Physical Activity, Cognitive Performance and Academic Achievement in Adolescents

Findings From The GOALS Study

The research reported here was carried out at the

Open Universiteit
www.ou.nl

In the context of the research school

ico

Interuniversity Centre for Educational Sciences

And was funded by

National Initiative Brain & Cognition

the National Initiative Brain and Cognition (NIHC), which is part of the Netherlands Organisation for Scientific Research (NWO)
Project No: 056-32-012

ISBN: 978-90-9029-182-6

Cover design: Sjoerd Cloos
Layout: Chris Peeters
Printed by: Strijp-CS

Physical Activity, Cognitive Performance and Academic Achievement in Adolescents

Findings From The GOALS Study

PROEFSCHRIFT

ter verkrijging van de graad van doctor
aan de Open Universiteit
op gezag van de rector magnificus
prof. mr. A. Oskamp
ten overstaan van een door het
College voor promoties ingestelde commissie
in het openbaar te verdedigen

op vrijdag 4 september 2015 te Heerlen
om 16.00 uur precies

door

Martin Leonard van Dijk
Geboren op 13 juni 1983 te Naaldwijk

Promotores
Prof. dr. P. A. Kirschner, Open Universiteit
Dr. R. H. M. de Groot, Open Universiteit

Overige leden beoordelingscommissie
Prof. dr. M. J. M. Chin A Paw, VU University Medical Center Amsterdam
Prof. dr. J. J. Reilly, University of Strathclyde
Prof. dr. J. F. M. Claessen, Open Universiteit
Prof. dr. L. Lechner, Open Universiteit
Dr. M. P. J. van Boxtel, Maastricht University

TABLE OF CONTENTS

CHAPTER 1

General Introduction

Health benefits of physical activity (PA) are well-documented. For example, PA has been found to increase bone density (Forwood & Burr, 1993) and cardiovascular fitness (Strong et al., 2005) and decrease the risks of developing obesity, cardiovascular diseases, and type 2 diabetes (Warburton, Nicol, & Bredin, 2006). The more and the more intensive the PA, the greater the health benefits appear to be (Janssen & Leblanc, 2010; Warburton et al., 2006), though also light intensity PA might have beneficial health effects as it decreases risks on developing cardiovascular diseases and type 2 diabetes (Duvivier et al., 2013). In addition, emerging evidence indicates that substantial health benefits may even be achieved by small increases in the amount of PA, particularly in inactive individuals (Ekelund et al., 2015). Despite of the well-known health benefits, habitual PA levels have decreased during the past decades (Pate, Mitchell, Byun, & Dowda, 2011). This move towards a more sedentary lifestyle has dramatic consequences: physical inactivity is nowadays the fourth leading cause of death worldwide (Kohl et al., 2012) responsible for nearly 1 on 10 deaths (Lee et al., 2012).

In addition to the generally positive impact of PA on physical health and functioning, an increasing amount of literature shows also the positive effects of PA on brain functioning (Hillman, Erickson, & Kramer, 2008), which might result in improved cognitive performance and academic achievement. The majority of studies investigating associations between PA and cognitive performance and academic achievement focused on young children (<12 years old) or older adults (> 55 years old), while adolescents (12-18 years old) as a group has received less attention (Hillman, Erickson, & Kramer, 2008, Tomporowski, Davis, Miller & Naglieri, 2008). Most of the studies in adolescents used questionnaires to measure PA, a subjective instrument which has been found to have several limitations (Shephard, 2003). Only six studies in adolescents used an objective instrument to measure PA and reported mixed results. Therefore, the main aim of this dissertation is to get more insight into the associations between objectively measured PA and cognitive performance and academic achievement in adolescents. In addition, it investigates the associations between active commuting to school, cognitive performance and academic achievement, as well as the associations between PA and mental health and PA and school absenteeism due to illness.

In the next paragraphs, the concepts cognition, academic achievement, and the adolescent period will be explained. Subsequently, the biological mechanisms of PA on brain functioning will be described. Previous studies investigating associations between PA and cognitive performance and academic achievement in adolescents will be discussed, as well as their limitations and possible methodological improvements. Finally, the research questions and an overview of the studies in this dissertation will be described.

Physical Activity

PA is defined as any bodily movement produced by skeletal muscles that results in energy expenditure (Caspersen, Powell, & Christenson, 1985). PA can be categorized in occupational/school, sports, conditioning, household or other activities, such as active commuting or taking the stairs in a public building. It is also possible to define PA by its intensity (i.e., light, moderate-to-vigorous and vigorous). Light intensity PA is defined as any activity in which humans use on average less than 3 times as much energy compared to sitting quietly. Examples of light intensity activities are washing dishes, walking at slow speed (<4km/h) and playing billiards (Ainsworth et al., 2000). Light intensity PA is the predominant activity in total daily energy expenditure (Donahoo, Levine, & Melanson, 2004). Moderate-to-vigorous intensity PA (MVPA) is defined as any activity in which humans use on average 3 to 6 times as much energy compared to sitting quietly, for example brisk walking (at a speed about 4-7 km/h), easy bicycling (at a speed about 14-19km/h), dancing, and mopping (Ainsworth et al., 2000). Vigorous intensity PA is defined as any activity in which humans use on average more than 6 times as much energy compared to sitting quietly, such as many physical sports, running, bicycling (at a speed >19 km/h) and high impact aerobics (Ainsworth et al., 2000).

Cognition, Academic Achievement and Mental Health

Cognition is derived from the Latin verb 'cognoscere' that means 'knowing'. Cognition refers to mental abilities involved in knowledge and comprehension, such as attention, information-processing (Chodzko-Zajko et al., 1992), memory, reasoning (Tatemichi et al., 1994), and evaluation (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956). A special group of cognitive abilities are the executive functions, which refer to general purpose control mechanisms that modulate the operation of various cognitive sub-processes (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). Executive functions allow us to shift our mind-set quickly and adapt to diverse situations while in the same time inhibiting inappropriate behaviours. In addition, executive functions enable us to create a plan, initiate its execution and stay focused on the task until completion (Jurado & Rosselli, 2007).

Academic achievement refers to the performance on school subjects such as mathematics and English or on specific tests thereof. Cognitive functions are of crucial importance in academic achievement (Trautmann & Zepf, 2012), in particular executive functions (Crone & Dahl, 2012). However, it is important to note that these concepts are not equal and influenced by different factors (Esteban-Cornejo, Tejero-Gonzalez, Sallis, & Veiga, 2014).

Mental health can refer to psycho-social outcomes (e.g., self-esteem), and mental well-being, for example (a lack of) experienced depressive symptoms (Biddle & Asare, 2011). Self-esteem refers to the evaluation that persons make about themselves that expresses a self-judgment of approval, disapproval, and personal worth (Rosenberg, 1965). Depressive symptoms refer to an overall reduced sense of well-being and can be expressed in affective symptoms, such as depressed mood and loss of pleasure, and somatic symptoms, such as sleep disturbances, eating problems and lack of energy (Stavrakakis, de Jonge, Ormel, & Oldehinkel, 2012).

The Adolescent Period

All of the above mentioned concepts (i.e., PA, cognition, academic achievement, mental health) are crucial in the adolescent period, the transition phase from a dependent child to an autonomous adult in which many physical, mental and behavioural changes occur (Crone & Dahl, 2012). The adolescent period is an important age group to investigate associations between PA and cognitive performance and academic achievement, because high levels of cognition and academic achievement during adolescence have been associated with job success (Diamond, 2013) and health during adulthood (Gale et al., 2012) and might delay late-life cognitive deficits (Dik, Deeg, Visser, & Jonker, 2003).

The adolescent brain shows remarkable changes in both structure and function during adolescence (Romeo & McEwen, 2006). In particular, the frontal brain lobes develop rapidly through the formation of 'high-speed' communication networks (i.e., myelination) and synaptic pruning, which means removing of inefficient connections (Steinberg, 2005). The frontal brain lobes are thought to be strongly involved in the regulation of executive functions (Miyake et al., 2000; Stuss & Levine, 2002). PA has been found to have positive effects particularly on executive functions associated with frontal brain activity (Guiney & Machado, 2013). Because the adolescent frontal brain lobes develop rapidly, PA might be particularly beneficial for this age group (Etnier & Chang, 2009). In addition, the adolescent brain is flexible and sensitive to lifestyle factors, such as PA (Chaddock-Heyman, Hillman, Cohen, & Kramer, 2014) and an active lifestyle during adolescence may have protective effects on brain functioning and physical health across the lifespan (Hillman et al., 2014). Therefore, a physically active lifestyle during adolescence is of high importance, however, the adolescence is the period of life with the greatest decline in PA levels across the lifetime (Sallis, 2000; Van Mechelen, Twisk, Post, Snel, & Kemper, 2000). Taken together, the adolescent period is an interesting age group to investigate the role of (changing) habitual PA levels on brain functioning and consequently cognitive performance, in particular executive functioning, and academic achievement.

The Effects of PA on Brain Functioning

PA is one of the lifestyle factors which might have beneficial effects on brain functioning (Cotman, Berchtold, & Christie, 2007). These effects can be separated in acute effects and chronic effects.

Acute effects. Acute beneficial effects mean that a bout of exercise immediately upregulates brain functioning. For example, an acute bout of exercise increases the heart rate and blood epinephrine concentrations, which are related with increases in arousal (i.e., a physiological and psychological state of being awake and reactive to stimuli) and consequently improved attention and memory consolidation (Brisswalter, Collardeau, & Rene, 2002; Winter et al., 2007). In addition, a bout of exercise might improve event-related brain potentials; patterns of neuro-electric activation that occur in response to, or preparation for, a stimulus or response (Hillman et al., 2009). Improvements in event-related brain potentials may increase cognitive performance and academic achievement, because people may devote more attentional resources (Hillman, Kamijo, & Scudder, 2011). Finally, exercise can increase the blood plasma level of β-endorphin (Ernst, Olson, Pinel, Lam, & Christie, 2006) which has been found to be related to positive moods and an overall enhanced sense of well-being (Craft & Perna, 2004). These mental health benefits are in turn positively related to cognitive performance and academic achievement (Frojd et al., 2008; Kovacs & Goldston, 1991; O'Malley & Bachman, 1979).

Chronic effects. Chronic beneficial effects mean that only when people are physically active for long periods will there be improvements in brain functioning. These periods of habitual PA range from 3-6 weeks training up to 10 years in some studies (Padilla, Perez, & Andres, 2014). Habitual PA stimulates the formation of new neurons (i.e., neurogenesis) and new blood vessels (i.e., angiogenesis) in the brain (Thomas, Dennis, Bandettini, & Johansen-Berg, 2012). The formation of new blood vessels in the brain may result in enhanced transport of oxygen and other resources to the brain (Chodzko-Zajko, Schuler, Solomon, Heinl, & Ellis, 1992), resulting in improved cognitive performance and academic achievement because of the increased resources available in the cerebral environment (Etnier, Nowell, Landers, & Sibley, 2006). Finally, habitual PA facilitates neuronal survival (Cotman & Berchtold, 2002) and synaptic plasticity (Vaynman, Ying, & Gomez-Pinilla, 2004), which refers to the capability of the connections in the brain to vary their function, to be replaced, and to increase or decrease in number when required.

Taken together, several biological mechanism of PA may improve brain functioning and consequently cognitive performance and academic achievement as well as mental health. However, the associations between PA and cognitive performance and academic achievement are not clear across all ages.

PA Associated With Cognitive Performance and Academic Achievement

Studies in older adults. The majority of studies investigating associations between PA and cognitive performance focused on older adults (Chaddock-Heyman et al., 2014). This focus is motivated by the often-observed decline of brain functioning that accompanies aging, which might be slowed or even stopped with PA (Kramer, Erickson, & Colcombe, 2006; Leckie et al., 2014). Kirk-Sanchez and McGough (2014) reported in a recent review paper a dose-dependent neuroprotective relationship between PA and cognitive performance in older adults. They concluded that well-designed exercise programs promise preserving cognitive performance in older adults.

Studies in children. The majority of studies in children and adolescents focused on young children (< 12 years old). A recent review of Chaddock-Heyman et al. (2014) in 7 to 10 years old children showed a positive relationship between PA and cognitive performance and academic achievement. Higher fit children have superior performance on tasks of memory, executive functioning, and academic achievement when compared to their lower fit peers. Also, Sibley and Etnier (2003) and Fedewa and Ahn (2011) reported in meta-analyses including 3 to 18 years old children and adolescents a positive impact of PA on cognitive performance and academic achievement. In addition, Fedewa and Ahn

(2011) reported that the greatest benefits were found when mathematics performance was used as outcome measure.

Studies in adolescents. A total of 17 studies investigated associations between PA and cognitive performance or academic achievement in adolescents (12-18 years old). Of these, 8 studies reported positive associations (Coe, Pivarnik, Womack, Reeves, & Malina, 2006; Correa-Burrows, Burrows, Orellana, & Ivanovic, 2014; Esteban-Cornejo, Gomez-Martinez, et al., 2014; Fox, Barr-Anderson, Neumark-Sztainer, & Wall, 2010; Kantomaa et al., 2013; Kristjansson, Sigfusdottir, & Allegrante, 2010; Sigfusdottir, Kristjansson, & Allegrante, 2007; So, 2012). In contrast, 4 studies reported no significant association (Daley & Ryan, 2000; Jaakkola, Hillman, Kalaja, & Liukkonen, 2015; Pindus et al., 2014; Syväoja et al., 2013) and 1 study reported a negative association (Tremblay, Inman, & Willms, 2000). In addition, 4 studies reported mixed results (Booth, Leary, et al., 2013; Booth, Tomporowski, et al., 2013; Kwak et al., 2009; Syväoja et al., 2014). Taken together, results of observational studies in adolescents are not uniform, but a small majority of studies reported positive associations between PA and cognitive performance or academic achievement. This was also concluded in a recent review of Esteban-Cornejo, Tejero-Gonzalez et al. (2014), who included also studies involving active commuting to school (Martinez-Gomez et al., 2011) and sports participation (yes/no) during leisure time (Ruiz et al., 2010) instead of the total amount of PA or MVPA per week.

In addition to above-mentioned observational studies, also a few experimental studies in children and adolescents have been published and reported mixed results. Ardoy et al. (2014) showed that four compared to two physical education classes per week (55 min/class, mean heart rate 129 beats/min) during four months did not improve cognitive performance and academic achievement in 12 to 14 years old adolescents. However, four physical education classes per week of intensive activities (mean heart rate 147 beats/min) improved average school grades and cognitive performance compared to the control group (Ardoy et al., 2014). In the Trois Rivieres study (Shephard, Lavallee, Volle, LaBarre, & Beaucage, 1994), children in the experimental group received one hour of physical education class per day throughout their six years of primary school, compared to the children in the control group who received the standard (one physical education class per week). Results indicated that children in the experimental group showed better academic performance in grades 2, 3, 5 and 6 compared with the control subjects (Shephard et al., 1994). In contrast, a cross-over experimental study of Coe et al. (2006) showed no effect of an physical education intervention (55 min/day, five times a week during six months) on academic achievement in 11-12 years old pre-adolescents. Finally, in a study of Dwyer, Coonan, Leitch, Hetzel, and Baghurst (1983) in 10 years old pre-adolescents, the experimental group received one hour physical education class per day during a period of 14 weeks, while the control group continued the usual curriculum, which included more academic instruction. Results showed no effect of the daily physical education class on academic achievement, therefore the authors concluded that there was no loss of academic achievement in spite of 45-60 minutes loss of formal teaching (Dwyer et al., 1983).

In conclusion, the majority of studies in children and adolescents show positive associations between PA and cognitive performance or academic achievement. However, it is difficult to draw a conclusion for the group of adolescents, because a very broad age range (3-18 years old) has been used in meta-analyses, while experimental studies show mixed results. Results of observational studies have to be taken with caution, because most of them have an important limitation, as explained below.

Limitations of previous studies in adolescents. The majority of the observational studies described above determined PA using questionnaires (i.e., self-report). This subjective measure of PA has several limitations, such as social desirability (Adams et al., 2005) and recall bias (Duncan, Sydeman, Perri, Limacher, & Martin, 2001). In addition, people tend to overestimate time spent in MVPA (Chinapaw, Slootmaker, Schuit, Van Zuidam, & Van Mechelen, 2009) and children in particular (Corder et al., 2010). Also, people underestimate time spent in light intensity PA (Bassett, Cureton, & Ainsworth, 2000). Taken together, subjectively measuring PA has several limitations, which might decrease the accuracy of the PA measures. Therefore, it is important to measure PA objectively when investigating the associations with cognitive performance or academic achievement.

Objectively Measuring PA

To investigate habitual PA levels, periods long enough to be representative of the daily PA levels should be investigated with minimal discomfort for the subject (Plasqui & Westerterp, 2007). Accelerometry has become the preferred method of objectively examining PA under free-living circumstances (Dowd, Harrington, & Donnelly, 2012) and is seen as golden standard in large study samples (Kwak et al., 2009). Accelerometers are small devices usually attached on the hip, back, waist or thigh, which register accelerations of segmental movements (Ryan, Grant, Tigbe, & Granat, 2006). Accelerations are measured by sensors, for example using piezoelectric or piezoresistive technique, in single or multiplanes of motion (Kavanagh & Menz, 2008). The accelerations are defined as the change in velocity over time, as such it quantifies the volume and intensity of movement (Trost, McIver, & Pate, 2005). Accelerometers attached on the participants thigh might be preferred, because these devices are also able to capture activities with little displacement of the upper body, such as cycling (Steeves et al., 2014).

