulting in a maximum score of 36. The ToL has been tested and validated for use with children from age 7 (Anderson, Anderson, & Lajoie, 1996).

Statistical analysis

Data analyses were performed using SPSS 20.0 for Windows (IBM Corp., Armonk, NY, USA). Analyses of covariance (ANCOVA) were used to test group differences on physical fitness and executive functioning measures at posttest, adjusting for gender and baseline scores. Covariates (age, SES) were included if they were related to the dependent variable. Level of significance was set at 5% ($\alpha = .05$).

5.3 Results

Six children in the intervention group were excluded from analyses as they participated less than 80% of the sessions, bringing the total sample to 99 children. As the intervention group consisted of relatively more girls, it was decided to include gender as a covariate in all analyses. Age was related to SBJ ($r = .31$, $p = .002$), TMT ($r = -.35$, $p < .001$), and ToL ($r = .25$, $p = .01$) posttest score, and was included as covariate in all corresponding analyses. SES was not related to any of the dependent variables and was left out of the analyses.

Table 5.2. Unadjusted scores on physical fitness and executive functioning by group at baseline and posttest, and estimated means at posttest adjusted for baseline scores and covariates.

	Intervention group (n = 47)			Control group (n = 52)			*p*-value
	Baseline	Posttest	Adjusted post	Baseline	Posttest	Adjusted post	1-sided
Physical fitness							
SBJ[a] (cm)	131.7 (2.8)	132.5 (3.2)	134.6 (2.2)	135.4 (2.9)	140.0 (3.3)	138.1 (2.0)	.13
10x5m SR[b] (s)	23.0 (0.3)	22.9 (0.3)	22.9 (0.2)	23.2 (0.3)	22.7 (0.3)	22.7 (0.2)	.22
SUP[a] (n)	14.6 (0.8)	16.6 (0.6)	17.1 (0.5)	15.4 (0.5)	17.2 (0.7)	16.8 (0.5)	.34
20m SR[a] (stage)	3.8 (0.2)	4.2 (0.2)	4.5 (0.2)	4.2 (0.2)	4.5 (0.3)	4.2 (0.2)	.16
Executive functioning							
Stroop[a] (ratio)	.64 (0.02)	.68 (0.02)	.68 (0.02)	.68 (0.02)	.64 (0.01)	.64 (0.02)	.04*
VMS[a] (points)	7.0 (0.2)	7.2 (0.2)	7.2 (0.2)	7.0 (0.2)	7.0 (0.2)	6.9 (0.2)	.15
DS[a] (points)	6.1 (0.3)	7.2 (0.3)	7.2 (0.3)	6.1 (0.2)	6.4 (0.3)	6.4 (0.3)	.02*
TMT[b] (s)	79.7 (5.0)	65.1 (3.8)	63.7 (3.9)	77.9 (4.4)	69.5 (4.4)	70.7 (3.7)	.10
ToL[a] (points)	27.5 (0.5)	29.3 (0.4)	29.4 (0.4)	27.8 (0.5)	29.9 (0.4)	29.7 (0.4)	.35

Note. [a] A higher score indicates a better performance. [b] A lower score indicates a better performance. Values are expressed as means (SD) or estimated means (SE). Adjusted means at posttest adjusted for gender and baseline scores (all variables), and age (SBJ, TMT, ToL). SBJ = Standing broad jump. 10x5m SR = 10x5 meter shuttle run. SUP = Sit-ups. 20m SR = 20-meter shuttle run. Stroop = Stroop color word test. VMS = Visual memory span test. DS = Digit span test. TMT = Trailmaking test. ToL = Tower of London.
* $p < .05$

Table 5.2 shows the results of the ANCOVA for the physical fitness and executive functioning measures. Significant differences between the intervention and control group were found on adjusted posttest scores for the Stroop test (F(1, 97) = 3.07, p = .04, η_p^2 = .03) and Digit Span test (F(1, 96) = 4.50, p = .02, η_p^2 = .05), indicating that children in the intervention group showed greater improvement on inhibition and verbal working memory scores compared to children in the control group, when taking the test score at baseline into account. The accompanying effect sizes were small (Stevens, 1996). No significant differences between the intervention and control group were found on the other executive functioning measures, and any of the physical fitness variables. Interaction effects of group and gender or group and age were not significant for all physical fitness and executive functioning measures.

5.4 Discussion

This study tested the effects of a physical activity program during lunch recess, on physical fitness and executive functioning of primary school children. The intervention consisted of aerobic exercise and cognitively engaging activities. It was found that children in the intervention group showed a significantly greater improvement on the Stroop test, measuring inhibition, and on the DS test, which measures verbal working memory, in comparison to the control group. No significant effects were found on the other executive functioning measures and any of the physical fitness variables.

Physical fitness, including aerobic and strength components, did not significantly improve in the intervention group compared to the control group. This might be due to the frequency or intensity of the intervention. While the intensity of the physical activity intervention was found to be moderate to vigorous in three randomly selected sessions, this might not have been representative for all sessions. In addition, aerobic fitness of children has a strong genetic component, and might need more frequent or intense activity programs to differentiate from gains due to normal growth and development (Baquet, Van Praagh, & Berthoin, 2003). Nevertheless, as research on children's behavior during recess shows that they are active at low intensities, with only small amounts of time spent in moderate to vigorous physical activity (Ridgers, Stratton, & Fairclough, 2005), providing a physical activity program during recess can contribute to increase time spent in moderate to vigorous physical activity.

The improvements found on inhibition and working memory are broadly consistent with findings from Hillman et al. (2014) and Kamijo et al. (2011) who also found effects of an intervention on inhibition and working memory respectively. While it is frequently mentioned that inhibition is the first executive function to emerge during early childhood, it shows its greatest development during late childhood (6 to 10 years of age), with mastery of this skill evident around 12 (Jurado & Rosselli, 2007). Inhibition might therefore be most sensitive to environmental factors around ages 6-12 years. Improvements on the DS test reflect improvements in memory strategies, that may reflect a more effective working memory network (Kamijo et al., 2011). Working memory is shown to be related to inhibition (Davidson, Amso, Anderson, & Diamond, 2006). Perhaps the activities of the physical activity program required the children to hold information in working memory while inhibiting interfering information, leading to improvements in those domains. It is however notable that the Stroop test and the DS test are the most simple executive functioning tasks, without involving a visuomotor component. In a review on the effects of physical activity on executive functioning in children, the authors (Barenberg et al., 2011) conclude that the more difficult the executive functioning measure, the more difficult it was to find an effect.

Results of this study show improvements on aspects of executive functioning without an improvement in aerobic fitness, suggesting that the cognitively engaging physical activities may account for these improvements. It has been demonstrated that executive functions must continually be repeated and challenged by increases in task difficulty to promote improvements in children (Diamond, 2013). Children engaging in a lot of different activities involving both physical and cognitive effort, will therefore show gains in executive functioning, even in low dose physical activity, as has also been shown in a study by Crova et al. (2014). While this seems to contradict the aerobic exercise interventions used by Kamijo et al. (2011) and Davis et al. (2011), in both studies games and motor skills were included in the physical activity program in order to keep their participants motivated to continue. This suggests that also in these interventions cognitive engaging activities were included that might have had an effect on executive functioning. It thus seems to be difficult to clearly differentiate between aerobic exercise and cognitively engaging exercise. More research is needed to investigate this, and to determine children's optimal challenge point in terms of intensity and cognitive engagement of physical activity.

The current study provides some insight into the effects of in school physical activity interventions on fitness and cognition in children, however there are some study limitations. First of all, it was not possible to randomly assign children to the intervention and control group, which resulted in an unequal distribution of boys and girls in both groups. In addition, the control group followed their normal routine during lunch time, and there was no control on their physical activity behavior. Also, while this study used multiple measures for executive functioning, including more indices of each executive functioning would strengthen the results. Nevertheless, the findings from the current study provide evidence that executive functioning can be improved by providing extra physical activity at school.

