Physical activity and cognition in children
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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.
Summary and general discussion

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!
References