Objectively Measured PA Associated with Cognitive Performance and Academic Achievement in Adolescents

Previous studies. Thus far, only six studies in adolescents investigated associations between objectively measured PA and cognitive performance or academic achievement and reported mixed results. A study of Kwak et al. (2009) in 16 years old Swedish adolescents revealed a positive association between vigorous intensity PA and academic achievement in girls, but no significant association in boys. In addition, Syväoja, Tammelin, Ahonen, Kankaanpää, and Kantomaa (2014) reported that MVPA was positively correlated with reaction speed in 12 years old Finnish adolescents. In the same cohort, MVPA was not significantly associated with executive functioning and visual memory (Syväoja et al., 2014) and academic achievement (Syväoja et al., 2013). In addition, Pindus et al. (2014) found that MVPA was not significantly associated with cognitive processing speed in 15 years old English adolescents. Findings from the ALSPAC cohort, a longitudinal study in English adolescents aged 11 to 16 years old, showed that total PA volume was negatively associated with academic achievement in unadjusted models (Booth, Leary, et al., 2013). In contrast, MVPA, as a percentage of the total PA volume, was positively associated with academic achievement (Booth, Leary, et al., 2013). Finally, from the same ALSPAC cohort, Booth et al. (2013) reported that total volume of PA predicted lower attention scores in boys at age 11 and 13 years, while MVPA predicted higher attention scores in boys at age 11 and 13 years old. In addition, the results were not uniform across all administered task and less convincing for females, therefore Booth, Tomporowski et al. (2013) concluded that the association between PA and attention and executive functioning is complex.

Taken together, thus far the associations between objectively measured PA and cognitive performance and academic achievement in adolescents are unclear. These associations might be impacted by sex, age, volume and intensity of PA and the tasks used to measure cognitive performance and academic achievement.

Limitations previous studies. A limitation of the six studies described above is that the accelerometers they used were attached on the hip, a place which limit capturing activities with little movement of the upper body such as cycling (Chillon et al., 2011). Furthermore, the accelerometers were prone to exhibiting missing data as they had to be removed during bathing and sleeping; participants possibly forgot to re-attach them (Sirard & Slater, 2009). In addition, as a consequence swimming was not registered by the accelerometers. Also, not all these studies took differences in adolescents' activity levels between weekdays and weekend days (Comte et al., 2013) into account. Finally, adolescents' PA levels tend to decrease (Ruiz et al., 2011), but none of these studies investigated the associations between changes in PA and changes in cognitive performance or academic achievement.

Methodological Improvements

Four methodological improvements will be introduced in the studies in this dissertation compared to the above-mentioned previous studies in adolescents. First, habitual PA levels will be measured by a waterproofed accelerometer to allow wear time during all activities (24 hours/day). Second, the accelerometers will be placed on the thigh (see Figure 1.1), thus activities with little movement of the upper body, such as cycling, will also be captured. Third, habitual PA levels will be based on at least four complete days (24 hours of wear time), including both weekend days. Fourth, habitual PA levels will be measured both at baseline and one-year follow-up.

Figure 1.1 *Physical activity was objectively measured by a waterproofed accelerometer attached on the thigh during one full week (24 hours/day).*

Research Questions

The main research questions of the studies in this dissertation are:

1) What is the association between habitual PA levels and cognitive performance and academic achievement in adolescents?
2) What is the association between active commuting to school and cognitive performance and academic achievement in adolescents?
3) What is the association between habitual PA levels and school absenteeism due to illness in adolescents?
4) What is the association between change in adolescent's habitual PA levels over one-year time and change in cognition and academic achievement?
5) What is the association between change in adolescents' habitual PA levels over one-year time and change in mental health?

Overview of the Dissertation

In Chapter 2 the research design is presented. All empirical studies described in this dissertation are part of The GOALS (Grootschalig Onderzoek naar Activiteiten van Limburgse Scholieren [Large-scale Research of Activities in Dutch Students]) Study. This observational longitudinal study was conducted between October 2011 and May 2013 at a secondary school in the Netherlands.

In Chapter 3 the cross-sectional associations between PA and academic achievement are presented. In addition, the mediating role of executive functioning in the association between PA and academic achievement is described.

In Chapter 4 active commuting to school, a common activity in Dutch adolescents, is discussed associated with cognitive performance and academic achievement. In addition, the moderating role of sex and the mediating role of depressive symptoms in the association between active commuting to school and cognitive performance and academic achievement is described.

In Chapter 5 the association between PA and school absenteeism due to illness is shown. Health benefits of PA are well documented in the literature, but no study so far investigated the association between PA and school absenteeism. Though, school absenteeism is a topic of high importance, for example because high levels of school absenteeism are related to learning delays and lowered academic achievement.

In Chapter 6, changes in adolescents' habitual PA levels are described using objective data at baseline and one-year follow-up. Subsequently, the associations between changes in PA and changes in cognitive performance and academic achievement are discussed.

Chapter 7 is the last empirical study in this dissertation, in which the associations between change in PA during adolescence and change in mental health are described. Mental health is defined by measures of depressive symptoms and self-esteem.

This dissertation concludes with a general discussion in which the findings of the separate chapters are integrated and the findings are discussed in the light of practical relevance for parents, schools and public health.

CHAPTER 2

Cohort Profile of The GOALS Study: A Large-scale Research of Physical Activity in Dutch Adolescents

The GOALS (Grootschalig Onderzoek naar Activiteiten van Limburgse Scholieren [Large-scale Research of Activities in Dutch Students]) Study was set up to investigate possible associations between different forms of physical activity with cognitive performance, academic achievement and mental well-being. It was conducted at a secondary school in the south of the Netherlands. Data collection took place during normal school weeks from October 2011 to March 2012 and one year later from October 2012 to May 2013. The study was approved by the local Ethical Committee of the Open University of the Netherlands. All students in grades 7 and 9 of senior general secondary education and university preparatory education were invited to participate ($N = 526$). At baseline a sample of 440 Dutch-speaking adolescents was willing to participate (83.7%). Of these, 344 participated in the follow-up. Physical activity was measured objectively by an ActivPal3^{TM} accelerometer. Cognitive performance was measured by the d2 Test of attention and the Symbol Digit Modalities Test. Academic achievement was determined using the mean of school grades in Dutch, English, and Mathematics. Several well-validated instruments were used to determine mood/depressive symptoms, self-esteem and goal orientation. Information on several covariates such as sex, academic year, school level, ethnicity, socioeconomic status, body mass index, pubertal status, smoking, drinking, computer use etc. are available.

This chapter is based on: De Groot, R. H. M., Van Dijk, M. L., & Kirschner, P. A. (2015). Cohort Profile of The GOALS Study: A Large-scale Research of Physical Activity in Dutch Students. *British Journal of Educational Technology (Published online ahead of print)*.

The relationship between physical activity level and cognitive performance (Ploughman, 2008) or academic achievement (Trudeau & Shephard, 2008) has become a field of interest for many. An increasing amount of research suggests a positive association between physical activity and brain functioning (Hillman, Erickson, & Kramer, 2008). Similarly, a negative association between physical inactivity and brain functioning is also becoming more evident (Kesse-Guyot et al., 2012; Tremblay et al., 2011). Most research in this field has focused on young children (Fedewa & Ahn, 2011) or older adults (Colcombe & Kramer, 2003), while adolescents – as a group - have not received much attention. Research in older adults has shown that physical activity yielded the largest benefits on executive-control processes (Colcombe & Kramer, 2003). The prefrontal cortex, the area still developing during adolescence is the most important brain domain involved in these executive functions. Investigation of the association between physical activity and cognitive and academic performance during adolescence is therefore of great value.

Previous studies, investigating the associations between physical activity and cognitive performance (including executive functioning) and academic achievement, predominantly measured physical activity subjectively through questionnaires. It could be argued that the results from these studies might be biased due to social desirability (Adams et al., 2005), recall bias (Duncan, Sydeman, Perri, Limacher, & Martin, 2001), and over or underestimation of time spent in physical activity (Bassett, Cureton, & Ainsworth, 2000; Chinapaw, Slootmaker, Schuit, Van Zuidam, & Van Mechelen, 2009). The GOALS (Grootschalig Onderzoek naar Activiteiten van Limburgse Scholieren [Large-scale Research of Activities in Dutch Students]) Study is one of the first studies in which physical activity is measured objectively in adolescents and linked to cognitive performance, academic achievement and mental well-being. In addition, it is the first study in which physical activity as well as cognitive performance and academic achievement are measured objectively in a longitudinal design.

Methods

Design, Procedures, Participants

The GOALS Study has a longitudinal observational design. All students from grades 7 and 9 of senior general secondary education or university preparatory education from a secondary school in the south of the Netherlands were invited to participate in the study (N = 526). In the classroom, information was distributed to the students as well as an invitation for an information evening for their parents/guardians. In total, 440 students (mean age 13.8 years, 46.8% girls, 52.7% from grade 7, 39.5% of senior general secondary education) agreed to participate (participation rate = 83.7%).

At baseline (October 2011 till March 2012) waterproofed ActivPAL3™ accelerometers, which had to be worn for one full week (24 hours/day), were taped on the midpoint of the anterior part of the thigh to measure physical activity. A 20-m shuttle-run test was executed, data with respect to weight and height were collected and several questionnaires regarding mood, self-esteem and goal orientation were filled in.

Exactly one week later the accelerometers were removed and the participants performed several cognitive tests in a classical setting. At the end of the academic year, the school provided school grades and absenteeism information. A one-year follow-up took place by repeating the above-mentioned procedures in the same participants one-year later (October 2012 till May 2013). A total of 297 adolescents (67.5% of the participants at baseline) participated at follow-up.

Independent Measures

Objectively measured physical activity. The ActivPAL3™ accelerometer (Paltechnologies, Glasgow, UK) was used to measure physical activity during a normal school week. This small device (53 x 35 x 7 mm) measures bodily accelerations and identifies the wearer's posture. Data were recorded at 20 Hz and summarised in 15-second time intervals (epochs). Data output for each epoch included number of steps, energy expenditure (i.e., metabolic equivalent/h), and time spent sitting/lying, standing, and moving.

Self-reported physical activity. The IPAQ-A (International Physical Activity Questionnaire in Adolescents) was used to subjectively assess the physical activity behaviour of the study population (Ottevaere et al., 2011).

Computer Gaming. Participants were asked about their gaming habits and their favorite gaming categories (i.e., sports, strategic, fighting, puzzle, adventure, learning games).

Dependent Measures

Cognitive performance. The Symbol Digit Modalities Test (Smith, 2010) was used to measure basic information-processing speed (Hinton-Bayre & Geffen, 2005). The d2 Test of attention (Brickenkamp & Zillmer, 1998) was used to measure selective attention and response inhibition (Budde, Voelcker-Rehage, Pietrabyk-Kendziorra, Ribeiro, & Tidow, 2008).

Academic achievement. End of year school grades (ranging from 1.0 = fail to 10 = outstanding) were acquired from the school's administration. Academic achievement was determined by the arithmetic mean of three subjects, namely Dutch, mathematics and English as a foreign language.

Mood / depressive symptoms. The Centre for Epidemiologic Studies Depression Scale (CES-D) was used to measure depressive symptoms in the general population (Radloff, 1977). Respondents rated the frequency - over the previous week - of twenty symptoms ranging from rarely or none of the time (0) to most or all of the time (3). A total score was calculated as the sum of all items, and ranged from 0 (not depressed) to 60 (high amount of depressive symptoms).

Self-esteem. The Rosenberg self-esteem scale was used to measure self-esteem (Rosenberg, 1979). It consists of ten statements dealing with general feelings about the respondent's own personality. Participants had to indicate on a 4-point Likert scale, whether they strongly agree (1), agree (2), disagree (3) or strongly disagree (4) with the statements.

Covariates

Parents were asked to report both parents' educational level. Socioeconomic status was defined as the highest educational level of the parents. Pubertal phase was measured through Petersen, Crockett, Richards, and Boxer's (1988) self-administered Pubertal Developmental Scale. Weight in kilograms and height in meters (two decimals) were measured in light clothing without shoes. The body mass index was then calculated by dividing the weight by the height squared. The 20-m shuttle-run test was used to measure cardiovascular fitness, as described by Leger, Mercier, Gadoury, and Lambert (1988). Alcohol consumption was measured via a short questionnaire and will be dichotomised into 'high' (>2 drinks containing alcohol >2 evenings per week) or 'low/none' intake categories. Smoking status was assessed with a single question ('current smoker?' yes/no).

Ethical Considerations

The local Ethical Committee of the Open University of the Netherlands (reference number: U2013/ 07405/HVM) approved the study. A comprehensive description of the nature and purpose of the study was given to parents/guardians, school supervisors and adolescents. Parents and/or guardians signed an objection form in case they did not agree with participation of their children or in case the students themselves did not agree to take part in the study.

Limitations

Our data are collected at one secondary school in the Netherlands, therefore results cannot be generalized to the whole Dutch adolescent population. On the other hand, this choice for only one school increases the homogeneity of the variables regarding academic achievement, because schools often differ in grading and teaching policies. Like in all studies and inherent to scientifically designed studies, selection bias might be present in our study. It can be expected that girls or obese adolescents were possibly less inclined to participate in the study compared to boys or slender adolescents, respectively. However, an equal number of boys and girls participated in The GOALS Study and the mean body mass index was in accordance with the overall Dutch adolescent population (Snoek, Van Strien, Janssens, & Engels, 2007), suggesting that this selection bias was not a serious issue in this population.

CHAPTER 3

The Association Between Objectively Measured Physical Activity and Academic Achievement in Adolescents: Findings From The GOALS Study

The main goal of this study was to investigate the association between objectively measured physical activity and academic achievement in adolescents. Students in grades 7 and 9 (*N* = 255) were included. Overall, physical activity was not significantly associated with academic achievement. However, in grade 7 total physical activity volume (Total PA) was negatively associated with academic achievement, while moderate-to-vigorous physical activity (MVPA) was negatively associated with both academic achievement and mathematics performance. In contrast, in grade 9 both Total PA and MVPA were positively associated with mathematics performance. In addition, the overall association between MVPA and academic achievement followed an inverted U-shaped curve. Finally, Total PA was positively associated with executive functioning, while executive functioning in turn mediated the associations between Total PA and both academic achievement and mathematics performance. These results indicate that the association between physical activity and academic achievement in adolescents is complex and might be impacted by academic year, physical activity volume and intensity, and school grade.

This chapter is based on: Van Dijk, M. L., De Groot, R. H. M., Savelberg, H. H. C. M., Van Acker, F., & Kirschner, P. A. (2014). The Association Between Objectively Measured Physical Activity and Academic Achievement in Adolescents: Findings From the GOALS Study. *Journal of Sport and Exercise Psychology, 36,* 460-473.

Physical activity generates positive structural changes in the brain, such as neurogenesis, angiogenesis, and improved connectivity (Thomas, Dennis, Bandettini, & Johansen-Berg, 2012). These positive effects of physical activity on the brain may consequently improve academic achievement. Many studies have indicated that children who spend more time in physical activities have better academic achievement than those who are less physically active (Fedewa & Ahn, 2011). Most of these studies have focused on young children (<12 years old), while adolescents (12 to 18 years old) as a group has received less attention. Results from children are difficult to generalize to adolescents because of the multiple physiological, emotional, and behavioural changes that occur during the adolescent period (Crone & Dahl, 2012). For example, the frontal brain lobes develop rapidly through myelination and synaptic pruning during the adolescent years (Steinberg, 2005). It is known that the frontal brain lobes are involved in the regulation of executive functions, which are of crucial importance to success in school (Crone & Dahl, 2012) and are positively correlated with mathematics performance (Bull & Scerif, 2001). Because physical activity has been found to have positive effects particularly on the frontal brain lobes (Guiney & Machado, 2013), the adolescent period is an interesting period to investigate the association between physical activity and (frontal lobe) brain functioning and consequently academic achievement.

Most studies on the associations between physical activity and academic achievement in adolescents have used questionnaires (i.e., self-report) to measure physical activity (Coe, Pivarnik, Womack, Reeves, & Malina, 2006; Daley & Ryan, 2000; Fox, Barr-Anderson, Neumark-Sztainer, & Wall, 2010; Sigfusdottir, Kristjansson, & Allegrante, 2007; So, 2012; Tremblay, Inman, & Willms, 2000). This subjective measure of physical activity has several limitations, such as social desirability (Adams et al., 2005), recall bias (Duncan, Sydeman, Perri, Limacher, & Martin, 2001), overestimation of time spent in moderate-to-vigorous physical activity (Chinapaw, Slootmaker, Schuit, Van Zuidam, & Van Mechelen, 2009), and underestimation of time spent in light-intensity physical activity (Bassett, Cureton, & Ainsworth, 2000). The latter, underestimation of time spent in light physical activity, is an important limitation for researchers investigating associations between physical activity and academic achievement. First, time spent in light physical activities accounts for a high proportion of the variability in total physical activity volume (McCrorie, Duncan, Granat, & Stansfield, 2012). Second, light physical activity is positively associated with physical health in adolescents (McCrorie et al., 2012) and thus might be positively associated with academic achievement as well (Ickovics et al., 2014).