5.5 Conclusion

This study shows that physical activity interventions within a school day are feasible without complex changes of time schedules. Offering a physical activity program twice a week during lunch recess was shown to be beneficial for inhibition and verbal working memory in children aged 8-12 years. Interventions focusing on aerobic fitness should also include cognitively engaging activities to enhance executive functioning in preadolescent children.

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6

Effects of a physical activity program on physical fitness and executive functions in children with developmental language disorders

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Abstract

Children with developmental language disorders (DLD) have lower physical fitness and executive functioning performance than typically developing peers. As research on typically developing children shows positive benefits of extra physical activity on physical fitness and executive functioning, children with DLD might also benefit from these exercise-induced effects. The aim of this study therefore was to evaluate the effects of a 22 week physical activity program on the physical fitness levels and executive functioning of 8 to 11 year old children with DLD (n = 27; 12 intervention, 15 controls). The physical activity program consisted of aerobic exercise, circuit training and various games. Physical fitness was measured using four tests of the Eurofit test battery (standing broad jump (SBJ), sit-ups (SUP), 10 x 5 m shuttle run (10 x 5 m SR), and the 20 m shuttle run test (20 m SR)). Executive functions were assessed using tasks measuring visual working memory (Visual Memory Span test) and planning (Tower of London). Children in the intervention group showed greater improvement on the SUP than children in the control group. No differences were found on the executive functioning measures. This study reveals that providing extra physical activity at school for children with DLD is feasible, and can be a means to improve specific aspects of physical fitness. Improving executive functions with extra physical activity might need a more personalized approach to be effective. Recommendations are made for future intervention studies in children with DLD.

6.1 Introduction

Language is a complex social behavior that depends on a wide range of specialized sensory, motor, and cognitive skills (Jacob, 2013; Knudsen, 2004). The development of language competency is essential for children to engage in and interact with their physical and social environment and access the school curriculum. Children with developmental language disorders (DLD) are characterized by language problems in the absence of an underlying mental or physical handicap or a specific sensory or emotional cause (Bishop, 1992). In the Netherlands, the prevalence of language delay in children has been estimated to be between 5 and 10% (Reep-Van den Berg, De Koning, De Ridder-Sluiter, Van der Lem, & Van der Maas, 1998), and more boys than girls are affected. Children with DLD show nonverbal intelligence quotients in the average range. However, DLD are not limited to language, but co-occur with other disorders such as Attention Deficit Hyperactivity Disorder (Ullman & Pierpont, 2005). Furthermore, several studies have shown that children with DLD have difficulties with motor skills (Visscher, Houwen, Scherder, Moolenaar, & Hartman, 2007; Webster et al., 2006) and executive functions (Henry, Messer, & Nash, 2012; Vugs, Hendriks, Cuperus, & Verhoeven, 2014). Executive functions refer to the cognitive processes responsible for purposeful and goal-directed behavior (Banich, 2009), and encompass processes like strategic planning, flexibility of thought and action, inhibition and working memory (Miyake et al., 2000). In other words, executive functions are the cognitive control processes that regulate thought and action (Friedman et al., 2008), which highlights the importance of inner speech in these processes. Language and executive functioning are thus intertwined and co-emerge throughout various phases of development (Ardila, 2008; Nip, Green, & Marx, 2011).

Research in typically developing children shows that executive functioning can be improved by increasing levels of physical activity (Davis et al., 2011; Hillman et al., 2014; Tomporowski, Davis, Miller, & Naglieri, 2008). It is suggested that chronic exercise at moderate to vigorous intensity will induce neurochemical changes in brain areas associated to executive functioning (Hötting & Röder, 2013), or that the cognitive demand inherent in most physical activity and play will impact executive functioning directly (Best, 2010). In addition, regular involvement in physical activity is essential for promoting physical fitness of children (Strong et al., 2005). Physical fitness is a set of attributes associated with the capacity to perform a variety of physical activities (Ortega, Ruiz, Castillo, & Sjöström, 2008), and consists of several dimensions like muscular strength, muscular endurance, speed and cardiovascular endurance. Physical fitness has been related to general health and mental well-being in children (Ortega et al., 2008). Moreover, physical fitness has been shown to be related to executive functioning (Van der Niet, Hartman, Smith, & Visscher, 2014), and cardiovascular fitness to language skills like reading and spelling (Scudder et al., 2014) in typically developing children. A recent study by Van der Niet et al. (2014) showed that children with DLD display lower performance on physical fitness than typically developing peers. In addition, Müürsepp, Aibast, Gapeyeva and Pääsuke (2014) showed that 5-year-old children with mild DLD performed significantly worse on a vertical jump test compared to typically developing children, probably due to a deficient ability to coordinate the leg muscles. Children with DLD can thus benefit from extra physical activity, as it might increase their physical fitness and executive functioning.

To date, no studies have investigated the effects of a physical activity program on physical fitness or executive functioning in children with DLD. Only a few studies have examined the effects of an exercise intervention in atypical target groups. For example, improved physical fitness was found after a six months individually designed physical exercise program in children with mild intellectual disorders (Golubović, Maksimović, Golubović, & Glumbić, 2012). Westendorp et al. (2014) found improvements on balls skills, but not on executive functioning after a 16 week ball skill intervention in children with learning disorders. However, children in the intervention group who showed larger improvements in ball skills also showed larger improvements in problem solving. Two other studies (Reynolds, Nicolson, & Hambly, 2003; Reynolds & Nicolson, 2007) showed improved motor skill, speech/language fluency, phonology, and working memory in children with reading difficulties, after a six months home based exercise program. However, the possible exercise-induced positive effects on physical fitness and executive functions in children with DLD are unknown.

The aim of this study therefore was to evaluate the effects of extra physical activity at school on physical fitness and executive functioning in children with DLD aged 8 to 11 year old. More specifically, effects on both cardiovascular fitness and strength components of physical fitness were analyzed. In addition, as DLD are thought to be related to some sort of procedural memory and sequencing deficiencies (Ullman & Pierpont, 2005), working memory and planning were measured to analyze effects on executive functioning. The physical activity program consisted of aerobic exercise, circuit training and various games, as it was expected that this would be most beneficial to have an effect on physical fitness and executive functioning (Diamond & Lee, 2011). To minimize the effect of impaired verbal skills, two executive functioning tests were selected in which the child was able to solve problems without verbal communication to an experimenter (Lum, Conti-Ramsden, Page, & Ullman, 2012). It was hypothesized that children in the intervention group would show more improvement on physical fitness and executive functioning measures than children in the control group who didn't participate in the physical activity program.

6.2 Materials and methods

Participants and study design

All children were within a specialized school setting, with no interaction with typically developing children during school hours. A total of 36 children with DLD (26 boys, 10 girls) between 8 and 11 year old were recruited for this study. All children had been diagnosed as language-impaired, with both severe receptive and expressive deficits, and received special education for children with DLD in the northern Netherlands. A quasi-experimental design was used. Children from four classes, representing two grades, participated. Two classes were assigned as the intervention groups, and the other two classes as control groups. Three children were excluded from analyses because they were categorized as having impaired hearing (loss of > 35dB). Six children were excluded as they had an IQ below 80. The final sample consisted of 27 children (18 boys, 9 girls), of which 9 children were diagnosed with Attention Deficit Hyperactivity Disorder or Attention Deficit Disorder. Table 6.1 shows the scores on two subtests of the CELF-4-NL (Clinical Evaluation of Language Fundamentals-4th edition-NL) (Kort, Schittekatte, & Compaan, 2008) and the PPVT-3-NL (Peabody Picture Vocabulary Test-3rd edition-NL) (Schlichting, 2005), for children in the intervention and control group. Statistical differences were found between the intervention and control group on age and height, with children in the intervention group significantly older and longer than children in the control group. No statistical differences were found between the intervention and control group on weight, BMI, the percentage of children with normal and overweight/obese, non-verbal intelligence quotient (IQ) and scores on the CELF-4-NL subtests and PPVT-3-NL (Table 6.1).