Positive associations between self-reported physical activity and academic achievement in adolescents have been found in the majority of studies (Coe et al., 2006; Fox et al., 2010; Sigfusdottir et al., 2007; So, 2012). In contrast, no association was found between physical activity and academic achievement in English adolescents (Daley & Ryan, 2000). In addition, Tremblay et al. (2000) identified a weak but negative association between physical activity and academic achievement in 12-year-old Canadian adolescents. The authors suggested that physical activity might, up to some optimal level, be positively associated with academic achievement, while too much time spent on physical activity might detract from academic pursuits, resulting in a poorer academic achievement. The study of Syväoja et al. (2013) supports this conclusion; an inverse U-shaped curvilinear association was found between self-reported moderate-to-vigorous physical activity and academic achievement in Finnish early adolescents.

To our knowledge, only three studies have investigated the associations between objectively measured physical activity and academic achievement in adolescents, and they reported mixed results. Kwak et al. (2009) found a positive association between vigorous physical activity and academic achievement in Swedish adolescent girls, but no significant association in boys. In contrast, Syväoja et al. (2013) reported no significant association between moderate-to-vigorous physical activity and academic achievement in Finnish early adolescents. Finally, Booth, Leary et al. (2013) determined that total physical activity volume was negatively associated with academic achievement in unadjusted models. In contrast, moderate-to-vigorous physical activity, as a percentage of the total physical activity volume, was positively associated with academic achievement in English adolescents. A limitation of these studies was that the accelerometers they used were placed on the participants' hip, which limits the ability to capture non-ambulant activities, such as cycling (Chillon et al., 2011). In addition, differences in adolescents' physical activity levels between weekdays and weekend days (Jago, Anderson, Baranowski, & Watson, 2005) were not taken into account.

The main goal of this study was to investigate the association between objectively measured physical activity and academic achievement in Dutch adolescents in grades 7 and 9. In addition, we investigated whether this association was moderated by sex and academic year. Finally, we explored whether the association between physical activity and academic achievement was mediated by executive functioning. We measured habitual physical activity levels with an ActivPAL3™ accelerometer placed on the thigh and account for differences between weekdays and weekend days. We used two measures of physical activity: total physical activity volume per week (Total PA) and total moderate-to-vigorous physical activity per week (MVPA). Results were controlled for several covariates related to physical activity and academic achievement, such as sex, nationality, socioeconomic status (SES), body mass index (BMI), cardiovascular fitness, depressive symptoms, and self-esteem (Castelli, Hillman, Buck, & Erwin, 2007; Kwak et al., 2009; Sigfusdottir et al., 2007). We hypothesized a positive dose-response association between physical activity and academic achievement in adolescents, in line with research of Booth, Leary et al. (2013) and Kwak et al. (2009). In addition, we explored whether the association between physical activity and academic achievement followed an inverted U-shaped curve based on research of Syväoja et al. (2013).

We investigated several factors, such as sex, academic year and executive functioning, which might influence the association between physical activity and academic achievement in adolescents. First, we explored interaction effects between physical activity and sex on academic achievement and hypothesized that the association was more positive in girls than in boys, in line with Kwak et al. (2009). Second, the transition from elementary school to secondary school (grade 7 is the first year of secondary school in the Netherlands) might result in more negative thoughts about school and lower academic motivation (Wigfield, Eccles, Iver, Reuman, & Midgley, 1991). Because of the transition from elementary to secondary school in grade 7 students, we hypothesized that the association between physical activity and academic achievement was weaker in grade 7 compared to grade 9. Third, a study of Booth et al. (2013) showed that physical activity might benefit key components of executive functioning in adolescents, while executive functioning in turn has been found to be importantly related with academic achievement (Crone & Dahl, 2012). Therefore, we investigated whether the association between physical activity and academic achievement was mediated by executive functioning and explored interaction effects of sex and academic year.

Methods

Study Sample

The data source was The GOALS (Grootschalig Onderzoek naar Activiteiten van Limburgse Scholieren [Large-scale Research of Activities in Dutch Students]) Study. This cross-sectional study was conducted at a secondary school in the south of the Netherlands. Data collection took place during normal school weeks from October 2011 to March 2012. The study was approved by the local Ethical Committee of the Open University of the Netherlands.

All students in grade 7 and grade 9 of senior general secondary education or university preparatory education level were invited to participate (N = 526). A sample of 440 Dutch-speaking adolescents was willing to participate (83.7%). To increase the homogeneity of the study sample, students who had either skipped or repeated a year were excluded (73). Also, 24 students were excluded from our analyses because of health or concentration problems (8), illness or injuries throughout the entire week (8) or measurement failures of the accelerometer during the data collection week (8). Also, 88 participants did not wear the accelerometer for at least four valid days, including both weekend days, and were, therefore, excluded. As a result, 255 participants were included in analyses.

Procedures

Before starting the study, information about the background, goals, and procedures of the study was distributed to students of the selected classes. An invitation to an informative presentation about the study was attached for the parents and/or guardians. Parents and/or guardians signed an objection form in case they did not agree with participation of their children or in case the students themselves did not agree to take part in the study. Whenever possible, data were collected by the same research assistants who had been trained with standard protocols and were given standardized instructions to use.

Accelerometers were taped on the midpoint of the anterior part of the right thigh of the participants using a Tegaderm (3M, St. Paul, MN, US) transparent film roll. Participants were asked to wear the device continuously for one full week, 24 hours/day. To increase compliance, participants were allowed to shift the device to the left thigh if it irritated their skin. Prior to our study, a pilot study employing 23 students wearing an ActivPAL3™ accelerometer for one complete day on both legs reported an almost perfect Pearson's correlation (r = .997, $p < .001$) in the number of accelerometer steps between the left and right thigh. After attaching the accelerometers, participants took a 20-m shuttle-run test and then completed several questionnaires. They were also asked to keep a diary during the full week in which they reported vigorous physical activities, the times they went to bed and awoke, and any other relevant details such as problems with the accelerometer, illness, or injuries. Exactly one week later, participants returned their accelerometers and diaries. After finishing the study, participants received a gift voucher of 15 euro for their full participation. At the end of the academic year, school grades for Dutch, mathematics and English throughout the entire academic year were provided by the school.

Measures

Physical Activity. The ActivPAL3™ accelerometer (Paltechnologies, Glasgow, UK) was selected to measure habitual physical activity levels during a normal school week. This small device (53 x 35 x 7 mm) measures bodily accelerations and identifies the wearer's posture. Data were recorded at 20 Hz and summarized in 15-second time intervals (epochs). Data output for each epoch included number of steps, energy expenditure (metabolic equivalent/h), and time spent sitting/lying, standing, and moving.

Data were downloaded and processed with ActivPAL™ Professional software (version 6.4.1). A valid day was considered to be a day that the student wore the accelerometer for the whole day (i.e., 24 hours of wear time). Atypical schooldays (i.e., weekdays without school lessons) and days when the student reported sickness or injury in his/her diary were excluded. Because the accelerometer was taped at the thigh of the students, non-wear time was not an issue. Nevertheless, we used the weekly overviews of the accelerometer data to determine whether the students removed the accelerometer during the week, see Figure 3.1.

Habitual physical activity levels were estimated using a maximum of six valid days per student. According to prescribed accelerometer testing protocols, at least four valid days were required to estimate habitual physical activity levels per week (Trost, McIver, & Pate, 2005). In addition, complete accelerometer data for both Saturday and Sunday were required to be included in the analyses because physical activity levels in adolescents differ between weekdays and both weekend days (Jago et al., 2005), a trend that was also found in our data (see the Results section).

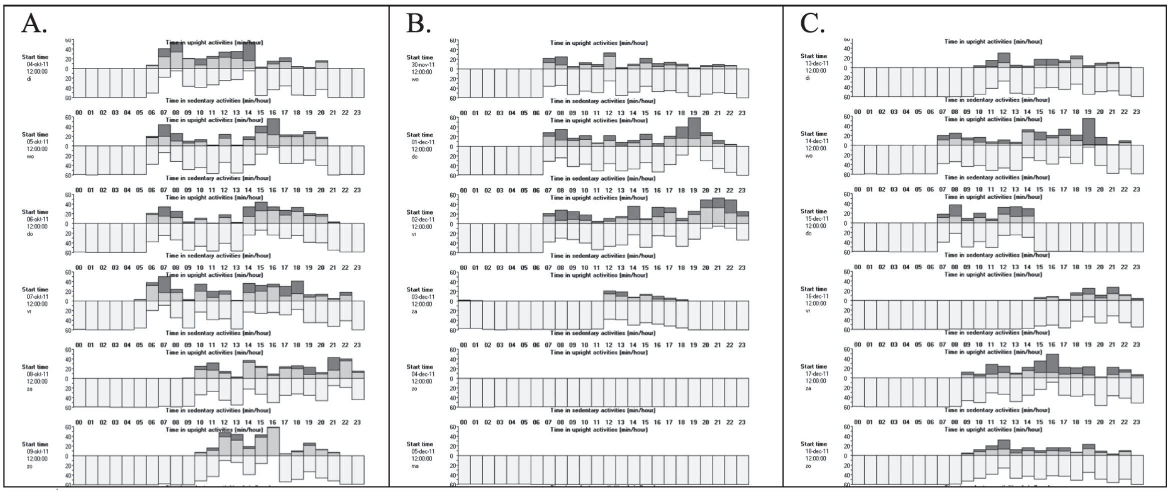

Figure 3.1 *Weekly overviews of the accelerometer data: A) This student wore the accelerometer six whole days (24 hours/day); B) This student wore the accelerometer on Wednesday, Thursday and Friday the whole day. The participant removed the accelerometer on Saturday and did not wear it on Sunday and Monday; C) This student wore the accelerometer on Tuesday and Wednesday the whole day. This student removed the accelerometer on Thursday, replaced it on Friday, and then wore it on Saturday and Sunday the whole day again.*

Two measures of physical activity were used as independent variable: (1) total physical activity volume per week (Total PA), and (2) total moderate-to-vigorous physical activity per week (MVPA). Total PA was determined by the total number of accelerometer steps per week measured by the accelerometer. MVPA was calculated by the total number of accelerometer steps per week with a cadence of ≥100 steps/minute, which was based on the growing consensus that a cadence of 100 steps/minute represents a reasonable minimum level for moderate physical activity in adolescents and adults (Dall, McCrorie, Granat, & Stansfield, 2013).

Academic achievement. School grades (ranging from 1.0 = very bad to 10.0 = outstanding) were provided by the school at the end of the academic year. The mean scores of the school grades for Dutch (native language), mathematics, and English as a modern foreign language were used as measures of academic achievement, according to research of Sigfúsdóttir, Kristjánsson, and Allegrante (2007). In addition, the largest effects in academic achievement due to physical activity were expected in mathematics performance (Howie & Pate, 2012), so the mean school grade for mathematics was analysed separately as well.

Executive functioning. The d2 Test of Attention (Brickenkamp & Zillmer, 1998) was used as measure of response inhibition (Budde, Voelcker-Rehage, Pietrabyk-Kendziorra, Ribeiro, & Tidow, 2008), a key component of executive functioning (Alvarez & Emory, 2006), and more broadly selective attention and concentration (Budde et al., 2008). The d2 Test of attention is a widely used neuropsychological test and the construct validity has been well supported in European samples (Bates & Lemay, 2004). It consists of 14 rows, each with 47 interspersed “p” and “d” characters. The characters had one to four dashes configured individually or in pairs above and/or below each letter. The target symbol was a “d” with two dashes (hence “d2”), regardless of whether the dashes appeared both above the “d”, both below the “d”, or one above and one below the “d”. The participant’s task was to cross out as many target symbols as possible, moving from left to right, with a limit of 20 seconds/row. No pauses were allowed. An overall performance score was calculated by the total number of correctly crossed-out symbols minus total number incorrectly crossed-out symbols.

Covariates. Several demographic and behavioural variables associated with physical activity and academic achievement were used as covariates. Sex (coded as -0.5 = boys, 0.5 = girls), nationality (coded as -0.5 = native Dutch, i.e., both parents/guardians born in the Netherlands and 0.5 = non-native Dutch), academic year (coded as -0.5 = grade 7, 0.5 = grade 9), and school level (coded as -0.5 = senior general secondary education [HAVO] and 0.5 = university preparatory education [VWO]) were centred.

Socioeconomic status (SES) was measured by the highest educational level of the parents/guardians as reported by the parents or guardians themselves. If the parents/guardians had at most a secondary vocational education level, SES was coded as ‘low-medium’ = -0.5; in all other cases SES was coded as ‘high’ = 0.5 following the Dutch national classification (Dutch Ministry of Public Health, Welfare and Sport, 2011). In cases where the parents/guardians did not report their educational levels, SES was based on student report (44.9%).

Weight in kg (rounded) and height in meters (two decimals) were measured in light clothing without shoes. The body mass index (BMI) was then calculated by dividing the weight by the height squared. Maximum oxygen consumption (VO_2 max) was used as indication of cardiovascular fitness and estimated by the 20-m shuttle run test (Leger, Mercier, Gadoury, & Lambert, 1988). The test consisted of 1-min stages of continuous incremental pace running. Participants were required to run between two lines placed on the floor 20 meters apart while keeping pace with audio signals. All measurements were carried out under standardised conditions on an indoor rubber-floored gymnasium. The initial speed was 8.5 km/h, which increased by 0.5 km/h each successive minute, reaching 18.0 km/h at minute 20. Participants were encouraged to continue running as long as possible throughout the course of the test. The test was finished when the participant failed to reach the end lines concurrent with the audio signals on two consecutive occasions. Otherwise, the test ended when the participant stopped because of fatigue. The last completed stage or half-stage at which the participant dropped out was scored. Using this score and the variables of sex, age, and BMI, VO_2 max was estimated using the equation of Matsuzaka et al. (2004): VO_2 max = 25.9 - 2.21 * Sex - 0.449 * Age - 0.831 * BMI + 4.12 * (8 + 0.5 * 20-m shuttle run test score). This equation was validated in children and adolescents and correlated strongly ($r = .80$, $p < .001$) with VO_2 max measured directly on a treadmill.

The Pubertal Developmental Scale was used to determine the participants’ phase of pubertal development (Petersen, Crockett, Richards, & Boxer, 1988). The scale has good reliability (alpha coefficients of the items range from .63 to .83, $p < .001$) (Petersen et al.,

1988) and high correlations (ranging from .61 to .67, $p < .001$) with physician ratings in adolescent girls (Brooks-Gunn, Warren, Rosso, & Gargiulo, 1987). Participants were asked about growth, body hair and skin changes (all), changes to voice, growth of facial hair (males), breast development, and onset age of menstruation (females). The pubertal phase (ranging from 1 = pre pubertal to 4 = post pubertal) was calculated by the average score of the answered questions.

The Center for Epidemiologic Studies Depression Scale (CES-D) was used to measure depressive symptoms experienced by participants (Radloff, 1977). Recent research has shown that the CES-D is an appropriate measurement instrument for depression in adolescents, with an internal consistency (Cronbach's alpha) ranging from .78 to .82 (Verhoeven, Sawyer, & Spence, 2013). In this 20-item self-report scale, students rated the frequency of 20 depressive symptoms over the previous week. A total severity score was calculated by summing all items, and the score ranged from 0 (not depressed) to 60 (a high amount of depressive symptoms).

The Rosenberg Self-Esteem Scale was used to measure global self-esteem (Rosenberg, 1979). Research in adolescents has revealed that the Rosenberg Self-Esteem Scale is a strong indicator of an adolescent's global self-esteem (Hagborg, 1993). The scale consists of ten statements dealing with general feelings about the respondent's own self. The score is calculated by summing all items and ranges from 0 (minimum score of self-esteem) to 30 (maximum score of self-esteem).

Total light-intensity physical activity volume per week (LIPA) was used as covariate in MVPA analyses only. LIPA was calculated by determining the total number of accelerometer steps per week with a cadence of <100 steps/minute: in other words, the Total PA minus the MVPA.

Statistics

Analyses were performed with the Statistical Package for the Social Sciences (SPSS) for Windows (version 19.0; SPSS, Inc., Chicago, IL, US). The level of significance was .05. Sex and academic year differences were analysed by independent sample *t*-tests and Pearson's chi-square test for continuous and dichotomous variables, respectively. Pearson's correlation was used to investigate the correlations between both Total PA and MVPA and health outcomes BMI, cardiovascular fitness, self-esteem and depressive symptoms.

Associations between Total PA and academic achievement were analysed by multiple linear regression analyses involving three steps, while controlling for covariates. Continuous variables and covariates were transformed into z-scores before they were entered in the multiple regression models. Associations between covariates and academic achievement were modelled (Step A). This step allowed us to control the results for possible confounding effects of the covariates. We considered controlling the results for MVPA as well; however, this action would have falsified the assumption of absence of multicollinearity, as the Pearson's correlation between Total PA and MVPA was large (r = .837, $p < .001$). Then, Total PA was added to the model (Step B). This step allowed us to investigate the added explained variance of Total PA to the model. Finally, data were explored for potential interaction effects of sex and academic year on the associations between Total PA and academic achievement. Interaction terms were calculated between the z-score of the Total PA and the centred (i.e., -0.5 and + 0.5 coded) scores of sex and academic year and then added to the model (Step C). Additionally, simple slopes analyses were performed for significant interaction effects in model C to further investigate the nature of the statistical interactions. The same steps were conducted to analyse the associations between MVPA and academic achievement; however, to investigate whether MVPA was associated with academic achievement independently of LIPA, we added LIPA as a covariate to this model. This process did not falsify the assumption of absence of multicollinearity because the Pearson's correlation between LIPA and MVPA was small to medium (r = .320, $p < .001$).