Table 6.1. Descriptive statistics for children in the intervention and control group at baseline.

	Intervention	Control	*p*-value
Subjects (n)	12 (4 girls)	15 (5 girls)	
Age (year)	9.1 (0.8)	8.2 (0.6)	.002*[b]
Height (cm)	141.0 (6.7)	134.4 (6.8)	.02*[b]
Weight (kg)	34.3 (8.0)	31.2 (6.1)	.29[b]
BMI (kg/m^2)	17.0 (2.8)	17.2 (2.4)	.90[b]
% normal weight[a]	83	71	.47[c]
% overweight/obese[a]	17	29	
Nonverbal IQ	98.0 (9.0)	92.0 (9.0)	.10[b]
CELF-4 language structure	65.9 (9.8)	61.6 (8.3)	.23[b]
CELF-4 language content	74.8 (12.8)	74.8 (11.2)	.99[b]
PPVT-receptive	90.6 (10.9)	84.3 (10.5)	.14[b]

Note. Values are expressed as means (SD) [a] Calculated from cut-off criteria of Cole, Bellizzi, Flegal and Dietz (2000). [b] Student's t-test. [c] Non parametric Chi square test. Intervention = Intervention group. Control = Control group. IQ = Intelligence Quotient. CELF-4 = Clinical Evaluation of Language Fundamentals 4. PPVT = Peabody Picture Vocabulary Test.
* $p < .05$

Procedure

All children followed their normal daily school routine, including two physical education lessons per week. Children in the intervention group received additional physical activity programmed on two non-physical education days. Physical fitness and executive functions were assessed at baseline and posttest. All children were tested individually by trained examiners, who were unaware of the child's experimental condition. One week after the baseline tests, the physical activity program started. As all children had continuous school days, the time of the intervention was fit within the timetable.

Training program

A 22 week, twice a week physical activity program was designed, that included both aerobic exercise, games and circuit training. Examples of aerobic exercise included running exercises, relay games or obstacle runs. Games included team games like dodgeball, handball, football or floorball. During circuit training, children had to perform various exercises individually, like rope jumping, sit-ups and jumping jacks, for a short time interval, and were encouraged to try to improve their previous score. All exercises were executed in pairs or small groups, to maximize time spent active. The emphasis in all activities was on intensity, but also on understanding and execution of the rules of the games or circuit training. The program lasted approximately 30 minutes each session, and consisted of a warming up (5 min), a core activity (20 min), and a cooling down (5 min). The intensity of the physical activity program was measured using heart rate (Team 2 Polar system, Polar Vantage) during three randomly selected sessions. The mean heart rate of all participants was 147.8 (± 12.4) bpm. Based on their maximum heart rate, as measured during a 20 m shuttle run test, this intensity ranged from 63 to 79 % of their maximum, which can be categorized as moderate to vigorous physical activity (Armstrong, 1998). The intervention was provided by a student physical education teacher specialized in teaching atypical groups of children, under supervision of the physical education teacher of the school.

Instruments

Physical fitness test. Physical fitness was assessed using four tests from the European physical fitness test battery (EUROFIT) (Adam, Klissouras, Ravazzolo, Renson, & Tuxworth, 1988). The tests included were the standing broad jump (SBJ, in cm), the number of sit-ups (SUP, number in 30 s), the 10 x 5 m shuttle run test (10 x 5 m SR, in s), and the 20 m shuttle run test (20 m SR, in stages). The SBJ is measuring explosive leg strength. In this test, the child is asked to jump as far as possible with two feet from a standing position. Each child has two attempts, the best attempt is taken as a measure for SBJ. In the SUP test the child has to perform as many sit-ups as possible in 30 s. The test measures trunk strength and endurance. The 10 x 5 m SR test measures speed and agility. In this test, the child is asked to run back and forth between two lines 5 m apart, 10 times, as fast as possible, covering a total distance of 50 m. In the 20 m SR test, children have to run back and forth between two lines 20 m apart, on the pace of a beep that progressively increases in difficulty. Children run until they are unable to make it to the line on the sound of the beep. The test measures cardiovascular endurance. The 20 m SR test was assessed during a regular physical education lesson, while the remaining three tests were assessed in a circuit form during another regular physical education class. The test-retest reliability, ranging from .62 to .97, and construct validity of the four tests for children are adequate (Léger, Mercier, Gadoury, & Lambert, 1988; Van Mechelen, Van Lier, Hlobil, Crolla, & Kemper, 1991).

Executive functioning. Executive functioning was measured using two tests that reflected working memory skills and planning. The Visual Memory Span test (VMS) is measuring visuo-spatial working memory. In this test the child is presented with colored squares on a paper, at which the examiner is pointing in a predefined order. The child is asked to replicate this sequence of movements in reverse order. This implies that the child will hold and manipulate the information in mind (Diamond, 2013). The test starts with two sequences and increases to seven sequences. The child gets two attempts at each level, resulting in a maximum of 12 attempts. Each correct trial is awarded with one point, resulting in a maximum of 12 points. The test discontinues when the child is unable to repeat two sequences of the same length. The VMS test has been used in children from age 6, and shows reliability ranging from .70 to .90 (Strauss, Sherman, & Spreen, 2006). Visuo-spatial working memory tests similar to the one adopted here have been used in children with DLD (Marton, 2008; Vugs et al., 2014).

In the Tower of London (ToL) test, a child has to solve a problem by moving three colored balls between three pegs of differing heights, from a fixed start state to a depicted target pattern. This implies that the child creates a strategy and keeps in mind the target pattern while evaluating the progress after each move. The test measures the ability to plan and sequence behavior towards a goal. A total of 12 problems have to be solved, in which the prescribed number of moves increases from two to five. Three attempts can be made for each problem, and points are assigned when a child solves the problem, ranging from 0 (not solved in three attempts) to 3 (solved in one attempt). The maximum score therefore is 36. The ToL has been tested and validated for use with children from age 7 (Anderson, Anderson, & Lajoie, 1996), and has also been used in children with DLD (Marton, 2008).

Data analysis

Data analyses were performed using SPSS 20.0 for Windows (IBM Corp., Armonk, NY, USA). A two (baseline and posttest) by two (condition: intervention and control group) repeated measures analysis of variance (ANOVA) was used to examine group differences on the change in mean scores on physical fitness and executive functioning measures. It was assumed that this test is most powerful to detect effects in a small sample size (Field, 2005). Covariates (gender, age, IQ) were included if they were related to the posttest score of the dependent variable. Level of significance was set at 5% ($\alpha = .05$).

6.3 Results

One child in the intervention group was excluded from analyses as this child missed half of the physical activity program. The total sample for analyses therefore was 26. As we found a difference between the intervention and control group on age, this variable was included as covariate in all analyses. In addition, gender correlated to posttest scores on the SBJ test (r = -.52, p = .007) and 10 x 5 m SR test (r = .65, p = .001), and was included as covariate in the corresponding analyses. No significant correlations were found between IQ and any of the posttest scores of the physical fitness measures, and no significant correlations were found between gender and IQ and posttest scores of the executive functioning measures visual working memory and planning.

Table 6.2 shows the results of the repeated measures ANOVA for the physical fitness and executive functioning measures. Significant differences between the intervention and control group were found on the SUP (F(1, 23) = 6.8, p = .01, η_p^2 = .24), indicating that children in the intervention group showed greater improvement on trunk strength and endurance than children in the control group. The accompanying effect size was large (Stevens, 1996). No significant effects of the physical activity intervention were found on the other physical fitness measures or on the executive functioning variables visual working memory and planning.

Table 6.2. Scores on physical fitness and executive functioning by group at baseline and posttest, and estimated means at posttest adjusted for covariates.

	Intervention group (n = 11)			Control group (n = 15)			*p*-value 1-sided	
	Baseline	**Post**	**Adjusted post**	**Baseline**	**Post**	**Adjusted post**	**Group**	**Age**
Physical fitness								
SBJ[a] (cm)	121.3 (29.9)	127.0 (23.4)	123.9 (6.3)	110.7 (22.8)	114.9 (18.0)	116.9 (4.9)	.30	
SUP[a] (n)	10.1 (6.7)	16.0 (4.3)	15.3 (1.5)	10.3 (6.1)	13.8 (4.2)	14.3 (1.2)	.01*	.02*
10 x 5m SR[b] (s)	23.6 (2.6)	24.8 (3.0)	24.5 (0.9)	26.8 (2.0)	26.2 (2.4)	26.4 (0.6)	.29	
20 m SR[a] (stage)	5.2 (2.6)	6.5 (2.7)	6.1 (0.7)	2.9 (1.1)	3.8 (1.6)	4.1 (0.6)	.19	
Executive functioning								
VMS[a]	6.7 (1.7)	6.9 (1.2)	7.1 (0.5)	4.6 (1.8)	5.9 (1.7)	5.8 (0.4)	.44	.01*
ToL[a]	27.4 (2.2)	28.9 (2.0)	29.0 (1.0)	25.8 (3.1)	26.2 (3.5)	26.2 (0.8)	.11	

Note. [a] A higher score indicates a better performance. [b] A lower score indicates a better performance. Values are expressed as means (SD) or estimated means (SE). Adjusted means at posttest adjusted for age at pretest (all variables), and gender for the variables SBJ and 10 x 5 m SR. SBJ = Standing broad jump. SUP = Sit-ups. 10 x 5 m SR = 10 x 5 m shuttle run. 20 m SR = 20 m shuttle run. VMS = Visual memory span test. ToL = Tower of London.

* $p < .05$

6.4 Discussion

This study was primarily designed to study the effects of extra physical activity during school time on physical fitness and executive functioning of children with DLD. The main findings revealed that children in the intervention group showed significantly greater improvements than children in the control group on one aspect of physical fitness, reflecting trunk strength and endurance. No effects of the physical activity intervention were found on the other physical fitness measures or on the two executive functioning measures visual working memory and planning.

To our knowledge, this is the first study that focused on increasing physical fitness and executive functioning in children with DLD by offering a physical activity program at school. Apart from the SUP, no significant effect was found for the SBJ, 10 x 5 m SR and 20 m SR test. Performance on the SBJ, SUP and 10 x 5 m SR test require a high degree of motor competence, good coordination and explosive movement (Hands & Larkin, 2006), and might be limited by possible motor impairment of children with DLD. Trunk strength was practiced in the circuit training of the physical activity program. The difference found between the intervention and control group on the SUP may therefore be the result of the circuit training within the physical activity program, making the training effect rather specific. Although performance on the 20 m SR test, reflecting cardiorespiratory endurance, was not significantly different between the intervention and control group, performance improved dramatically in both groups, especially in the intervention group. Cardiorespiratory endurance in children has a strong genetic component (Ortega et al., 2008). The improvements in both groups might therefore indicate that performance in the post-test more closely resembles their maximum performance in comparison to the baseline test, as a result of a maturation or practice effect. In addition, it should be noted that considerable variation in performance of children might have had an effect on the physical fitness results, as has also been reported in other studies on children with DLD (Rintala, Pienimäki, Ahonen, Cantell, & Kooistra, 1998).

No significant effects of the physical activity program were found on VMS and ToL performance, reflecting respectively visuo-spatial working memory and planning. It was expected that executive functioning would benefit from increased cardiovascular fitness, or that the games in the physical activity program would challenge aspects of executive functioning, as rules had to be kept in mind or strategies planned for optimal performance. However, while it has been shown that children with DLD have impairments in visuo-spatial working memory performance (Hick, Botting, & Conti-Ramsden, 2005; Vugs et al., 2014), and planning (Marton, 2008), the mechanisms involved in these impairments remain unclear. This makes it difficult to know if impairments in executive functioning are manifest in physical activity situations, and if these situations are suitable to target impairments in executive functioning. For example, if the cognitive demand of physical activity tasks are greater than the resources of the children, performance might suffer (Im-Bolter, Johnson, & Pascual-Leone, 2006), and it is questionable if executive functions are trained. In addition, it should be noted that in the field of executive functioning research the question of the ecological validity of the tasks measuring executive functioning has emerged (Chaytor, Schmitter-Edgecombe, & Burr, 2006), especially for the assessment of children with disorders such as DLD. Future studies should therefore also include observational rating scales to get a more comprehensive view of executive functioning in various physical activity contexts (Vugs et al., 2014), which can then be used to design more carefully targeted (physical activity) interventions.

The strengths of this study are the pre and post measures of physical fitness and executive functioning in children with DLD and the implementation of the physical activity intervention (systematic training). It shows that offering extra physical activity is feasible in this atypical target group. In addition, a process evaluation showed that children enjoyed the program, which was also reflected by significant improvements from baseline to posttest on the athletic competence and physical appearance scale of the self-perception profile for children that was part of this evaluation. However, some limitations should be taken into account. It was not possible to randomly assign children to the intervention and control group, due to the complex and individually designed schedules of children involved. Therefore, we cannot completely rule out the possibility that improvements found were due to alternative explanations (e.g. attention, enjoyment). In addition, while the current intervention focused on increasing executive functioning by increasing physical fitness, there might be other programs that can stimulate executive functioning. Reynolds and Nicolson (2007) already demonstrated that balance, timing and coordination training rather than cardiovascular fitness was effective in stimulating a range of cognitive skills in children with reading difficulties. Last, given the heterogeneity of the DLD group, physical activity interventions that use a more personalized approach, in which goals are set for each individual child, will probably be more efficient to increase physical fitness and executive functioning. Nevertheless, this study contributes to the knowledge on effects of extra physical activity on physical fitness and two important aspects of executive functioning in children with DLD.

6.5 Conclusions

This study shows that it is feasible to implement a physical activity intervention at school for children with DLD. It was found that children in the intervention group showed significantly more improvement on abdominal muscle strength and endurance compared to the control group. This finding indicates that children with DLD can benefit from systematic training, but that the benefits on fitness are rather specific. No significant effects were found on executive functioning. Also, children with DLD enjoyed the physical activity program. Promoting children with DLD to be physically active is very important as it can increase their general health and well-being, which in turn might impact participation in physical activity and enhance physical fitness. Further research is required before conclusions can be drawn about the possible effects of physical activity on physical fitness and executive functioning in children with DLD.

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7

Summary and general discussion

7.1 Purpose of this thesis

The main purpose of this thesis was to explore the relationships between physical activity, physical fitness, executive functioning and academic achievement in primary school aged children, and to investigate the effects of manipulating physical activity on children's physical fitness and executive functioning. Both typically developing (TD) children as well as children with language problems were studied. Language competency plays an important role in executive functioning processes, and is crucial for participation in play activities in children.

We started by examining if the relationships between physical fitness, executive functioning and academic achievement were present in TD children (Chapter 2). In addition, the mediating role of executive functioning within the relationship between physical fitness and academic achievement was examined. Then, in Chapter 3, we analyzed relationships between daily physical activity and executive functioning in TD children. More specifically, total volume of physical activity, time spent in sedentary behavior and time spent in moderate to vigorous physical activity were related to executive functioning. In Chapter 4, physical activity and physical fitness of children with developmental language disorders (DLD) were compared to those of TD children. Finally, in chapters 5 and 6, we analyzed the effects of a physical activity intervention program on physical fitness and executive functioning in TD children (Chapter 5), and children with DLD (Chapter 6). In the following section, short overviews of the main findings of each chapter will be described. In the general discussion some reflections are made about the results and theoretical framework that was used as the foundation of this study.