Furthermore, possible inverted U-shape associations between physical activity (both Total PA and MVPA) and academic achievement were analysed by multiple linear regression analyses. In these analyses, a model with a centred score of Total PA or MVPA was compared with a model with a centred as well as a squared score. The difference in explained variance between these models was compared to determine if any inverted U-shape association existed.

Finally, whether the association between physical activity and academic achievement was mediated by executive functioning was investigated by multiple linear regression analysis using the method of Preacher and Hayes (2008). Using this method, the same variables and steps as described above were used to investigate the association between physical activity and executive functioning, and in turn between executive functioning and academic achievement. Additionally, when these associations were found to be significant, we analysed whether executive functioning mediated the association between physical activity and academic achievement using the indirect bootstrap analyses for mediation models of Preacher and Hayes (2008).

The p-p plots of the multiple regression analyses indicated a normal distribution of the errors and multicollinearity was no issue (Pearson's correlation between covariates <.80). The reported results of the multiple regression analyses excluded outliers (>3 standard deviations).

Results

Preliminary Results

Total physical activity volume per day differed significantly between weekdays (10,733 ± 3104 accelerometer steps) and Saturday (9675 ± 5968 accelerometer steps, $p = .001$, paired *t*-test), between weekdays and Sunday (6294 ± 4159 accelerometer steps, $p < .001$), and between Saturday and Sunday ($p < .001$). Total moderate-to-vigorous physical activity per day also differed significantly between weekdays (4474 ± 2145 accelerometer steps) and Saturday (3250 ± 3326 accelerometer steps, $p < .001$, paired *t*-test), between weekdays and Sunday (1570 ± 2277 accelerometer steps, $p < .001$), and between Saturday and Sunday ($p < .001$).

Characteristics of the Study Participants

The descriptive statistics are shown in Table 3.1. Total PA was significantly higher in boys than in girls and in grade 7 than in grade 9. MVPA was also significantly higher in boys than in girls, while LIPA was significantly higher in grade 7 than in grade 9. Boys had significantly higher cardiovascular fitness and self-esteem than girls, while the pubertal phase and self-reported depressive symptoms were higher in girls than in boys. BMI and pubertal phase were significantly higher in grade 9 than in grade 7, while self-esteem was higher in grade 7 than in grade 9. Academic achievement and mathematics performance were significantly greater in girls than in boys and also in grade 7 than in grade 9. Executive functioning was significantly greater in girls than in boys and also in grade 9 than in grade 7.

Associations Between Physical Activity and Health Outcomes

Total PA was positively associated with cardiovascular fitness (r = .313, $p < .001$) and self-esteem (r = .158, $p = .012$), and negatively associated with BMI (r = -.184, $p = .003$) and depressive symptoms (r = -.158, $p = .012$). MVPA was positively associated with cardiovascular fitness (r = .238, $p < .001$) and self-esteem (r = .126, $p = .048$).

Associations Between Total PA and Academic Achievement or Mathematics Performance

Multiple linear regression analyses revealed that Total PA was overall not significantly associated with academic achievement and mathematics performance (Table 3.2, Step B). A significant interaction effect between Total PA and academic year on academic achievement was found (Table 3.2, Step C). Simple slopes analysis showed a significantly negative association between Total PA and academic achievement in grade 7 (β = -.23, $p = .007$) and no significant association in grade 9 (β = .09, $p = .393$), see Figure 3.2 left panel. Furthermore, a significant interaction effect between Total PA and academic year on mathematics performance was found (Table 3.2, Step C). Simple slopes analysis revealed a significantly positive association between Total PA and mathematics performance in students in grade 9 (β = .27, $p = .018$), but no significant association in students in grade 7 (β = -.17, $p = .057$), see Figure 3.2 right panel.

Table 3.1 *Descriptive statistics of the study sample*

	All (*n*=255)	**Boys (*n*=116; 45.5%)**	**Girls (*n*=139)**	**Grade 7 (*n*=152; 59.6%)**	**Grade 9 (*n*=103)**
Age (years)	13.02 (1.08)	12.91 (1.04)	13.10 (1.10)	12.21 (0.46)[b]	14.20 (0.42)[b]
Nationality					
Native Dutch	224 (88.9%)	105 (91.3%)	119 (86.9%)	133 (88.7%)	91 (89.2%)
Non-native Dutch	28	10	18	17	11
School level					
SGSE	84 (32.9%)	38 (32.8%)	46 (33.1%)	56 (36.8%)	28 (27.2%)
UPE	171	78	93	96	75
SES					
Low-medium	55 (22.0%)	21 (18.6%)	34 (24.8%)	35 (23.6%)	20 (19.6%)
High	195	92	103	113	82
BMI	18.82 (2.75)	18.81 (2.83)	18.82 (2.69)	18.06 (2.76)[b]	19.92 (2.33)[b]
Cardiovascular fitness	50.59 (4.92)	54.30 (5.19)[a]	49.82 (4.50)[a]	51.71 (5.57)	52.05 (4.90)
Pubertal phase	2.44 (0.77)	2.14 (0.66)[a]	2.70 (0.77)[a]	2.11 (0.67)[b]	2.94 (0.63)[b]
Depressive symptoms	11.44 (8.53)	9.15 (7.03)[a]	13.27 (9.18)[a]	11.19 (8.84)	11.81 (8.08)
Self-esteem	21.99 (5.04)	23.51 (4.57)[a]	20.78 (5.09)[a]	22.61 (5.17)[b]	21.12 (4.74)[b]
LIPA	42086 (11198)	42747 (10748)	41535 (11569)	45041 (11364)[b]	37727 (9428)[b]
MVPA	26777 (11634)	29504 (12295)[a]	24501 (10568)[a]	28203 (12087)	24673 (10641)
Total PA	68863 (18395)	72251 (19037)[a]	66036 (17409)[a]	73243 (18780)[b]	62400 (15801)[b]
Percentage MVPA of Total PA	38.03%	39.91% [a]	36.45% [a]	37.62%	38.63%
Total included valid days	5.82 (0.42)	5.80 (0.46)	5.84 (0.39)	5.76 (0.46)[b]	5.91 (0.35)[b]
Academic achievement	6.94 (0.76)	6.74 (0.73)[a]	7.10 (0.75)[a]	7.13 (0.73)[b]	6.65 (0.71)[b]
Mathematics performance	7.04 (1.04)	6.89 (1.04)[a]	7.16 (1.04)[a]	7.23 (1.01)[b]	6.75 (1.03)[b]
D2 Test of Attention	174.65 (24.71)	170.60 (25.65)[a]	178.05 (23.44)[a]	169.14 (22.41)[b]	182.86 (25.77)[b]

SGSE = senior general secondary education, UPE = university preparatory education, SES = socioeconomic status, BMI = body mass index, LIPA = total light-intensity physical activity volume per week, MVPA = total moderate-to-vigorous physical activity volume per week, Total PA = total physical activity volume per week. a = statistically significant difference between the sexes at p < .05. b = statistically significant difference between the school grades at p < .05.

***Table 3.2** Multiple linear regression analyses using Total PA as independent variable*

	Academic achievement			Mathematics performance			D2 Test of Attention		
	ΔR²	**Adj. R²**	***β***	**ΔR²**	**Adj. R²**	***β***	**ΔR²**	**Adj. R²**	***β***
Step A	.26*	.23		.17*	.13		.12*	.08	
Sex			.30*			.25*			.15
Nationality			.17*			.14*			.02
Academic year			-.41*			-.22*			.21*
School level			.17*			.19*			.10
SES			.07			.04			.07
BMI			.05			.01			.02
Cardiovascular fitness			.08			.10			.07
Pubertal phase			.03			-.06			.09
Depressive symptoms			-.06			-.05			.09
Self-esteem			.00			.07			.08
Step B	.01	.24		.00	.13		.02*	.09	
Total PA			-.11			-.01			.15*
Step C	.02**	.25		.04*	.16		.00	.09	
Total PA * Sex			-.02			.09			.04
Total PA * Academic year			.15*			.18*			.04

Step A = model including covariates; Step B = model including Step A and independent variable Total PA; Step C = model including Step B and potential interaction effects. SES = socioeconomic status, BMI = body mass index, Total PA = total physical activity volume per week. β = standardized regression coefficients. $p < .05$. ** $p = .053$.*

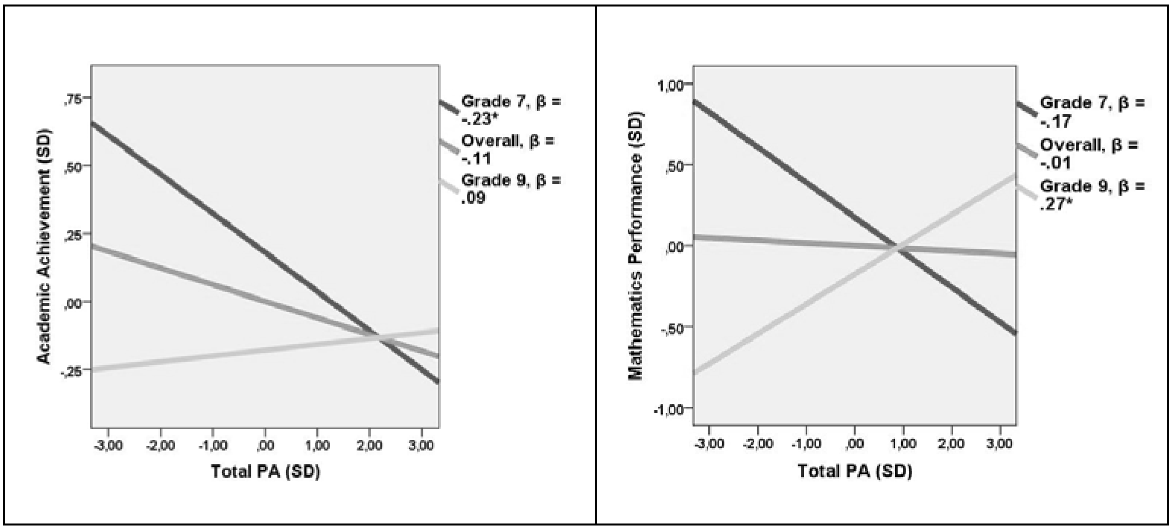

***Figure 3.2** Interactions between Total PA and academic year on academic achievement and mathematics performance. Left: Associations between Total PA and academic achievement. Right: Associations between Total PA and mathematics performance. Associations were analysed overall by multiple linear regression analyses (see Table 3.2, Step B) and separately in grade 7 and grade 9 by simple slopes analysis (see Results section).Total PA = total physical activity volume per week. SD = standard deviation. β = standardized regression coefficients. *p < .05.*

Inverted U-shape analysis showed that the multiple regression model including centred Total PA as the independent variable explained 27.2% of the variance in academic achievement. The multiple regression model that included both centred Total PA and centred and squared Total PA as independent variables explained 27.4% of the variance in academic achievement. The difference in explained variance between these models was not significant (ΔR^2 = .002, *p* = .501); therefore, no inverted U-shape association was found between Total PA and academic achievement.

Associations between MVPA and academic achievement or mathematics performance

MVPA was overall not significantly associated with academic achievement and mathematics performance (Table 3.3, Step B). A significant interaction effect between MVPA and academic year on academic achievement was found (Table 3.3, Step C). Simple slopes analysis showed a significantly negative association between MVPA and academic achievement in grade 7 (β = -.22, *p* = .011) and no significant association in grade 9 (β = .15, *p* = .147), see Figure 3.3 left panel. At the same time, a significant interaction effect between MVPA and academic year on mathematics performance was found (Table 3.3, Step C). Simple slopes analysis revealed a significantly negative association between MVPA and mathematics performance in grade 7 (β = -.23, *p* = .013), but a significantly positive association in grade 9 (β = .24, *p* = .035), see Figure 3.3 right panel.

Inverted U-shape analyses showed that the multiple regression model including centred MVPA as the independent variable explained 25.9% of the variance in academic achievement. A multiple regression model including both centred MVPA and centred and squared MVPA as independent variables explained 27.3% of the variance in academic achievement. The difference in explained variance between these models was significant (ΔR^2 = .014, *p* = .039); therefore, an inverted U-shape association was found between MVPA and academic achievement.

Associations Between Both Total PA and MVPA and Executive Functioning

Total PA was positively associated with performance on the d2 Test of attention (Table 3.2, Step B). As a result, a basic requirement for mediation analyses was fulfilled for executive functioning (i.e., performance on the d2 Test of attention) in the association between Total PA and academic achievement or mathematics performance. In addition, no significant interaction effects between Total PA and both sex and academic year on executive functioning were found (Table 3.2, Step C).

MVPA was not significantly associated with performance on the d2 Test of attention (Table 3.2, Step B) and also no significant interaction effects were found (Table 3.2, Step C). Therefore, executive functioning did not mediate the associations between MVPA and academic achievement or mathematics performance.

Table 3.3 *Multiple linear regression analyses using MVPA as independent variable*

	Academic achievement			**Mathematics performance**			**D2 Test of Attention**		
	ΔR^2	**Adj. R^2**	***β***	**ΔR^2**	**Adj. R^2**	***B***	**ΔR^2**	**Adj. R^2**	***β***
Step A	.26*	.22		.17*	.13		.13*	.08	
Sex			.31*			.24*			.13
Nationality			.17*			.14*			.02
Academic year			-.38*			-.21*			.25*
School level			.16*			.19*			.10
SES			.06			.04			.07
BMI			.03			.00			-.02
Cardiovascular fitness			.06			.09			.03
Pubertal phase			-.02			-.06			.10
Depressive symptoms			-.05			-.05			.11
Self-esteem			.03			.07			.09
LIPA			-.08			.03			.12
Step B	.00	.22		.00	.12		.01	.09	
MVPA			-.07			-.04			.09
Step C	.03*	.24		.05*	.17		.01	.09	
MVPA * Sex			.00			.10			.05
MVPA * Academic year			.17*			.20*			.05

*Step A = model including covariates; Step B = model including Step A and independent variable MVPA; Step C = model including Step B and potential interaction effects. SES = socioeconomic status, BMI = body mass index, LIPA = total light-intensity physical activity volume per week, MVPA = total moderate-to-vigorous physical activity volume per week. β = standardized regression coefficients. *p < .05.*

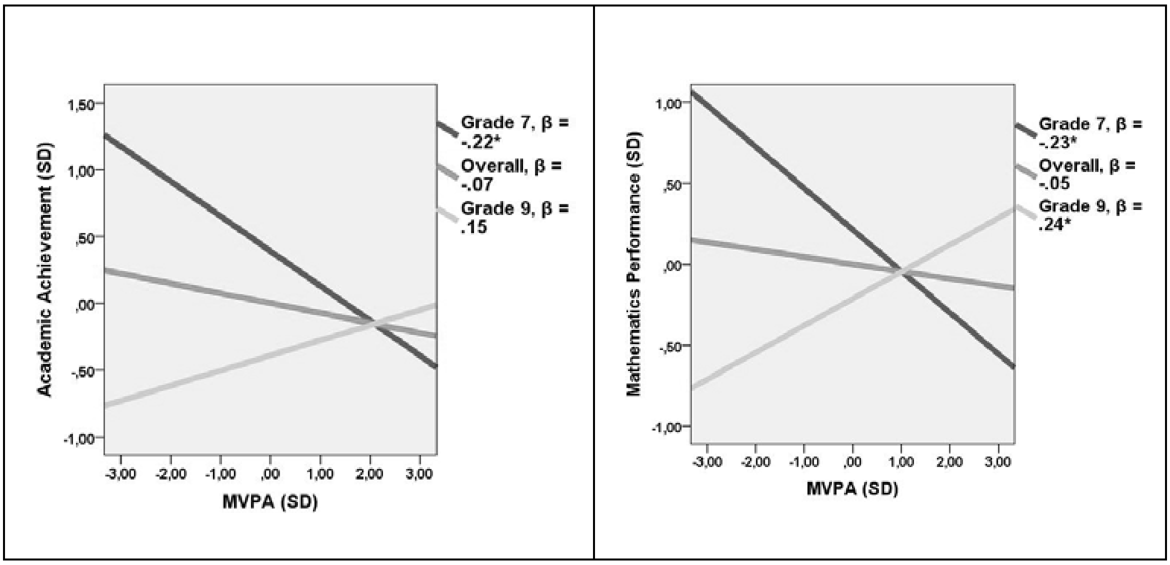

Figure 3.3 *Left: Associations between MVPA and academic achievement. Right: Associations between MVPA and mathematics performance. Associations were analysed overall by multiple linear regression analyses (see Table 3.3, Step B) and separately in grade 7 and grade 9 by simple slopes analysis (see Results section). MVPA = total moderate-to-vigorous physical activity volume per week. SD = standard deviation. β = standardized regression coefficients. *p < .05.*

Associations Between Executive Functioning and Academic Achievement or Mathematics Performance

Performance on the d2 Test of attention was positively associated with academic achievement (β = .14, p = .027) and mathematics performance (β = .23, p < .001). As a result, a second requirement for mediation analyses was fulfilled for executive functioning (i.e., performance on the d2 Test of attention) in the association between Total PA and academic achievement or mathematics performance. In addition, no significant interaction effects (sex and academic year) between performance on the d2 Test of attention and academic achievement or mathematics performance were found.