7.2 Summary of the main findings

In Chapter 2 it was shown that there were relationships between physical fitness, executive functioning and academic achievement in the sample of typically developing (TD) children. Physical fitness, executive functioning and academic achievement are latent factors, which means that they are constructs that can be measured using several variables. Physical fitness was measured using the Eurofit test battery. Confirmatory factor analysis showed that physical fitness comprised of both cardiovascular and strength components. Executive functioning was measured with the Tower of London, reflecting planning ability, and the Trailmaking test, reflecting cognitive flexibility. Scores on reading, spelling and mathematics, assessed with the Dutch child academic monitoring system, were used to give a measure of academic achievement. In addition to the confirmation of the relationships between physical fitness, executive functioning and academic achievement, we investigated whether the relationship between physical fitness and academic achievement was direct or indirect, via executive functioning. In other words, the mediating role of executive functioning was analyzed. Structural equation modeling revealed that executive functioning served as a mediator in the relation between physical fitness and academic achievement. Development of executive functioning might even be a prerequisite for academic achievement in children, highlighting the importance of studying executive functioning in children.

Chapter 3 described the relationship between daily physical activity and aspects of executive functioning in TD children. Physical activity, which was defined as all bodily movement produced by the muscular system that increases energy expenditure above normal physiological demands, was analyzed independently from sedentary behavior, which is marked by low energy expenditure. It was found that more time spent in sedentary behavior was related to worse inhibition on the Stroop test, and a higher total volume of physical activity was associated with better planning ability, as measured with the Tower of London. Both correlations were small. In addition, more time spent in moderate to vigorous physical activity and a higher total volume of physical activity were related to a shorter total execution time of the Tower of London, which is a measure of how fast the child can solve the problem. A faster execution time indicates that the task has been planned adequately in advance. The results of this study confirm the suggestion that it is necessary to analyze physical activity and sedentary behavior separately. The total volume of physical activity consists mainly of light intensity exercise. Children are often engaged in physically and socially playful activities of low intensity that place a demand on their executive functioning. Therefore, what children do (type of exercise) might be interesting to include in future studies on physical activity behavior, in addition to how much children do.

As language competency is important to understand and engage in interactive behaviors with other children, children with developmental language disorders (DLD) are more likely to avoid activities that involve social interaction. This may result in less or less variable physical activity and lower physical fitness levels than TD children. In Chapter 4 it was shown that children with DLD show lower physical fitness levels on strength and speed components in comparison to age and gender matched TD peers. No difference was found on cardiovascular endurance. Also, their physical activity (total volume, time spent in sedentary behavior and time spent in moderate to vigorous physical activity) was not different from TD children, which could be explained by the fact that all children with DLD in this study were within a specialized school setting, with little or no interaction with TD children during school hours. Therefore, they could interact with peers that show similar problems, which will likely limit withdrawal from physical activity. However, the language difficulties could have resulted in less varied physical activity behavior. The lower scores of children with DLD on strength and speed components of physical fitness compared to TD children, can indicate that they are possibly less involved in exercises such as jumping and sprint running, that require good motor skills.

Chapters 5 and 6 showed the results of the effects of a physical activity intervention program in TD children and children with DLD respectively. The goal of the intervention was to improve physical fitness and executive functioning. The physical activity intervention program for TD children was provided twice a week during lunch recess, thirty minutes each time. Children with DLD followed the intervention program as part of the regular school day, also twice a week for thirty minutes each time. Children in the control group had lunch as they normally did (TD children), or followed the regular academic schedule (children with DLD). In both instances, the physical activity program was run for 22 weeks, and consisted of a combination of aerobic exercise, circuit training and games. It was found that TD children who followed the intervention did not show more improvements on any of the physical fitness measures in comparison to children in the control group (Chapter 5). In contrast, children in the intervention group showed a significantly greater improvement than children in the control group on the Stroop test and Digit Span test, measures reflecting inhibition skills and verbal working memory respectively. Accompanying effect sizes were small. No effects of the physical activity intervention were found on the other measures of executive functioning; the Visual Memory Span test, the Trailmaking test and the Tower of London, which reflect visual working memory, cognitive flexibility and planning respectively. As improvements on aspects of executive functioning were found without an improvement in aerobic fitness, it is suggested that the cognitive engagement apparent in the physical activity program may have accounted for these improvements.

In children with DLD, a rather specific fitness effect was found, as children in the intervention group showed significantly larger improvement on the sit-ups, reflecting trunk strength and endurance, compared to the control group (Chapter 6). The accompanying effect size was large. The physical activity program was thus effective only on one aspect of physical fitness that was specifically trained in the intervention program. The study revealed that there were no effects of the extra physical activity on executive functioning measures reflecting planning and visual working memory. Planning was measured using the Tower of London, while the Visual Memory Span test was used to reflect visual working memory. It was expected that executive functioning would benefit from increased cardiovascular fitness, or that the games in the physical activity program would challenge aspects of executive functioning. However, as the mechanisms involved in DLD remain unclear, there might be other factors that limit the potential of physical activity to target impairments in executive functioning. Further research is required before conclusions can be drawn about the possible effects of physical activity on physical fitness and executive functioning in children with DLD.

Overall, the results confirm the associations between physical activity, physical fitness and cognition in children, as has been found in previous studies. Physical activity and physical fitness were related, however, improving physical fitness in school aged children by increasing physical activity was found to be difficult. Also, improving executive functioning by manipulating physical activity or improving physical fitness is not straightforward. The findings reveal the complexity of the relations between and effects of increased physical activity on children's physical fitness and executive functioning, which will be discussed below in light of the theoretical background as described in the introduction of this thesis.

7.3 General discussion

Physical activity, physical fitness and cognitive performance

This thesis confirmed the positive relationship between *physical fitness* and executive functioning, as well as between physical fitness and academic achievement in typically developing (TD) children (Chapter 2). There was also a strong link between performance on executive functions and academic achievement, which has been found in previous studies (Best, Miller, & Naglieri, 2011; St Clair-Thompson & Gathercole, 2006). Importantly, it revealed that executive functioning served as a mediator within the relationship between physical fitness and academic achievement, as the indirect relation via executive functioning was stronger than both the direct and total relation between fitness and academic achievement. The relations as discussed in Chapter 2 suggest that physiological changes as a result of increased physical fitness will be beneficial for executive functioning.

Furthermore, in Chapter 3 it was shown that *physical activity* was related to planning aspects of executive functioning in children. Results from this chapter indicate that not only physical activity at moderate to vigorous intensities, but also activities at lower intensity levels can stimulate executive functioning. The results add to the mounting evidence on the relationships between physical activity, physical fitness and cognitive development in children, by highlighting the specificity of the relationships, and giving insight into possible mechanisms explaining these relationships. In addition, it draws attention to the importance of considering both physical activity and sedentary behaviour of children. It has recently been suggested that sedentary behaviour might be behaviourally independent from light intense and moderate to vigorous physical activity, and may even counteract the positive benefits of being physically active (Voss, Carr, Clark, & Weng, 2014). This thesis confirmed this line of reasoning, as it was shown that sedentary behaviour was negatively related to performance on the Stroop test, meaning that children who spent more time in sedentary behaviour, perform worse on an inhibition task (Chapter 3). As research shows that lifestyle changes and constraints have resulted in children becoming more sedentary, playing less outside and showing less risky play than previous generations (Hillman, 2006; Karsten, 2005), we have to think of ways in which we can activate children during the day. Offering more opportunities for all children to be physically active at school might be a good start to reduce time spent in sedentary behaviour.