Mediating role of executive functioning in the association between Total PA and academic achievement or mathematics performance

Bootstrap analysis for mediation models showed a positive indirect effect of Total PA on academic achievement through executive functioning (effect = .0357; bootstrap confidence intervals between .0050 and .0849). In addition, also a positive indirect effect of Total PA on mathematics performance through executive functioning has been found (effect = .0351; bootstrap confidence intervals between .0064 and .0803).

Discussion

The main goal of the present study was to investigate the association between objectively measured physical activity and academic achievement in adolescents. The results indicated no significant overall dose-response association between Total PA or MVPA and academic achievement in our study sample of Dutch adolescents in grades 7 and 9. However, in grade 7 Total PA was negatively associated with academic achievement, while MVPA was negatively associated with both academic achievement and mathematics performance. In contrast, in grade 9 both Total PA and MVPA were positively associated with mathematics performance. In addition, the overall association between MVPA and academic achievement followed an inverted U-shape curve. Finally, we found a positive association between Total PA and executive functioning, and an indirect positive association between Total PA and both academic achievement and mathematics performance by executive functioning. Our research expands previous studies of Kwak et al. (2009) Syväoja et al. (2013) and Booth, Leary et al. (2013) by using four complete days (24 hours/day) with accelerometer data, including both weekend days, to calculate habitual physical activity levels. In addition, we investigated whether the association between physical activity and academic achievement was mediated by executive functioning.

Association Between Physical Activity and Academic Achievement

We hypothesized a positive dose-response association between physical activity and academic achievement in adolescents. Our main result, that there was no significant association between physical activity and academic achievement overall, is in contrast with this hypothesis. We have three explanations for this.

First, both Total PA and MVPA were negatively associated with academic achievement in grade 7, which is in line with the findings of Tremblay et al. (2000). In contrast, both Total PA and MVPA were positively associated with mathematics performance in grade 9, which is in agreement with Kwak et al. (2009). This discrepancy between grade 7 and grade 9 might be explained by physically active students who spent time on physical activities at the expense of time devoted to homework (Syväoja et al., 2013). Indeed, additional analyses of our data showed that both MVPA and Total PA were negatively correlated with self-reported time devoted to homework in grade 7 but not in grade 9. However, these results have to be interpreted with caution because it was unclear whether some students reported the total time devoted to homework per week or per day, which kept us from including this variable in the multiple regression analyses. In conclusion, we found possibly no significant overall dose-response association between physical activity and academic achievement because this association was moderated by academic year.

Second, it might be that physical activity, up to some optimal level, is positively associated with academic achievement, while too much time spent on physical activity might detract from academic pursuits such as time devoted to homework, resulting in a poorer academic achievement (Tremblay et al., 2000). Indeed, we found an inverted U-shape association between MVPA and academic achievement, which is in line with previous work of Syväoja et al. (2013). Furthermore, additional analysis of our data showed that MVPA was overall negatively correlated with time devoted to homework, while time devoted to homework was positively correlated with academic achievement, though not statistically significant. In addition, students in the lowest quartile of MVPA devoted 136 minutes per week to homework and students in the highest quartile of MVPA 110. However, this difference was again not statistically significant. In conclusion, it might be possible that MVPA is overall positively associated with academic achievement provided that time spent in MVPA, for example during sport activities, does not detract from time devoted to homework. However, because of the methodological limitations of the current study, this conclusion has to be taken with caution.

Finally, physical activity could have specific benefits in the academic domain associated with executive functioning. For example, the most beneficial effects of physical activity has been found on mathematics performance (Howie & Pate, 2012), which is positively correlated with several components of executive functioning in youth (Bull & Scerif, 2001). We found in grade 9 that both Total PA and MVPA were positively associated with mathematics performance, but not with academic achievement (i.e., the mean of the school grades Dutch, English, and mathematics). These results might be explained by the executive function hypothesis; the largest improvements in cognition due to physical activity will be on executive functions (Davis et al., 2007), which are correlated with mathematics performance (Bull & Scerif, 2001). In conclusion, we found that the association between physical activity and academic achievement might be impacted by school grade.

Mediating role of executive functioning in the association between physical activity and academic achievement

We found a positive association between Total PA and executive functioning, while executive functioning in turn was positively associated with academic achievement and mathematics performance. As a result, it might be concluded that executive functioning mediated the associations between Total PA and both academic achievement and mathematics performance. As we found no overall association between Total PA and academic achievement or mathematics performance, the mediating role of executive functioning in the association between Total PA and academic achievement might be offset by other factors such as time devoted to homework as described above. In addition, an interaction between physical activity and academic year on executive functioning might explain the moderating role of academic year in the association between physical activity and academic achievement. We explored interaction effects between both Total PA and MVPA and academic year on executive functioning, however we found no significant results (Tables 3.2 and 3.3, Step C).

In addition, Best, Miller and Naglieri (2011) found that the correlation between executive functioning and academic achievement varied across ages. Therefore, an interaction between executive functioning and academic year on academic achievement or mathematics performance might explain the moderating role of academic year in the association between physical activity and academic achievement. However, additional analyses of our data showed no significant interaction effects between executive functioning and academic year on academic achievement or mathematics performance. Taken together, executive functioning did not explain the interaction effect between physical activity and academic year on academic achievement in our study sample of Dutch adolescents.

Strengths

The major strength of this study is that physical activity was measured objectively using the ActivPAL3™ accelerometer, which has been found to be a reliable instrument to investigate physical activity in adolescents (Dowd, Harrington, & Donnelly, 2012) and adults (Dahlgren, Carlsson, Moorhead, Hager-Ross, & McDonough, 2010). In addition, because this accelerometer was placed on the thigh, it was capable of measuring non-ambulant activities, such as cycling (Dahlgren et al., 2010), a common activity in Dutch adolescents (Chinapaw et al., 2009). Second, academic achievement and executive functioning were measured objectively. Finally, we controlled for several potential confounders, such as cardiovascular fitness and self-esteem, which were significantly correlated with Total PA in line with the literature (Biddle & Asare, 2011; Santos et al., 2013).

Limitations

Our study had some limitations. First, its cross-sectional design made it impossible to determine causal relations. Second, results cannot be generalised to the whole Dutch adolescent population because only one secondary school was used. On the other hand, as schools often differ in grading and teaching policies, the choice for one secondary school increased the homogeneity of the variables regarding academic achievement. Third, a selection bias might have been present in this study because girls or obese adolescents were possibly less inclined to participate in the study compared to boys or slender adolescents, respectively. Nevertheless, the study sample was equally distributed by sex and the mean BMI was similar to the overall Dutch adolescent population (Snoek, Van Strien, Janssens, & Engels, 2007).

Conclusions

The main results of this study showed no significant dose-response association between physical activity and academic achievement in adolescents overall; however, this association might be impacted by academic year, physical activity volume and intensity, and school grade. To get more insight into the complex association between physical activity and academic achievement in adolescents, we recommend that future studies account for differences in physical activity levels between weekdays and weekend days and also take executive functioning and time devoted to homework into account. Finally, we found several positive associations between physical activity and both physical and mental health outcomes, including executing functioning, and an indirect positive association between physical activity and academic achievement by executive functioning. Therefore, despite the fact that we found no overall dose-response association between physical activity and academic achievement, we recommend schools to stimulate physical activity in adolescents.

CHAPTER 4

Active Commuting to School, Cognitive Performance and Academic Achievement in Adolescents

The current study examined the associations between active commuting to school, cognitive performance, and academic achievement in Dutch adolescents. In addition, it was explored whether these associations were moderated by sex and mediated by depressive symptoms. Students in grades 7 and 9 (N = 270; mean age 13.4 years; 53% boys) were included. Active commuting to school constituted 28% of the total amount of time spent moving per week. Active commuting to school was not significantly associated with cognitive performance and academic achievement, overall. However, there was a significant interaction between active commuting to school and sex on executive functioning. Active commuting to school was positively associated with executive functioning in girls (β = .17, p = .037), while this association was not significant in boys (β = -.03, p = .660). The associations were not mediated by depressive symptoms. The associations between active commuting to school and cognitive performance and academic achievement are weak and might be moderated by sex, while the greatest benefits on cognition due to active commuting to school might be with regard to executive functioning. Future studies might make use of experimental designs, because causal relations between active commuting to school and cognitive performance or academic achievement would provide important implications for both education and public health.

This chapter is based on: Van Dijk, M. L., De Groot, R. H. M., Van Acker, F., Savelberg, H. H. C. M., & Kirschner, P. A. (2014). Active Commuting to School, Cognitive Performance and Academic Achievement: An Observational Study in Dutch Adolescents Using Accelerometers. *BMC Public Health, 14,* 799.

An increasing amount of literature investigates the correlations between active commuting to school (i.e., walking, cycling and other forms of non-motorised transportation) and health outcomes. For example, active commuting to school is positively associated with cardiovascular fitness (Cooper et al., 2008) and negatively associated with overweight (Bere, Seiler, Eikemo, Oenema, & Brug, 2011). In addition, active commuting to school is an opportunity to increase physical activity levels (Chillon et al., 2010). Physical activity in turn has been shown to have positive effects on brain structures (Thomas, Dennis, Bandettini, & Johansen-Berg, 2012) as well as on cognitive performance (Van Dijk, De Groot, Savelberg, Van Acker, & Kirschner, 2014) and academic achievement (Singh, Uijtdewilligen, Twisk, Van Mechelen, & Chinapaw, 2012) in adolescents. As a result, habitual active commuting to school activity may be positively associated with physical activity levels, and consequently cognitive performance and academic achievement in adolescents. Furthermore, active commuting to school can be considered as an acute bout of exercise immediately before the start of school. An acute bout of exercise may immediately increase several cognitive functions (Davis et al., 2011), which may enhance academic achievement (Hillman, Kamijo, & Scudder, 2011). Therefore, active commuting to school may have acute positive effects on daily cognitive performance at school, and consequently long-term academic achievement. Taken together, habitual active commuting to school might have long-term positive effects on cognitive performance and academic achievement by increasing physical activity levels, as well as long-term positive effects on academic achievement by increasing daily cognitive performance at school.

To the best of our knowledge, no study so far investigated the association between active commuting to school and academic achievement, while only one study has examined the association between active commuting to school and cognitive performance in adolescents. In this study conducted by Martinez-Gomez et al. (2011), active commuting to school was measured subjectively by self-report, which has several limitations (Shephard, 2003). Therefore, we used an objective instrument to measure active commuting to school and investigated the associations with both cognitive performance and academic achievement in Dutch adolescents.

Martinez-Gomez et al. (2011) found that self-reported active commuting to school was positively associated with cognitive performance in Spanish adolescent girls, but not in boys. In addition, girls who reported spending more than 15 minutes in active commuting to school per day had better cognitive scores than those who spent less than 15 minutes in daily active commuting to school. The authors suggested that this sex-specific effect might be caused by brain-derived neurotrophic factor levels, which are negatively associated with depressive symptoms (improved psychological well-being) in female, but not in male, mice (Monteggia et al., 2007). As physical activity increases brain-derived neurotrophic factor levels (Marais, Stein, & Daniels, 2009), physical activity may decrease depressive symptoms (i.e., improve psychological well-being) in girls, but not in boys. Moreover, as depressive symptoms are negatively associated with cognitive performance (Hartlage, Alloy, Vazquez, & Dykman, 1993) and academic achievement (Frojd et al., 2008) in adolescents, physical activity may have beneficial effects on cognitive performance and academic achievement in adolescent girls, but not in boys. In addition, adolescent girls report higher levels of depressive symptoms than adolescent boys (Undheim & Sund, 2005). Therefore, the beneficial effects of physical activity on depressive symptoms, and consequently cognitive performance and academic achievement, might also be greater in girls than in boys. As a result, the association between active commuting to school and psychological well-being might be greater in girls than in boys, resulting in a positive association between active commuting to school and cognitive performance in girls, but not in boys (Martinez-Gomez et al., 2011).

In this study, we investigated the associations between habitual active commuting to school and cognitive performance and academic achievement in Dutch adolescents. In addition, we explored whether these associations were moderated by sex and mediated by depressive symptoms. We measured active commuting to school objectively using an ActivPAL3™ accelerometer. Results were controlled for covariates related to physical activity and cognitive performance or academic achievement, such as sex, ethnicity, socioeconomic status (SES), and body mass index (BMI) (Kwak et al., 2009; Sigfusdottir, Kristjansson, & Allegrante, 2007; Van Dijk et al., 2014). We hypothesised positive dose-response associations between active commuting to school and cognitive performance and academic achievement, in accordance with the findings of Martinez-Gomez et al. (2011). In addition, on the basis of the executive function hypothesis, we expected to observe the greatest cognition improvements in the area of executive functioning (Davis et al., 2007). Finally, the greatest improvements in academic achievement due to physical activity have previously been found in mathematics (Howie & Pate, 2012), so we also separately analysed the association between active commuting to school and mathematics performance.

Methods

Study design and participants

Data were gathered as part of The GOALS (Grootschalig Onderzoek naar Activiteiten van Limburgse Scholieren [Large-scale Research of Activities of Limburgs Students]) Study, which was primarily designed to investigate the associations between physical activity and cognitive performance and academic achievement in adolescents. This cross-sectional study was conducted at a secondary school in Heerlen, The Netherlands. Data collection took place from October 2011 to March 2012. All students (*N* = 526) in grade 7 and grade 9 of senior general secondary education or university preparatory education level were invited to participate. The local Ethical Committee of the Open University (reference number: U2013/07405/HVM) of the Netherlands approved the study.

A sample of 440 students (83.7%) was willing to participate. Of these, 8 were excluded from the analyses because of health or concentration problems, 8 because of injuries or illnesses throughout the entire week, and 8 due to measurement failures of the accelerometer during the data collection week. Moreover, 146 participants did not wear the accelerometer on at least three valid weekdays and were therefore also excluded, leaving a total of 270 students in the analyses.

Procedures

Before the start of the study, information regarding its background, goals and procedures was distributed to students in the selected classes. An invitation for an informative presentation on the study was attached for the students' parents/guardians. All students in the selected classes participated in the study, unless their parents/guardians signed an objection form or they themselves had serious objections to doing so. No written informed consent for participation in the study was obtained from the students or their parents/guardians, which was decided in consultation with the Ethical Committee. The Ethical Committee argued that this observational study did not impact health, the school programme or academic achievement of the students, and therefore decided that an informed consent was not necessary. In addition, the participation rate of 83.7% of the invited students indicates that both parents/guardians and students also argued that this study had no significant impact. As far as possible, data were collected by the same research assistants, who were trained in the standard protocols and were given standardised instructions to use.

During a normal gym class, accelerometers were taped on the midpoint of the anterior part of the right thigh of the participants using Tegaderm™ (3M, St. Paul, MN) transparent film roll. The participants were asked to wear the device continuously for one full week, 24 hours/day. To increase compliance, participants were allowed to shift the device to the left thigh when it irritated their skin. Prior to the study, an almost perfect Pearson's correlation ($r = .997$, $p < .001$) in number of accelerometer steps between the left and right thigh was found in a pilot study conducted in 23 students wearing an ActivPAL3™ accelerometer on both legs for one complete day. After attaching the accelerometers, participants took a 20-m shuttle-run test and then completed several questionnaires. They were also asked to keep a diary during the full week, in which they recorded their active commuting to school activities as well as relevant details, such as problems with the accelerometer, illness or injuries. At week 2, exactly 1 week later, the participants completed two neuropsychological tests; the d2 Test of attention and the Symbol Digit Modalities Test. Finally, the participants returned their accelerometers and diaries. After completing the study, participants received a gift voucher to the value of 15 euro in return for full participation. At the end of the academic year, school grades throughout that year were provided by the school.

Measures

Active commuting to school. The ActivPAL3™accelerometer (Paltechnologies, Glasgow, UK) was used to measure habitual active commuting to school activity. This small device (53 x 35 x 7 mm) was attached at the right thigh of the participants and measured the movements of the upper leg during a variety of activities, such as walking and cycling to school. Data were recorded at 20 Hz and summarized in 15-second time intervals (epochs). Data output for each epoch included number of steps, energy expenditure (metabolic equivalent/h), and time spent sitting/lying, standing, and moving.

The total amount of moving time (i.e., minutes spent moving) on weekdays between 7:00 a.m. and 8:40 a.m. was used as measure of habitual active commuting to school activity. This period was representative for active commuting to school activity, because the students reported, except of active commuting to school, no other physical activities before school. In addition, the ActivPAL3™accelerometer daily overviews showed that active commuting to school contained almost the entire amount of moving time before school, see for examples Figures 4.1 and 4.2. Starting point of 7:00 a.m. was chosen, because the accelerometer daily overviews showed that active commuting to school started at 7:00 a.m. at the earliest (see Figure 4.1a, for example), so all the active commuting to school activity was included. The students' first lesson of the school day started at 8:30 a.m.; however, to prevent an underestimation of active commuting to school activity in students arriving at school too late, 8:40 a.m. was used as cut-off point of the active commuting to school period.

Habitual active commuting to school activity was estimated on a minimum of three valid weekdays when the student wore the accelerometer the whole day (24 hours/day). Because the accelerometer was taped at the thigh of the students, non-wear time was not an issue. Nevertheless, we used the weekly overviews of the accelerometer data to determine whether the students removed the accelerometer during the week, a detailed description has been described elsewhere (Van Dijk et al., 2014). Weekdays were included when a student's first lesson began with the first period of the school day (i.e., 8:30 a.m.). The school timetable, students' diaries (filled in during the data collection week) and accelerometer daily overviews were used to determine whether a student's first lesson started at 8:30 a.m. Using the accelerometer daily overviews, weekdays were removed when the accelerometer data clearly showed that a student's first lesson did not start at 8:30 a.m. (see Figure 4.1b compared with Figure 4.2a, for example). Weekdays were not removed when it was clear from the accelerometer daily overviews that a student's first lesson started at 8:30 a.m., despite large differences in active commuting to school activity for the same student compared with other weekdays. Large within-subject weekday differences were possible, for example because some students went to school by bus or car one weekday and by bicycle another weekday (see Figure 4.1b compared to Figure 4.2d, for example). Because of the large within-subject weekday differences, we decided that at least three valid weekdays had to be available to determine active commuting to school, according to previous research of Borrestad, Ostergaard, Andersen, and Bere (2013). Paired sample t-tests showed no significant differences ($p > .05$) in active commuting to school activity between the weekdays, therefore we concluded that three random weekdays were appropriate for determining active commuting to school.

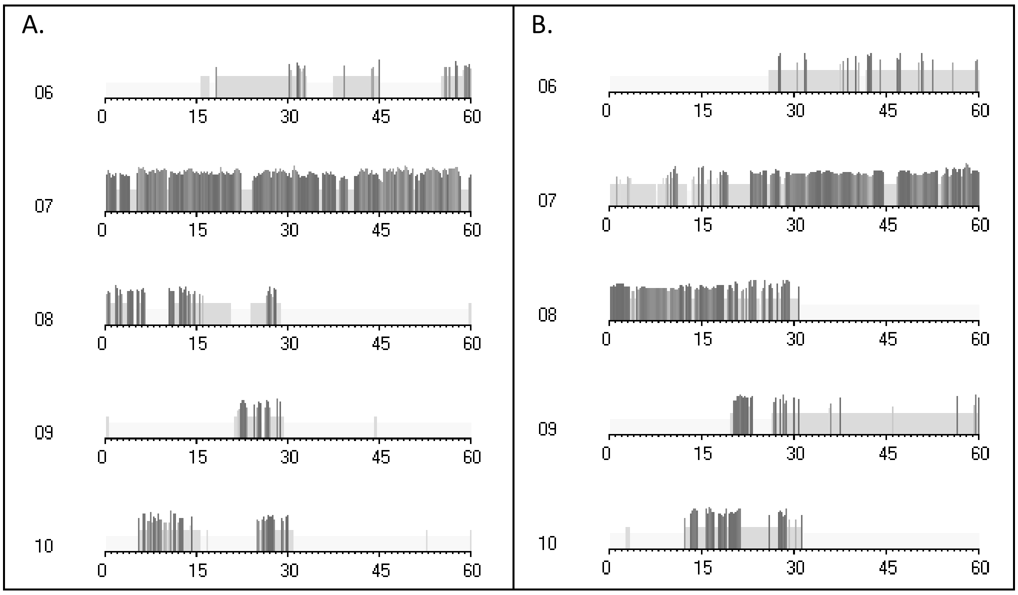

Figure 4.1 *Overviews of the accelerometer data between 6:00am and 10:00am: A) Student* ***2033****. Active commuting to school started this weekday around 7:00 a.m. and ended it around 8:00 a.m. Student* ***2108*** *at* ***Monday****. First lesson started at 8:30 a.m. Student reported in his/her diary going to school by bicycle this weekday.*

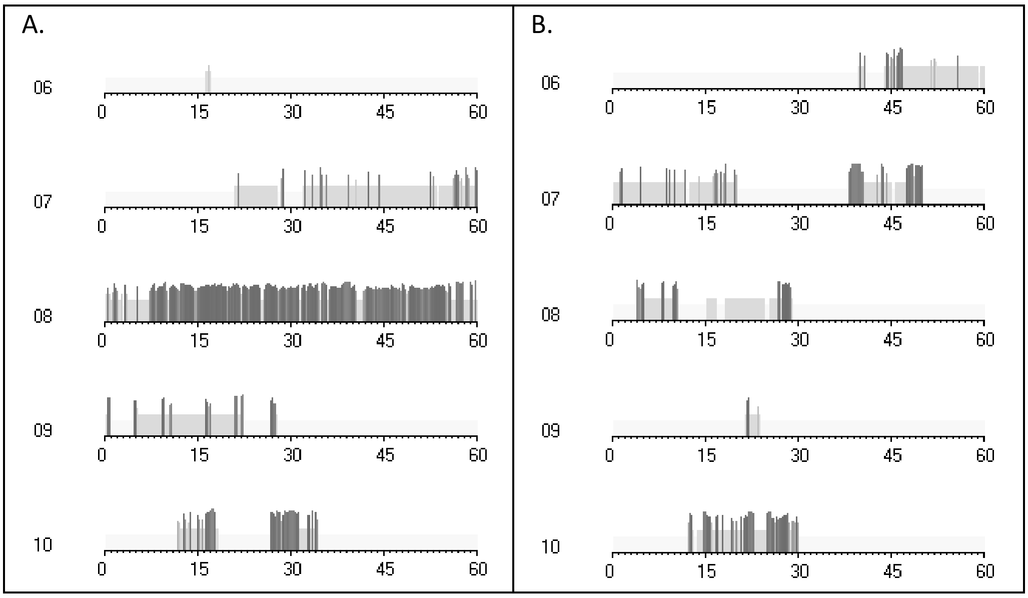

Figure 4.2 *Overviews of the accelerometer data between 6:00 a.m. and 10:00 a.m.: A) Student* ***2108*** *at* ***Friday****. This weekday was excluded. First lesson clearly did not start at 8:30 a.m., but at 9:20 a.m. Notice this weekday started approximately 50 minutes (duration of one school lesson) later than at Monday (see Figure 4.1b); B) Student* ***2108*** *at* ***Thursday****. First lesson started at 8:30 a.m. Student reported in his/her diary going to school by car this weekday. Notice the large difference in amount of physical activity compared with Monday (Figure 4.1b).*

Finally, to estimate the total amount of habitual active commuting to school activity per week, the total amount of time spent active commuting to school was computed assuming a round-trip, according to research of Tudor-Locke, Ainsworth, Adair and Popkin (2003). As a result, the mean moving time on weekdays between 7:00 a.m. and 8:40 a.m. was multiplied by five (the number of weekdays per week) and multiplied by two (to compute a round-trip). In formula: habitual active commuting to school activity = mean moving time (minutes) on weekdays between 7:00 a.m. and 8:40 a.m. * 5 (weekdays) * 2 (round-trip).

Cognitive performance. The d2 Test of attention (Brickenkamp & Zillmer, 1998) was selected as measure of response inhibition (Lendt et al., 2002), a key component of executive functioning (Alvarez & Emory, 2006), and more broadly selective attention and concentration (Budde et al., 2008). The d2 Test of attention is a widely used neuropsychological test and the construct validity has been well supported in several European samples (Bates & Lemay, 2004). The d2 Test of attention consists of 14 rows, each with 47 interspersed ‘p’ and ‘d’ characters. The characters had one to four dashes configured individually, or in pairs, above and/or below each letter. The target symbol was a ‘d’ with two dashes (hence ‘d2’), regardless of whether or not both the dashes appeared above the ‘d’, both appeared below the ‘d’, or one appeared above and one appeared below the ‘d’. The participants’ task was to cross out as many target symbols as possible, moving from left to right, with a limit of 20 seconds/row. No pauses were permitted. An overall performance score was calculated by the total number of correctly crossed-out symbols minus the total number of incorrectly crossed-out symbols.

The Symbol Digit Modalities Test (Smith, 2010) was selected as measure of information-processing speed. The Symbol Digit Modalities Test is widely used in many studies in children and adolescents and has shown good reliability (ICC > 0.87) in young adults (Hinton-Bayre & Geffen, 2005). This test contains nine numbers coupled with nine symbols in a random order on the top of a page. On the remainder of the page, boxes are presented with symbols only. Participants were asked to fill in as many corresponding numbers as possible within 90 seconds. The total number of digits correctly coupled to symbols was scored.

Academic achievement. The school provided school grades (ranging from 1.0 = very bad, to 10.0 = outstanding) at the end of the academic year. The mean of the school grades in Dutch (native language), mathematics and English as a modern foreign language was used as measure of academic achievement. We expected to observe the greatest effects of active commuting to school on mathematics performance, as this is significantly correlated with all measures of executive functioning (Bull & Scerif, 2001). Therefore, the mean school grade for mathematics was analysed separately as an indication of executive functioning.

Depressive symptoms. The Center for Epidemiologic Studies of Depression Scale (CES-D) was selected as measure of experience of depressive symptoms (Radloff, 1977). Recent research has shown that the CES-D is an appropriate instrument for measuring depression in adolescents, with an internal consistency (Cronbach's alpha) ranging from .78 to .82 (Verhoeven, Sawyer, & Spence, 2013). In this 20-item self-report scale, students rated the frequency of 20 depressive symptoms over the previous week. A total severity score was calculated by summing all items and ranged from 0 (not depressed) to 60 (high number of depressive symptoms).

Covariates. The dichotomous variables of sex (coded as -0.5 = boys, 0.5 = girls), academic year (coded as -0.5 = grade 7, 0.5 = grade 9), school level (coded as -0.5 = senior general secondary education, 0.5 = university preparatory education), and ethnicity (coded as -0.5 = native Dutch [both parents/guardians had been born in The Netherlands] and 0.5 = non-native Dutch) were centred. The highest educational level of the parents/guardians was used as a proxy of SES (Kaplan & Keil, 1993). If the parents/guardians had a secondary vocational education at most, SES was coded as 'low-medium' = -0.5, in all other cases SES was coded as 'high' = 0.5, following the classification of the Dutch Ministry of Public Health, Welfare and Sport (Dutch Ministry of Public Health, Welfare and Sport, 2011).

Weight in kg and height in m (to 2 decimal places) were measured by one of the researchers. BMI was then calculated by dividing weight by height squared.

Time spent moving per week corrected for active commuting to school was calculated by subtracting time spent active commuting to school from total time spent moving per week. Total time spent moving per week was measured by the ActivPAL3™ accelerometer and based on at least 4 valid days with complete accelerometer data (24 hours/day) including both weekend days. A detailed description of the methodologies used to calculate the total amount of physical activity per week have been previously reported (Van Dijk et al., 2014).

Statistics

Analyses were performed with SPSS for Windows (version 19.0; SPSS Inc., Chicago, Illinois). The level of significance was .05 in all analyses. Sex differences were analysed by independent sample t-tests and Pearson's Chi-square test for continuous and dichotomous variables, respectively.

Associations between active commuting to school and cognitive performance or academic achievement, controlling for covariates, were analysed by multiple linear regression analyses. Firstly, continuous variables and covariates were transformed into z-scores. Secondly, associations between covariates and cognitive performance or academic achievement were modelled (step A). Thirdly, active commuting to school was added to the model (step B). Fourthly, the potential interaction effect of sex on the associations between active commuting to school and cognitive performance or academic achievement was investigated. Therefore, the centred score of sex was multiplied with the z-score of active commuting to school and then added to the model (step C). Fifthly, significant interaction effects in step C were analysed by simple slopes analyses to further investigate the nature of the statistical interactions. Finally, significant associations between active commuting to school and cognitive performance or academic achievement were analysed by multiple linear regression analyses following the steps of Preacher and Hayes (2008) to investigate whether depressive symptoms mediated these associations.

The reported results of the multiple linear regression analyses exclude outliers (> 3 standard deviations). The p-p plots were normally distributed. There was no multicollinearity (Pearson's correlation between covariates < .80) in the multiple regression models.

Results

The descriptive statistics of the entire study sample are shown in Table 4.1. Boys (Table 4.2) had significantly lower scores on academic achievement (independent *t* test, $p < .001$) and mathematics performance ($p = .038$), and reported significantly lower levels of depression symptoms ($p < .001$) than did girls (Table 4.3). In addition, girls performed better on the Symbol Digit Modalities Test (independent *t* test, $p = .016$), however when corrected for covariates in the regression model, this difference in performance was not significant anymore (Table 4.4, step A).

Active Commuting to School

Students spent 231 minutes per week active commuting to school on average, with no significant difference between boys (237 minutes) and girls (224 minutes; independent *t* test, $p = .237$). Active commuting to school contained 28.2% of the total time spent moving per week, with no significant difference between boys (28.5%) and girls (27.8%; independent *t* test, $p = .588$).

Active Commuting to School and Cognitive Performance and Academic Achievement

Active commuting to school was not significantly associated with performance on the d2 Test of attention, the Symbol Digit Modalities Test, academic achievement and mathematics achievement, overall (Table 4.4, step B). A significant interaction between active commuting to school and sex on the d2 Test of attention was found (Table 4.4, step C). Furthermore, simple slopes analyses revealed a significantly positive association between active commuting to school and performance on the d2 Test of attention in girls ($\beta = .17$, $p = .037$), but no significant association in boys ($\beta = -.03$, $p = .660$).

Mediating Role of Depressive Symptoms in the Associations Between Active Commuting to School and Cognitive Performance and Academic Achievement

Active commuting to school was not significantly associated with depressive symptoms in girls ($\beta = .00$, $p = .970$). Therefore, a basic requirement for mediation was not fulfilled. It can be concluded that the association between active commuting to school and performance on the d2 Test of attention in girls was not mediated by self-reported depressive symptoms. In addition, all the other associations between active commuting to school and cognitive performance and academic achievement were not statistically significant. Therefore, all these associations were also not mediated by depressive symptoms, because a basic requirement for mediation was not fulfilled.

Table 4.1 *Descriptive statistics of the entire study sample (N = 270)*

	Mean ± SD	**Frequencies (%)**	**95% confidence limits**
Age	13.42 ± 1.28		13.27 - 13.57
Sex			
Boys		143 (53.0%)	
Girls		127	
Ethnicity			
Native Dutch		248 (91.9%)	
Non-native Dutch		22	
Academic year			
Grade 7		136 (50.4%)	
Grade 9		134	
School level			
Senior general secondary education		73 (27.0%)	
University preparatory education		197	
Socioeconomic status			
Low-medium		65 (24.4%)	
High		201	
Body mass index (kg/m2)	19.14 ± 2.70		18.81 – 19.46
Depressive symptoms	10.86 ± 8.26		9.86 – 11.86
Total time spent moving per week (min.)	834.60 ± 215.21		806.76 – 862.44
Active commuting to school (min. / week)	230.80 ± 94.75		219.44 – 242.15
Time spent moving per week corrected for active commuting to school (min.)	602.90 ± 188.91		578.46 – 627.33
Active commuting to school as % of total time spent moving per week	28.15 ± 10.34		26.60 – 30.40
D2 Test of attention	175.84 ± 26.66		172.61 – 179.06
Symbol Digit Modalities Test	60.11 ± 10.50		58.83 – 61.40
Academic Achievement	6.83 ± 0.78		6.73 – 6.92
Mathematics performance	6.97 ± 1.10		6.84 – 7.10

Table 4.2 *Descriptive statistics of the study sample of boys (N = 143) and statistical differences with girls*

	Mean ± SD	**Frequencies**	**95% confidence limits**	**Mean diffe-rence with girls (95% confidence intervals)**	**Effect size (Cohen's *d*)**
Age	13.40 ± 1.31		13.18 – 13.61	-0.04	0.03
Ethnicity					
Native Dutch		134 (93.7%)			
Non-native Dutch		9			
Academic year					
Grade 7		73 (51.0%)			
Grade 9		70			
School level					
Senior general secondary education		44 (30.8%)			
University preparatory education		99			
Socioeconomic status					
Low-medium		32 (22.9%)			
High		108			
Body mass index (kg/m2)	18.98 ± 2.81		18.51 – 19.45	-0.33	0.12
Depressive symptoms	9.12 ± 7.21		7.91 – 10.34	-3.63*	0.45
Total time spent moving per week (min.)	857.41 ± 222.09		817.60 – 897.21	48.10	0.22
Active commuting to school (min. / week)	237.23 ± 96.89		221.21 – 253.24	13.68	0.14
Time spent moving per week corrected for active commuting to school (min.)	618.38 ± 203.59		581.89 – 654.88	32.66	0.17
Active commuting to school as % of total time spent moving per week	28.50 ± 10.60		25.86 – 29.67	0.74	0.07
D2 Test of attention	173.27 ± 26.74		168.82 – 177.72	-5.49	0.21
Symbol Digit Modalities Test	58.60 ± 10.87		56.74 – 60.46	-3.15*	0.30
Academic Achievement	6.62 ± 0.75		6.49 – 6.75	-0.44*	0.59
Mathematics performance	6.83 ± 1.11		6.65 – 7.02	-0.28*	0.26