Physical activity interventions in children

In the current study, a physical activity program was developed that was implemented during lunch recess (Chapter 5). In addition, a similar program was implemented in the timetable of a school with a continuous school day, in a sample of children with developmental language disorders (DLD) (Chapter 6). The aim of both interventions was to increase cardiovascular fitness, strength and speed, as well as cognitive performance. The intervention for TD children included aerobic exercise, as well as circuit training and cognitively engaging games (Chapter 5). It was shown that an increase in physical activity resulted in significant improvements in inhibition and verbal working memory. While the intensity of the intervention in TD children in the current study was found to be moderate to vigorous during three randomly selected sessions, no improvements were found in physical fitness. This suggests that the cognitively engaging games might underlie the improvements found in executive functioning in the current intervention study. A recent intervention study also found support for this (Crova et al., 2014). Higher improvement in inhibitory ability was found in overweight children, compared to overweight controls and lean peers after a six month enhanced physical education program. The intervention consisted of object control skills which were assumed to be cognitively challenging. Aerobic fitness did not mediate the effects.

In other intervention studies improvements were found on aspects of executive functioning in children after an aerobic exercise program. Davis et al. (2011) found improvements in planning ability following a 13 weeks after school intervention program in overweight children. Two other studies found improvements in working memory performance (Kamijo et al., 2011), and inhibition and cognitive flexibility (Hillman et al., 2014) following a nine month after school intervention program. Children were between 7 and 11 years old, which is a similar age range as the children involved in the current study. Both studies showed that increases in cardiovascular fitness were associated with improvements in executive functioning, suggesting a mediating role of aerobic fitness (Hillman et al., 2014; Kamijo et al., 2011). However, it should be noted that the exercise programs in these studies also included games and motor skills, which indicates that it is difficult to clearly distinguish between aerobic exercise and cognitively engaging exercise effects.

Specificity of executive functions

In this thesis, not all aspects of executive functioning were related to physical activity, or improved as a result of the physical activity intervention program. It thus seems that the core abilities of executive functioning vary in sensitivity to exercise, raising the question what might explain this specificity. One suggestion is that there might be different sensitive periods for each executive function, during which performance might be affected by physical activity behavior. For example, most studies on relationships between physical activity or fitness and executive functioning in children have measured inhibition (Buck, Hillman, & Castelli, 2008; Chaddock et al., 2010; Pontifex et al., 2011). It is suggested that inhibition is the first executive function to emerge during infancy, and is sensitive between ages 6 and 10, when adult levels are reached (Jurado & Rosselli, 2007). Another suggestion is that the improvements will depend upon the activity trained. Physical activity can challenge inhibition skills and working memory, or require the child to shift attention. It has also been demonstrated that executive functions must continually be repeated and challenged by increases in task difficulty to promote improvements in children (Diamond & Lee, 2011). Children engaging in a lot of different activities involving both physical and cognitive effort, will continually stimulate their executive functioning. Interventions should therefore try to match children's optimal challenge point both in the intensity of physical activity as well as in cognitive engagement during physical activity.

Children with developmental language disorders

In children with DLD, no physical activity intervention studies have been reported before. As a result of their difficulties with communication and understanding, children with DLD likely withdraw from complex games and play more solitary and less varied physical activity than TD children. This has for example been shown in an observational study on playground behavior of children with DLD (Fujiki, Brinton, Isaacson, & Summers, 2001). In Chapter 4 of this thesis it was shown that children with DLD show lower scores on physical fitness than TD children. The physical activity intervention for children with DLD, as described in Chapter 6, therefore consisted of aerobic activity, circuit training and games, to maximize the variety of exercises, in addition to intensity. This resulted in improvements on the sit-ups, but no effects were found on executive functioning (Chapter 6). Children with DLD display lower scores on executive functioning measures than TD children (Henry, Messer, & Nash, 2012; Vugs, Hendriks, Cuperus, & Verhoeven, 2014). DLD are thought to be related to some sort of procedural memory and sequencing deficiencies (Ullman & Pierpont, 2005), which has been shown to result in impairments in visuo-spatial working memory (Hick, Botting, & Conti-Ramsden, 2005) and strategic planning (Marton, 2008). However, mechanisms involved in these impairments remain unclear, which makes it difficult to know if there are other limiting factors that will have an effect on the use of physical activity to target impairments in executive functioning. For example, if the motor or cognitive demand of physical activity tasks are greater than the resources of the children, performance might suffer (Im-Bolter, Johnson, & Pascual-Leone, 2006).

Methodological considerations

Implementation of a physical activity program in primary schools is a challenging task. In the current study, an intervention was developed that could easily be implemented in primary schools. The results show that it is feasible to implement a physical activity intervention program at schools, both for typically developing children as well as for children with special educational needs. The structured physical activity can be offered during lunch recess, or as an addition to the physical education lessons. In total, approximately two hundred children participated in this study, of which around 50 children with DLD. A quasi-experimental set up was used, in which children were assigned to the intervention group based on their willingness to participate (TD children) and on the possibilities in the academic schedule (children with DLD). Therefore, the results as presented in chapters 5 and 6 could have been influenced by gender or age, as the intervention group in TD children consisted of more girls than boys, and in children with DLD the intervention group was significantly older than children in the control group. The next step therefore would be to perform a randomized controlled trial. Nevertheless, it is promising to see that small doses of cognitively engaging physical activity can result in improvements in inhibition and verbal working memory in TD children, even with no differences in physical fitness variables. It is also encouraging that this intervention was able to take place during the school day, making it possible to target all children. In addition, a process evaluation showed that children really enjoyed the physical activity program, which is probably the best starting point to get children more active for a lifetime.

Physical activity was measured using an accelerometer, which provided valid data about the quantity of children's daily physical activity. The habitual physical activity of children, which is what children normally do, can also reveal activity patterns in comparison to time spent in sedentary behavior, which will probably determine the net result of being physically active. Physical fitness was found to be difficult to improve. In children with DLD specific training effects were found on physical fitness; only performance on the sit-ups improved, which was an exercise included in the circuit training of the physical activity program (Chapter 6). In TD children no significant differences were found on any of the physical fitness variables between the intervention and control group (Chapter 5). It is known that the physiological response of increased physical activity is highly variable and genetically influenced. Perhaps more frequent and intense activity programs are necessary to differentiate from gains due to normal growth and development in TD children. In addition, baseline aerobic capacity varies widely between children, making it difficult to raise the average physical fitness level of a group of children. Low fit children, or overweight children, will likely benefit most from physical activity interventions. The group of children with DLD shows considerable variation in performance, and is even characterized by their heterogeneity, which perhaps requires a more personalized approach in which goals are set for each individual child.

A broad range of neuropsychological tests was used in the current study to measure executive functioning in children. As mentioned in the introduction of this thesis, neuropsychological tests were developed to detect deficiencies in normal brain function (Pennington & Ozonoff, 1996). The tests are wide spread and frequently used. However, there are some main points to consider when studying executive functioning in children. Firstly, to what extent the tests are suitable to detect changes in children without deficiencies in normal brain function. Secondly, whether the currently used neuropsychological tests to measure executive functioning are appropriate instruments to capture the "real life" behaviors of children (Chaytor, Schmitter-Edgecombe, & Burr, 2006; Koziol & Lutz, 2013). That is, are the tasks ecologically valid for children's everyday activity. Perhaps future studies could include observational rating skills (Isquith, Roth, & Gioia, 2013; Vugs et al., 2014) in addition to neuropsychological tests to measure executive functioning. Nevertheless, the tests used in this thesis give a valid indication of a child's cognitive performance in a test setting.

7.4 Implications for future research

"Moveo ergo sum", I move therefore I am, or in other words, thinking beings are active beings (Anderson, 2003).