**Statistically significant difference between the sexes at p < .05.*

Table 4.3 *Descriptive statistics of the study sample of girls (N = 127)*

	Mean ± SD	Frequencies	95% confidence limits
Age	13.44 ± 1.25		13.22 – 13.66
Ethnicity			
Native Dutch		114 (89.8%)	
Non-native Dutch		13	
Academic year			
Grade 7		63 (49.6%)	
Grade 9		64	
School level			
Senior general secondary education		29 (22.8%)	
University preparatory education		98	
Socioeconomic status			
Low-medium		33 (26.2%)	
High		93	
Body mass index (kg/m2)	19.31 ± 2.58		18.86 – 19.76
Depressive symptoms	12.76 ± 8.92		11.19 – 14.32
Total time spent moving per week including active commuting to school (min.)	809.31 ± 205.36		770.50 – 848.11
Active commuting to school (min. / week)	223.55 ± 92.13		207.37 – 239.72
Time spent moving per week corrected for active commuting to school (min.)	585.72 ± 170.45		553.51 – 617.93
Active commuting to school as % of total time spent moving per week	27.76 ± 10.07		26.81 – 29.49
D2 Test of attention	178.76 ± 26.37		172.61 – 179.06
Symbol Digit Modalities Test	61.75 ± 9.87		58.83 – 61.40
Academic Achievement	7.06 ± 0.75		6.73 – 6.92
Mathematics performance	7.12 ± 1.08		6.84 – 7.10

Table 4.4 *Active commuting to school associated with cognitive performance and academic achievement*

	D2 Test of Attention	Symbol Digit Modalities Test	Academic Achievement	Mathematics performance
	β	*Β*	*β*	*Β*
Step A (R^2)	.12*	.24*	.23*	.16*
Sex	.07	.09	.26*	.15*
Ethnicity	.04	.02	.06	.09
Academic year	.31*	.42*	-.25*	-.09
School level	.18*	.15*	.15*	.14*
Socioeconomic status	.02	-.12	.07	.08
Body mass index	.03	.14*	-.11	-.17*
Depressive symptoms	-.01	.09	-.15*	-.20*
Time spent moving per week corrected for active commuting to school	.10	.15*	-.06	.01
Step B (ΔR^2)	.00	.00	.00	.01
Active commuting to school	.05	.04	.04	.08
Step C (ΔR^2)	.02*	.00	.00	.00
Active commuting to school * Sex	.13*	.02	.00	.07

β *= Standardised regression coefficients. * Statistically significant at p < .05.*

Discussion

The main findings of this study suggest that, in adolescent girls, active commuting to school is positively associated with performance on the d2 Test of attention, which measures response inhibition (i.e., a key component of executive functioning) and selective attention (Alvarez & Emory, 2006, Budde et al., 2008). In contrast, active commuting to school is not significantly associated with other measures of cognitive performance and academic achievement in both boys and girls. Furthermore, active commuting to school is not significantly associated with self-reported depressive symptoms, which indicates that the associations between active commuting to school and cognitive performance and academic achievement are not mediated by such symptoms. Our results are in accordance with those of Martinez-Gomez et al. (2011) who found that self-reported active commuting to school was positively associated with cognitive performance in adolescent girls. Our research expands on the research of Martinez-Gomez et al. (2011) by objectively measuring active commuting to school by accelerometry. Moreover, we investigated associations between active commuting to school and both cognitive performance and academic achievement, and investigated whether these associations were mediated by self-reported depressive symptoms.

In girls, active commuting to school was positively associated with performance on the d2 Test of attention, a measure of response inhibition, a key component of executive functioning (Alvarez & Emory, 2006). In contrast, active commuting to school was not significantly associated with performance on the Symbol Digit Modalities Test, a measure of information-processing speed, which is usually not classified as an executive function (Alvarez & Emory, 2006). These results concur with an increasing amount of literature suggesting that gains in children's cognitive functioning due to physical activity are most clearly observed in tasks that involve executive functioning (see Tomporowski, Davis, Miller and Naglieri (2008) for a review). Since executive functioning is of crucial importance to success in school (Crone & Dahl, 2012), this finding might be useful and important for education, although we did not find a significant association between active commuting to school and academic achievement.

The sex-specific association between active commuting to school and executive functioning observed in our study is in agreement with the findings of Kwak et al. (2009), who reported a positive association between objectively measured physical activity and academic achievement in adolescent girls, but not in boys. In addition, our results also showed that the associations between active commuting to school and both performance on the Symbol Digit Modalities Test and mathematics performance tended to be more positive in girls than in boys, although those associations were not statistically significant (Table 4.4, step C). Martinez-Gomez et al. (2011) suggested that these sex-specific associations might be explained by depressive symptoms. However, we found no evidence that the associations between active commuting to school and cognitive performance and academic achievement are mediated by self-reported depressive symptoms. Another explanation suggested by Martinez-Gomez et al. (2011) might be the higher levels of total time spent moving per week for boys compared to girls. Although many studies in adolescents have reported differences in physical activity levels between boys and girls (Sallis, Prochaska, & Taylor, 2000), we found no significant difference in total time spent moving per week between boys and girls (Table 4.2). On the basis of the results described above, we suggest that other factors may play a more important role in the sex-specific association between active commuting to school and executive functioning observed in our study, as well as that of Martinez-Gomez et al (2011). The first of these is (school-related) stress, which is negatively associated with cognitive performance and academic achievement in adolescents (Forrest, Bevans, Riley, Crespo, & Louis, 2013). Adolescent girls report significantly higher levels of (school-related) stress than boys (De Vriendt et al., 2012). Physical activity is associated with lowered stress (Haugland, Wold, & Torsheim, 2003) and might have relatively greater beneficial effects on (school-related) stress in girls (because of their higher stress levels) than in boys. Consequently, active commuting to school (i.e., physical activity before school) might decrease (school-related) stress levels and in turn increase cognitive performance more in girls than in boys, resulting in a positive association between active commuting to school and cognitive performance in girls, but not in boys. The second factor is physical activity, which increases the circulation and production of insulin-like growth factor I (Frystyk, 2010). Insulin-like growth factor I and female estrogen interact in the promotion of neuronal survival and neuroprotection (Garcia-Segura, Cardona-Gomez, Chowen, &

Azcoitia, 2000). Therefore, this sex-specific hormone might underlie the sex-specific associations between physical activity or active commuting to school and cognitive performance/academic achievement observed in our study and those of Martinez-Gomez et al. (2011) and Kwak et al. (2009). We suggest future studies in adolescents, which focus on the effects of physical activity or active commuting to school on cognitive performance/academic achievement, in order to account for the role of (school-related) stress and sex-specific hormones.

The major strength of this study is that active commuting to school was objectively measured by the ActivPAL3™ accelerometer. Previous research has shown that this device is a reliable instrument with which to measure physical activity in adolescent girls (Dowd, Harrington, & Donnelly, 2012) and young adults (Maddocks, Petrou, Skipper, & Wilcock, 2010). In addition, as this accelerometer was placed on the thigh, it was accurate in classifying time spent moving during 93.3% of the time spent cycling (Steeves et al., 2014), a common activity in commuting in Dutch adolescents (Chinapaw, Slootmaker, Schuit, Van Zuidam, & Van Mechelen, 2009). Also, we objectively measured cognitive performance and academic achievement and controlled for several potential confounders. Finally, 83.7% of the invited students participated in our study and the students included in analyses did not differ in sex, BMI, executive functioning, and academic achievement from students excluded from analyses because of missing accelerometer wear-time. Taken together, in our opinion, these methodological factors ensure that our results are representative of the associations between active commuting to school and cognitive performance and academic achievement in our study sample of Dutch adolescents.

However, our study also has some limitations. We used only one secondary school, which makes it hard to generalise our findings to the entire Dutch adolescent population. Information about the mode of active commuting to school is missing as the ActivPAL3™ accelerometer cannot accurately distinguish between activities, for example distinguish walking from cycling. Because cycling requires a higher intensity than walking (Chillon et al., 2010), this might be an important limitation. Finally, we based the active commuting to school period on the daily overviews of the accelerometer data, however, an objective definition of this period is missing.

Conclusions

Active commuting to school is positively associated with executive functioning in adolescent girls. In contrast, other associations between active commuting to school and cognitive performance and academic achievement in both boys and girls are not statistically significant. These results indicate that the associations between active commuting to school and cognitive performance and academic achievement are weak and might be moderated by sex, while the greatest benefits on cognition due to active commuting to school might be with regard to executive functioning. We conducted the first observational study in the associations between objectively measured active commuting to school and cognitive performance and academic achievement in adolescents. Causal relations between active commuting to school and cognitive performance or academic achievement would provide important implications for both education and public health; therefore we recommend future studies to use experimental designs.

CHAPTER 5

Physical Activity and School Absenteeism due to Illness in Adolescents

In this study, associations between habitual physical activity (PA) and school absenteeism due to illness in adolescents were investigated. In addition, it was explored whether mental health and cardiovascular fitness mediated this association. A total of 328 students in grades 7 and 9 (mean age 13.8 years; 49% boys) was included. PA was objectively measured by an ActivPAL3™ accelerometer attached on the thigh during one full week (24 hours/day). Depressive symptoms and self-esteem were self-reported by the Center for Epidemiologic Studies Depression Scale (CES-D) and Rosenberg Self-Esteem Scale respectively. Cardiovascular fitness was measured by the 20-m shuttle run test. School absenteeism due to illness data were provided by the school administration. PA was not significantly associated with school absenteeism, though there was an indirect association between PA and school absenteeism by cardiovascular fitness. Therefore, it is concluded that cardiovascular fitness mediated the association between PA and school absenteeism due to illness. More research is needed to confirm the results of this first study investigating associations between PA and school absenteeism in adolescents.

This chapter is based on: Van Dijk, M. L., Kirschner, P. A., Savelberg, H. H. C. M., Van Acker, F., & De Groot, R. H. M. (2015). Physical Activity and School Absenteeism due to Illness in Adolescents. Manuscript submitted for publication.

Physical activity (PA) has been shown to have beneficial health effects in adolescents, such as improved mental health (Biddle & Asare, 2011) and cardiovascular fitness (Hallal, Victora, Azevedo, & Wells, 2006). While many health benefits of PA are well-documented, no study has yet investigated a possible association between PA and decreased school absenteeism due to illness in adolescents. Nonetheless, school absenteeism is a topic of high importance, because high rates of school absenteeism are related to decreased relationships with peers on school (Weitzman, 1986), learning delays, lower academic achievement (Dunn, Kadane, & Garrow, 2003) and school drop-out (Kogan, Luo, Brody, & Murry, 2005). Therefore, the main goal of this study was to investigate the association between PA and school absenteeism due to illness in adolescents.

Thus far the relationship between PA and school absenteeism in adolescents has not been studied. PA, or variables related to PA, associated with illness-related absenteeism in adult workers have been studied though.

Jacobson et al. (2001) reported a negative relation between exercise-frequency and illness-related absenteeism in American adult workers. One day of exercise per week was associated with lower absenteeism when compared with no exercise, and two days of exercise per week was more favourable than one day. These data suggest a significant relationship between exercise frequency and illness-related absenteeism. The authors suggested that PA affects certain immune functions and improves mental health, resulting in decreased absenteeism rates. Mental health might be an important mediator in the association between PA and school absenteeism, because PA is positively related to mental health (Biddle & Asare, 2011). In turn, mental health outcomes, such as depression (Kearney, 2008) and self-esteem (Finn, 1989), play a major role in school absenteeism (Berg, 1992; Jones, Hoare, Elton, Dunhill, & Sharpe, 2009).

Van den Heuvel et al. (2005) found in a Dutch adult population that employees practicing physical sports take 21% less sick leave days than their colleagues not practicing sports. They suggested that participation in sports enhances physical capacities, thus facilitating a quick recovery. Surprisingly, no effect was found for the duration of practicing sports (i.e., number of years and intensity of sport participation), which might be due to the research method of self-report (Van den Heuvel et al., 2005).

Finally, Tucker, Aldana and Friedman (1990) found that high levels of cardiovascular fitness were significantly associated with low levels of absenteeism in American adult workers. Their most plausible explanation is that cardiovascular fitness leads to improved health and healthier employees are less likely to be absent. PA is positively related to cardiovascular fitness (Hallal et al., 2006; Ortega, Ruiz, Castillo, & Sjostrom, 2008), therefore cardiovascular fitness might mediate the association between PA and school absenteeism.

The main aim of the present study was to investigate the association between habitual PA levels and school absenteeism due to illness in adolescents. In addition, it explored whether mental health, measured by feelings of depressive symptoms and self-esteem, and cardiovascular fitness mediated the association between PA and school absenteeism. Variables related to PA and school absenteeism include sex, ethnicity, socioeconomic status, and weight status (Finn, 1989; Hallal et al., 2006; Reid, 2005; Sallis, Prochaska, & Taylor, 2000; Shore et al., 2008; Taras & Potts-Datema, 2005; Tremblay, Inman, & Willms, 2000). These variables were measured and controlled for statistically to avoid possible confounding effects.

Methods

Study design and participants

This study was part of The GOALS (Grootschalig Onderzoek naar Activiteiten van Limburgse Scholieren [Large-scale Research of Activities in Dutch Students]) Study Originally, the main goal of this study was to investigate the associations between objectively measured PA and cognitive performance and academic achievement in adolescents (see for details De Groot, Van Dijk, & Kirschner, 2015). The GOALS Study was conducted at a secondary school in the south of the Netherlands. Data collection took place from October 2011 to March 2012. Ethical permission was given by the local Ethical Committee of the Open University of the Netherlands.

A sample of 440 Dutch adolescents in grades 7 and 9 of senior general secondary education or university preparatory education was willing to participate. Of this sample, 112 students were excluded from analyses because of health or concentration problems (8), illness or injuries throughout the entire data-collection week (8), measurement failures of the accelerometer during the data-collection week (8), or non-compliance to accelerometer wear-time of at least two weekdays and both weekend days (88). As a result, 328 participants were included in analyses.

Procedures

Before the start of the study, information about the background, goals, and procedure was distributed to the students and parents/guardians of the selected classes. The majority of the invited students (83.7%) participated in the study, a few were absent during the data-collection week or their parents/guardians had serious objections.

At the begin of the study, ActivPAL3™ accelerometers were taped on the midpoint of the anterior part of the right thigh of the participants using a Tegaderm™ (3M, St. Paul, MN, US) transparent film roll. Participants were requested to wear the device continuously for one full week, 24 hours/day. Participants were allowed to shift the device to the left thigh if it irritated their skin, which might have increased the compliance. To this end, a pilot study employing 23 students wearing an ActivPAL3™ accelerometer for one complete day on both legs found an almost perfect Pearson's correlation ($r = .997$, $p < .001$) in the number of accelerometer steps between the left and right thigh. Then participants took a 20-m shuttle-run test and completed several questionnaires. In addition, participants were asked to keep a diary during the full week in which they reported relevant details such as problems with the accelerometer, illness, or injuries. Exactly one week later, participants returned their accelerometers and diaries. After finishing the study, participants received a gift voucher of 15 euro for their full participation. At the end of the academic year, absence lists throughout the entire academic year were provided by the school.

Measures

Physical activity. The ActivPAL3™ accelerometer (Paltechnologies, Glasgow, UK) was used to measure habitual PA levels during a normal school week. This small device (53 × 35 × 7 mm) measures body accelerations and identifies the wearer's posture. Data were recorded at 20 Hz and summarized in 15-second time intervals (i.e., epochs).

Data were downloaded and processed with ActivPAL™ Professional software (version 6.4.1). A valid day was considered to be a day that the student wore the accelerometer for the whole day (i.e., 24 hours of wear time). Atypical schooldays (i.e., weekdays without school lessons) and days when the student reported being ill or injured in his/her diary were excluded. Because the accelerometer was taped at the thigh of the students, non-wear time was not an issue. Nevertheless, the weekly overviews of the accelerometer data were used to determine whether the accelerometer was removed during the week; see for details and figures Van Dijk, De Groot, Savelberg, Van Acker, and Kirschner (2014).

According to prescribed accelerometer testing protocols, at least four valid days were required to determine the total PA volume per week (Trost, McIver, & Pate, 2005). In addition, complete accelerometer data for both Saturday and Sunday were required to be included in the analyses because PA-levels in adolescents differ significantly between weekdays and both weekend days (Van Dijk et al., 2014). Taken together, habitual PA levels were based on at least four complete days (24 hours of wear time), including both weekend days. The total PA volume per week was determined by the total number of accelerometer steps per week.

School absenteeism due to illness. The total number of school days that the participants were absent from school due to illness throughout the entire academic year was used as continuous measure of school absenteeism. School absenteeism data were registered by the school administration and at the end of the academic year provided to the research team. Students were registered absent due to illness in case the parents/guardians called the school administration on the first school day of illness. In addition, when students returned from illness, they had to hand in a signed letter from their parents/guardians confirming their illness. Days were counted only when school absenteeism was registered as ill. Other absences, such as dentist visit or wedding, were not counted as school absenteeism due to illness.