Studying brain-behavior relationships in children is a fascinating and complex area of research. Children are physically active by nature, and this evolutionary programmed necessity in our genes may have provided the drive for mental activity (Vaynman & Gomez-Pinilla, 2006). Offering various play opportunities, and creating environments that stimulate physical activity is thus necessary; a child that is more active, will generate more knowledge about action control, thus will develop more brain interactions (Koziol & Lutz, 2013). However, disentangling the close connection between physical activity and cognition in order to find out more about their common development, has shown some interesting results, and revealed some challenges for future studies. For example, the role of sedentary behavior in relation to cognition warrants more attention, as time spent sedentary might counteract the positive benefits of physical activity. In addition, future intervention studies need to consider the role of cognitively engaging exercise, in comparison to aerobic exercise. In other words, exercise cognition research should focus on how qualitative exercise characteristics can be used to obtain cognitive benefits (Pesce, 2012).

Also, research on executive functioning often uses "top down" models of cognitive control explaining the role of executive functioning in behavior. These models have emerged from an information processing view on cognition. In this view, the brain is divided into different parts that are responsible for a particular task within a complex behavior (Lieberman, 2002); brain functions are differentiated and the working of different behaviors such as cognitive, executive and motor domains are analyzed separately. However, insights from new techniques (CT, EEG, fMRI, and from brain surgeries) illustrate that the working of the brain is not so straightforward. In fact, neural models provide evidence that the same neurons are active in planning and movement execution (Cisek & Kalaska, 2010). The brain operates as an integrated whole, and executive functions are embedded in and inseparable from physical activity (Shaheen, 2013). Research on executive functioning in children should therefore focus on the interaction with the environment (Ardila, 2008; Koziol & Lutz, 2013). This is where human movement scientists should step in and raise their voice, to find ways in which executive functioning can be measured in the "real life" situations in which children are involved. That would be the way to move forward!

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Appendices

Nederlandse samenvatting

Doel van dit proefschrift

Het belangrijkste doel van dit proefschrift was het bestuderen van de relaties tussen fysieke activiteit, fysieke fitheid, executieve functies en schoolvaardigheden bij basisschoolleerlingen, en uit te zoeken of kinderen verbeteringen laten zien op fysieke fitheid en executieve functies na het volgen van een beweegprogramma. Zowel kinderen uit het reguliere onderwijs als kinderen met spraak- en/of taalstoornissen uit het speciaal onderwijs deden mee. Taalvaardigheid speelt een belangrijke rol bij executieve functies, en is essentieel voor deelname aan spelactiviteiten met andere kinderen.

Er werd gestart met het onderzoeken of de relaties tussen fysieke fitheid, executieve functies en schoolvaardigheden aanwezig waren bij de kinderen in het reguliere onderwijs (Hoofdstuk 2). Daarnaast werd de mediërende rol van executieve functies in de relatie tussen fysieke fitheid en schoolvaardigheden bestudeerd. Vervolgens is in Hoofdstuk 3 de relatie tussen fysieke activiteit en executieve functies onderzocht bij kinderen in het reguliere onderwijs. Meer specifiek is gekeken naar de totale hoeveelheid fysieke activiteit van kinderen, de tijd in sedentair gedrag en de tijd in matig tot hoog intensieve fysieke activiteit en de afzonderlijke relatie van deze variabelen met het executief functioneren. In Hoofdstuk 4 is een vergelijking gemaakt tussen de fysieke activiteit en fysieke fitheid van kinderen in het reguliere onderwijs en kinderen met een taalontwikkelingsstoornis (TOS). Tenslotte zijn in hoofdstuk vijf en zes de effecten bekeken van een fysieke activiteit interventie programma op de fysieke fitheid en het executief functioneren van kinderen in het reguliere onderwijs (Hoofdstuk 5) en kinderen met TOS (Hoofdstuk 6). Hieronder volgen korte samenvattingen van de bevinden in elk hoofdstuk.

Samenvatting van de bevindingen

In Hoofdstuk 2 is aangetoond dat er significant positieve relaties bestaan tussen fysieke fitheid, executieve functies en schoolvaardigheden bij kinderen op reguliere basisscholen. De relaties waren matig tot hoog van sterkte. Fysieke fitheid, executieve functies en schoolvaardigheden zijn latente factoren, wat betekent dat het constructen zijn die gemeten kunnen worden met meerdere variabelen. Fysieke fitheid werd gemeten met de Eurofit test batterij. Factoranalyse (Confirmatory Factor Analysis) liet zien dat fysieke fitheid bestond uit een combinatie van cardiovasculaire en krachtcomponenten. Executieve functies werden gemeten met de Tower of London, een maat voor planning, en de Trailmaking test, wat een maat is voor cognitieve flexibiliteit. Scores op de Cito test lezen, spelling en rekenen werden gebruikt als maten voor schoolvaardigheid. Naast de bevestiging van de relaties tussen fysieke fitheid, executieve functies en schoolvaardigheden, is onderzocht of de relatie tussen fysieke fitheid en schoolvaardigheden direct of indirect was, via executieve functies. Met andere woorden, de mediërende rol van executieve functies is onderzocht. Structurele vergelijkingsmodellen (Structural Equation Modeling) lieten zin dat het executief functioneren een mediërende factor is in de relatie tussen fysieke fitheid en schoolvaardigheden. De ontwikkeling van executieve functies is daarom mogelijk essentieel voor goede academische vaardigheden bij kinderen. Dit onderstreept het belang van het bestuderen van executieve functies bij kinderen.

Hoofdstuk 3 beschreef de relatie tussen de dagelijkse fysieke activiteit en de verschillende aspecten van het executief functioneren bij kinderen op reguliere basisscholen. Fysieke activiteit, gedefinieerd als alle lichamelijke inspanning van het musculaire systeem waardoor het energieverbruik toeneemt boven het fysiologische verbruik in rusttoestand, werd geanalyseerd onafhankelijk van sedentair gedrag, dat wordt gemarkeerd door een laag energieverbruik. Er werd aangetoond dat meer tijd in sedentair gedrag was gerelateerd aan een lagere (slechtere) inhibitie score op de Stroop test. Een hogere totale hoeveelheid fysieke activiteit was geassocieerd met een betere planning vaardigheid, gemeten met de Tower of London. Daarnaast was meer tijd in matig tot hoog intensieve fysieke activiteit en een hogere totale fysieke activiteit gerelateerd aan een kortere totale uitvoeringstijd van de Tower of London, een maat voor hoe snel een kind het probleem kan oplossen. Een snellere uitvoeringstijd geeft aan dat de taak vooraf goed is gepland. Al deze significante correlaties waren laag van sterkte. De resultaten van deze studie bevestigen de suggestie dat het noodzakelijk is om fysieke activiteit en sedentair gedrag onafhankelijk van elkaar te onderzoeken. De totale hoeveelheid fysieke activiteit bestaat voornamelijk uit licht intensieve inspanning. Kinderen zijn vaak actief in fysiek en sociaal speelse activiteiten op een lage intensiteit die een beroep doen op hun executief functioneren. Daarom is het wellicht interessant om naast de hoeveelheid aan fysieke activiteit, ook te bestuderen welke activiteiten kinderen ondernemen (type activiteit).

Een goede beheersing van taal is belangrijk om het gedrag van andere kinderen te begrijpen en om deel te nemen aan sociale interactie met anderen. Om die reden is het aannemelijk dat kinderen met taalontwikkelingsstoornissen (TOS) activiteiten vermijden waarbij sociale interactie belangrijk is. Dit kan resulteren in minder of minder variabele fysieke activiteit en een lagere fysieke fitheid. In Hoofdstuk 4 is laten zien dat kinderen met TOS een lagere fitheid hebben op kracht en snelheidsonderdelen in vergelijking met reguliere kinderen gematcht op leeftijd en geslacht. Er werd geen verschil gevonden in cardiovasculaire fitheid. Ook de fysieke activiteit van kinderen met TOS (totale hoeveelheid, tijd in sedentair gedrag en tijd in matig tot hoog intensieve fysieke activiteit) was niet verschillend ten opzichte van reguliere kinderen. Dit is mogelijk te verklaren door het feit dat de kinderen met TOS in deze studie allemaal leerlingen waren van een school in het speciaal onderwijs, met weinig tot geen contact met leerlingen in het reguliere onderwijs. Hierdoor gaan de kinderen met TOS onder schooltijd om met kinderen met dezelfde problematiek, waardoor ze zich mogelijk minder geremd voelen om met andere kinderen te spelen. Echter, de taalproblematiek kan wel leiden tot minder gevarieerde fysieke activiteit. De lagere scores van kinderen met TOS op de kracht en snelheidsonderdelen van fysieke fitheid in vergelijking met reguliere kinderen, duiden mogelijk aan dat ze minder deelnemen aan kortdurende intensieve activiteiten waarbij motoriek een grote rol speelt, zoals springen en sprinten.

Hoofdstukken 5 en 6 lieten de resultaten zien van de effecten van het beweegprogramma (interventie) bij respectievelijk reguliere kinderen en kinderen met TOS. Het doel van beide interventies was het verbeteren van de fysieke fitheid en executive functies. Het beweegprogramma voor kinderen in het reguliere onderwijs werd twee keer per week aangeboden tijdens de lunchpauze, dertig minuten per keer. Kinderen met TOS volgden het beweegprogramma als onderdeel van hun reguliere schooldag, eveneens twee keer per week dertig minuten. In beide gevallen werd de interventie 22 weken lang aangeboden en bestond het programma uit een combinatie van aerobe inspanning, circuit training en complexe spelvormen zoals het uitvoeren van bepaalde activiteiten afhankelijk van het getal op de dobbelsteen of de kleur van een object. Dit geeft de activiteiten een onvoorspelbaar en wisselend karakter, waardoor kinderen zowel fysiek als cognitief worden uitgedaagd. Er werd gevonden dat kinderen in het reguliere onderwijs die de interventie hadden gevolgd, op de nameting niet significant beter scoorden op fysieke fitheid dan kinderen in de controlegroep (Hoofdstuk 5). Kinderen in het interventieprogramma lieten daarentegen wel een significant grotere verbetering zien dan kinderen in de controlegroep op de Stroop test en de Cijferreeksen test, testen die respectievelijk inhibitie en verbaal werkgeheugen meten. De effectgrootte was klein. Er werden geen effecten van het beweegprogramma gevonden op de andere maten van executieve functies; de Visueel Geheugen test, de Trailmaking test en de Tower of London, maten die respectievelijk het visueel werkgeheugen, cognitieve flexibiliteit en planning (probleemoplossend vermogen) meten. Omdat er verbeteringen zijn gevonden op enkele aspecten van executieve functies zonder een verbetering in aerobe fitheid, is het aannemelijk dat de cognitieve component die aanwezig was in de complexe spelactiviteiten van het beweegprogramma mogelijk ten grondslag ligt aan deze verbeteringen.

Bij de kinderen met TOS werd een specifiek fitness effect gevonden; leerlingen die het beweegprogramma volgden waren significant meer vooruit gegaan op de sit-ups, een maat voor rompkracht en -uithoudingsvermogen, dan kinderen in de controlegroep (Hoofdstuk 6). De effectgrootte was sterk. Het beweegprogramma was dus effectief op één aspect van fitheid dat specifiek was getraind tijdens de interventie. De studie liet verder zien dat er geen effecten van het beweegprogramma waren op de executieve functie testen voor planning en visueel werkgeheugen. Planning werd gemeten met de Tower of Londen en de Visueel Geheugen test werd gebruikt als maat voor het visueel werkgeheugen. Er werd verwacht dat executieve functies zouden verbeteren via een toename in cardiovasculaire fitheid, of dat de complexe spelsituaties in het beweegprogramma een beroep zouden doen op aspecten van executieve functies. Echter, omdat de achterliggende mechanismen in TOS nog onduidelijk zijn, zijn er mogelijk andere factoren die verhinderen dat fysieke activiteit positief kan bijdragen aan het stimuleren van executieve functies. Meer onderzoek is nodig voordat er conclusies getrokken kunnen worden over de mogelijke effecten van fysieke activiteit op de fysieke fitheid en executieve functies bij kinderen met TOS.

Concluderend worden in dit onderzoek de verbanden tussen fysieke activiteit, fysieke fitheid en cognitie bij kinderen op de basisschool bevestigd, zoals ook gevonden in eerdere studies. Fysieke activiteit en fysieke fitheid zijn eveneens gerelateerd, echter, het verbeteren van de fysieke fitheid van basisschool leerlingen door het verhogen van de fysieke activiteit bleek moeilijker dan gedacht. Het verbeteren van het executief functioneren van kinderen door het verhogen van de fysieke activiteit lijkt wel mogelijk. De rol van fysieke fitheid hierin is echter niet eenduidig. De bevindingen laten de complexiteit zien van de relaties tussen en de effecten van een verhoging van de fysieke activiteit op de fysieke fitheid en het executief functioneren van kinderen.

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Oké, genoeg gezegd. Let's move on! Anneke

About the author / Over de auteur

Anneke van der Niet was born on January 8, 1982, in Amersfoort, The Netherlands. After graduating high school in Amersfoort, she started to study Human Movement Sciences at the VU University in Amsterdam. During her study she was actively involved in several courses on human physiology, as a student assistant. A few months after graduating in 2005, Anneke went to South Africa for half a year to teach physical education at several primary schools in a small village. There she was fascinated by the motor capacity of children and the way children make use of their bodies in comparison to children in the Netherlands. She realized that when studying motor skills, the culture in which a child grows up should be taken into account. She thus wanted to get a better understanding of the role of culture in child development and decided to start a two-year research master in African Studies at Leiden University. During this master, she again went to Africa, to study culture specific motor skills of children in a village in Sierra Leone. After finishing this master in 2009, she worked for a year at Nivel, the Netherlands institute for health services research, before she started her PhD project in Groningen.

Anneke van der Niet werd geboren op 8 januari 1982 in Amersfoort. Nadat ze de middelbare school in Amersfoort had doorlopen, ging ze bewegingswetenschappen studeren aan de Vrije Universiteit in Amsterdam. Tijdens haar studie was ze actief betrokken bij verschillende vakken over fysiologie, als student assistent. Een paar maanden na haar afstuderen in 2005, vertrok Anneke voor een half jaar naar Zuid-Afrika, waar zij gymnastiekles gaf op verschillende basisscholen in een dorpje. Daar raakte ze gefascineerd door de motorische vaardigheden van de kinderen en de manier waarop kinderen bewegen in vergelijking met kinderen in Nederland. Ze besefte dat wanneer men motorische vaardigheden bestudeert, ook de cultuur waarin een kind opgroeit meegenomen zou moeten worden. Ze wilde daarom meer kennis opdoen over de rol van cultuur in de ontwikkeling van kinderen en besloot om een tweejarige master Afrikastudies te volgen aan de Universiteit Leiden. Tijdens deze master ging zij opnieuw naar Afrika, om cultuur specifieke motorische vaardigheden te bestuderen van kinderen in een dorp in Sierra Leone. Na het behalen van deze master in 2009, werkte ze een jaar op het Nivel, het Nederlands instituut voor onderzoek van de gezondheidszorg, voordat ze begon aan haar PhD project in Groningen.

List of Publications / Publicatielijst

Van der Niet, A.G., Hartman, E., Moolenaar, B.J., Smith, J., Visscher, C. (2015). Effects of a physical activity program on physical fitness and executive functions in children with developmental language disorders. Submitted.

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