Mental health. Depressive symptoms were measured by the Center for Epidemiologic Studies Depression Scale (CES-D) designed by Radloff (1977). In this self-report scale, participants rated the frequency of 20 depressive symptoms over the previous week. The answers were: (0) Rarely or none of the time (on average less than 1 day), (1) Some or a little of the time (1-2 days), (2) Occasionally or a moderate amount of time (3-4 days), and (3) Most or all of the time (5-7 days). A total severity score was calculated by summing all items (positively worded items were reverse-scored), ranging from 0 (not depressed) to 60 (a high amount of depressive symptoms).

Self-esteem was measured by the Rosenberg Self-Esteem Scale (Rosenberg, 1979). The scale consists of ten statements dealing with general feelings about the participant's own self. The statements were answered by: (0) Strongly agree, (1) Agree, (2) Disagree, (3) Strongly Disagree. The self-esteem score is calculated by summing all items (negatively worded items were reverse-scored) and ranges from 0 (minimum score of self-esteem) to 30 (maximum score of self-esteem).

Cardiovascular fitness. The 20-m shuttle run test (Leger, Mercier, Gadoury, & Lambert, 1988) was used to measure cardiovascular fitness. This test consisted of 1-min stages of continuous incremental pace running. Participants were required to run between two lines placed on the floor 20 meters apart while keeping pace with audio signals. All measurements were carried out under standardized conditions on an indoor rubber-floored gymnasium. The initial speed was 8.5 km/h, which increased by 0.5 km/h each successive minute, reaching the maximum of 18.0 km/h at minute 20. Students were encouraged to continue running as long as possible throughout the course of the test. An extra incentive was given to the students to reach maximal capacity by giving them a mark for their performance, which counted in their final grade for physical education at school. The 20-m shuttle run test was considered to be finished when a student failed to reach the end lines concurrent with the audio signals on two consecutive occasions. Otherwise, the test ended when the participant stopped because of fatigue. The last completed stage or half-stage at which the participant dropped out was recorded. By using this score and the variables sex, age, and BMI, the maximal oxygen consumption (VO_2 max), considered as the best single marker for cardiovascular fitness (Dencker & Andersen, 2011) , was estimated using the equation of Matsuzaka et al. (2004):

VO_2 max (in ml/kg/min) = 25.9 - 2.21 * Sex - 0.449 * Age - 0.831 * BMI + 4.12 *
(8 + 0.5 * 20-m shuttle run test score).

This equation was validated in children and adolescents and correlated strongly ($r = .80$, $p < .001$) with maximal oxygen consumption measured directly on a treadmill (Matsuzaka et al., 2004).

Covariates. Sex (coded as 0 = boys, 1 = girls), ethnicity (coded as 0 = native Dutch, i.e., both parents/guardians born in the Netherlands, 1 = non-native Dutch), academic year (coded as 0 = grade 7, 1 = grade 9), and school level (coded as 0 = senior general secondary education [HAVO] and 1 = university preparatory education [VWO]) were dichotomised.

Socioeconomic status was determined by the highest educational level of the parents/guardians, and coded as 'low-medium' = 0 in case the parents and or guardians had at most secondary vocational education level. In all other cases, SES was coded as 'high' = 1, following the Dutch national classification (Dutch Ministry of Public Health, Welfare and Sport, 2011).

Weight status (coded as 0 = normal weight, 1 = overweight/obesity) was classified based on the sex-specific body mass index-for-age percentile defined by the CDC growth charts: normal weight < 85^{th} percentile, overweight/obesity ≥ 85^{th} percentile (Kuczmarski et al., 2000). Weight in kg (rounded) and height in meters (two decimals) were measured in light clothing without shoes by one of the researchers. The body mass index was then calculated by dividing the weight by the height squared.

Statistics

Analyses were performed with SPSS for Windows (version 19.0; SPSS, Inc, Chicago, Illinois). The level of significance was .05. The distribution of the p-p plots was normal for all tested models. There was no multicollinearity in the regression models (all Pearson's correlations < .80). The reported results of the linear regression analyses exclude outliers (> 3 standard deviations).

Sex differences in school absenteeism, mental health and cardiovascular fitness were analysed by independent sample *t* tests.

Associations between PA and school absenteeism, as well as between PA and mental health, cardiovascular fitness, were analysed by multiple linear regression analyses. First, associations between covariates and respective outcome variables were modelled (step A). This step allows for the control of possible confounding effects of covariates. Second, PA was added to the model (step B). This step allows investigation of the added explained variance of PA to the model.

Finally, whether the association between PA and school absenteeism was mediated by mental health or cardiovascular fitness was analysed using the method of Preacher and Hayes (2008). According to Preacher and Hayes (2004) tests of mediation are relevant even in the absence of a direct effect between two variables. Therefore mediation analyses were performed even when a direct effect was not present.

Results

The descriptive statistics are shown in Table 5.1. Boys were more active than girls. There was no significant difference between boys and girls in school absenteeism due to illness. Boys reported significantly higher levels of self-esteem and lower levels of depressive symptoms than did girls. In addition, boys had higher levels of cardiovascular fitness than girls.

Table 5.1 *Descriptive statistics of the study sample.*

	All (N = 328)	Boys (N = 162)	Girls (N = 166)
Age (years)	13.80 ± 1.22	13.83 ± 1.26	13.77 ± 1.18
Ethnicity			
Native-Dutch	291 (89.5%)	149 (92.5%)	142 (86.6%)
Non-native	34	12	22
Academic year			
Grade 7	178 (54.3%)	86 (53.1%)	92 (55.4%)
Grade 9	150	76	74
Educational level			
Senior general secondary education	118 (36.0%)	58 (35.8%)	60 (36.1%)
University preparatory education	210	104	106
Socioeconomic status			
Low-medium	75 (23.7%)	35 (22.2%)	40 (24.5%)
High	246	123	123
Body mass index (kg/m²)	19.05 ± 2.81	19.07 ± 2.88	19.02 ± 2.76
Weight status			
Normal weight	289 (88.7%)	138 (86.2%)	151 (91.0%)
Overweight	37	22	15
Depressive symptoms (score CES-D)	11.63 ± 8.71	9.63 ± 7.37*	13.52 ± 9.45
Self-esteem (score Rosenberg Self-Esteem Scale)	21.74 ± 5.16	23.13 ± 4.64*	20.43 ± 5.29
Cardiovascular fitness (VO_2 max in ml/kg/min)	51.74 ± 5.51	54.26 ± 5.11*	49.30 ± 4.75
Physical activity (accelerometer steps/week)	69103 ± 19135	72285 ± 19896*	65998 ± 17882
School absenteeism due to illness (days per academic year)	3.47 ± 3.89	3.59 ± 3.30	3.35 ± 4.40

*CES-D = Center for Epidemiologic Studies Depression Scale. *Statistically significantly different (p < .05) from girls.*

PA Associated With School Absenteeism

PA was not significantly associated with school absenteeism due to illness (β = -.06, *p* = .292), see Table 5.2.

PA was positively associated with cardiovascular fitness (β = .21, *p* < .001), see Table 5.2. Therefore, a basic requirement for mediation analyses was fulfilled for cardiovascular fitness in the association between PA and school absenteeism. In addition, cardiovascular fitness was negatively associated with school absenteeism due to illness (β = -.23, *p* = .002). As a result, the second requirement for mediation analyses was fulfilled. Bootstrap analysis for mediation models showed a positive indirect effect of PA on school absenteeism through cardiovascular fitness (effect = -.0395; bootstrap confidence intervals between -.0136 and -.0756). It can be concluded that cardiovascular fitness mediated the association between PA and school absenteeism.

PA was not significantly associated with depressive symptoms (β = -.05, *p* = .363) and self-esteem (β = .05, *p* = .390). Therefore a basic requirement for mediation analyses was not fulfilled for mental health in the association between PA and school absenteeism. It can be concluded that the association between PA and school absenteeism was not mediated by mental health.

Table 5.2 *Physical activity associated with mental health, cardiovascular fitness and school absenteeism due to illness.*

	Depressive symptoms		**Self-esteem**		**Cardiovascular fitness**		**School absenteeism due to illness**	
	ΔR^2	**β**	**ΔR^2**	**β**	**ΔR^2**	**B**	**ΔR^2**	**B**
Step A	.10*		.17*		.47*		.06*	
Sex		.23*		-.28*		-.47*		-.10**
Ethnicity		.13*		-.13*		-.12*		.05
Academic year		.09		-.18*		.00		.15*
Educational level		-.12*		-.17*		.07		.11
Socioeconomic status		.03		.07		.05		.03
Weight status		-.01		.06		-.49*		.10**
Step B	.00		.00		.04*		.00	
Habitual PA		-.05		.05		.21*		-.06

Note. Habitual PA = total physical activity volume per week determined by the total number of accelerometer steps. ΔR^2 = Change in explained variance. β *= Standardized linear regression coefficients, * Statistically significant at p < .05, ** Statistically significant at p < .10.*

Discussion

The results of this study in healthy adolescents showed that habitual PA levels were not significantly associated with school absenteeism due to illness. Though, PA was positively associated with cardiovascular fitness and indirectly associated with lower school absenteeism by cardiovascular fitness. In other words, cardiovascular fitness mediated the association between PA and school absenteeism. In addition, PA was not significantly associated with mental health. Consequently, mental health did not mediate the association between PA and school absenteeism. To the best of our knowledge, this is the first study investigating the association between objectively measured PA and school absenteeism due to illness in adolescents.

PA Associated With School Absenteeism, Cardiovascular Fitness and Mental Health

Results of this study are not in line with previous studies of Jacobson et al. (2001) and Van Den Heuvel et al. (2005), who reported lower absenteeism rates in adult workers who are physically active. An explanation might be that, in these studies, PA was measured by a questionnaire. This subjective instrument has been found to have several limitations (Shephard, 2003), such as social desirability (Adams et al., 2005) and recall bias (Duncan, Sydeman, Perri, Limacher, & Martin, 2001), which might have biased the results. We measured PA objectively, thus our results are not prone to social desirability or recall bias. Though, the contrast between our results and the results of Jacobson et al. (2001) and Van den Heuvel et al. (2005) might also be due to differences in age (adolescents versus adults) and context (work versus school absenteeism).

PA was positively associated with cardiovascular fitness, in line with literature (Hallal et al., 2006; Ortega et al., 2008). In addition, cardiovascular fitness mediated the association between PA and school absenteeism. Because there was no significant direct association between PA and school absenteeism, the mediating role of cardiovascular fitness might be offset by other factors. It is difficult to speculate about factors which might have impacted the association between PA and school absenteeism, because results were controlled for several potential confounders (i.e., sex, ethnicity, academic year, educational level, socioeconomic status and weight status). An explanation might be that long periods of intensive PA, such as training and competing in intensive physically sports, may result in chronic fatigue and injuries (Brenner, 2007; Taylor & Attia, 2000) and consequently more absence days. Therefore, there might be an optimal PA level related to health and consequently school absenteeism. However, additional analyses of our data showed no significant inverted U-shaped association between PA and school absenteeism due to illness, therefore this suggestion has to be taken with caution.

Finally, habitual PA was not significantly associated with higher levels of self-esteem and lower levels of depressive symptoms. A previous publication using data of The GOALS Study showed that PA was, in unadjusted models, positively associated with self-esteem and inversely associated with depressive symptoms (Van Dijk et al., 2014). Therefore, it is concluded that the association between PA and mental health tend to be positive, but the effect is small, which is in line with many studies in this field (Biddle & Asare, 2011). Due to the several factors (i.e., genetic factors, personality, socioeconomic status, and other lifestyle habits), which interact and jointly affect mental health (Stavrakakis et al., 2013), the association between PA and mental health in adolescents seems to be complex and weak at most.

Strengths

The major strength of our study is that PA was measured objectively by an ActivPAL3™ accelerometer, which has been found to be a reliable and user friendly instrument to investigate PA in adolescent girls (Dowd, Harrington, & Donnelly, 2012) and young adults (Berendsen et al., 2014). In addition, we used stringent inclusion criteria (i.e., ≥ 4 complete days of accelerometer wear time including both weekend days), which increases the accuracy and predictability of our independent variable. Finally, results were controlled for several potential confounders.

Limitations

Our study has some limitations. First, the cross-sectional design makes it impossible to draw causal relations. Second, results cannot be generalised to the whole Dutch population because only one secondary school was used, despite of the study sample was equally distributed by sex and the mean BMI was similar to the overall Dutch adolescent population (Snoek, Van Strien, Janssens, & Engels, 2007). Third, cardiovascular fitness levels of the adolescents in our study sample (maximal oxygen consumption of 52ml/kg/min on average) were high compared to the fitness levels in several studies in 12 to 18 years old European adolescents (41ml/kg/min, see review of Ortega et al., 2011). However, the participants in our study sample were stimulated to reach maximal capacity on the shuttle-run test by giving them a mark for their performance, which counted in their final grade for physical education at school. This has not been the case in the studies in European adolescents published by Ortega et al. (2011). As a consequence, adolescents in our study sample were possibly better motivated to perform well on the shuttle-run test, resulting in higher and more reliable cardiovascular fitness levels in our study sample compared to the study samples reported by Ortega et al (2011). Fourth, school absenteeism due to illness data were provided by the school. Days were counted only when absence days were registered due to illness. However, it is still possible that adolescents faked their illness on some absence dates, for example because of a lack of motivation to go to school.

Conclusions

Results of this study show no direct association between habitual PA levels and school absenteeism due to illness in adolescents, however, habitual PA is indirectly associated with school absenteeism by cardiovascular fitness. More research into the relations between PA and school absenteeism is necessary to confirm or reject the results of this first study in this field. We suggest future studies to control the data for potential covariates, such as sex, academic year, and weight status, and take cardiovascular fitness into account as mediator.

CHAPTER 6

Change in Physical Activity During Adolescence Associated With Change in Cognition and Academic Achievement

This study examined the association between change in objectively measured physical activity (PA) over one-year time and change in cognitive performance and academic achievement in adolescents. Dutch students (N = 151) in grades 7 and 9 with complete data on baseline and follow-up were included. Results showed a sharp decline in PA over one-year time (-15.6%), particularly in grade 7 (-20.2%). There was no significant association between change in PA and change in cognitive performance. Change in PA was negatively associated with change in academic achievement (β = -.20, p = .032); the more inactive adolescents became the better their academic achievement. Future studies should investigate the nature of the results of this first study in the field using objective measurements of PA, cognition and academic achievement on baseline and follow-up. In addition, results illustrate that Dutch adolescents develop a sedentary lifestyle, particularly in grade 7, the first year of secondary school in the Netherlands.

This chapter is based on: Van Dijk, M. L., Savelberg, H. H. C. M., Verboon, P., Kirschner, P. A., & De Groot, R. H. M. (2015). Change in Physical Activity During Adolescence Associated With Change in Cognition and Academic Achievement. Manuscript submitted for publication.

Reviews have provided evidence for beneficial effects of physical activity (PA) on cognitive performance and academic achievement (Biddle & Asare, 2011; Esteban-Cornejo, Tejero-Gonzalez, Sallis, & Veiga, 2014; Fedewa & Ahn, 2011; Hillman, Erickson, & Kramer, 2008; Tomporowski, Davis, Miller, & Naglieri, 2008). With respect to adolescents in particular, the reported associations are usually small and inconsistent (Biddle & Asare, 2011). However, the adolescent period is of special interest because the frontal brain lobes, which are associated with executive functioning (Alvarez & Emory, 2006), develop rapidly in that group (Steinberg, 2005). An increasing amount of literature shows positive effects of PA on the frontal brain lobes as well as executive functioning (Davis et al., 2011; Stroth et al., 2010; Tomporowski et al., 2008). Therefore, PA might particularly benefit frontal brain lobe development and consequently executive functioning and academic achievement in adolescents (Etnier & Chang, 2009). In addition, habitual PA levels in the adolescence retain during the transition to adulthood (Kall, Nilsson, & Linden, 2014). However, habitual PA levels have been found to decrease during the adolescent period (Kimm et al., 2002; Ruiz et al., 2011). Taken together, the adolescence is a key period in maintaining an active lifestyle throughout the life span and simultaneously stimulating frontal brain lobe development and thereby executive functioning and academic achievement. Therefore, the adolescence is an important period to investigate the change of habitual PA levels over time and its relation with change in cognitive performance and academic achievement.

Thus far, no study reported associations between change in PA over time and change in cognitive performance and academic achievement in adolescents. Two studies reported associations between habitual PA levels, measured objectively at baseline, and cognitive performance and academic achievement at two- and five-year follow-ups. Data from the Avon Longitudinal Study of Parents and Children (ALSPAC) cohort showed that higher levels of moderate-to-vigorous physical activity (MVPA) measured at 11 years was associated with better executive attention at both 11 and 13 years (Booth, Tomporowski, et al., 2013). Also from ALSPAC, a higher percentage MVPA of the total amount of PA at age 11 predicted increased academic achievement at both 13 and 16 years (Booth, Leary, et al., 2013). In addition, the highest quintile of MVPA minutes/day at age 11 had a higher predicted English attainment at age 16 compared to the lowest quintile in males, however not in females. A limitation of these studies is that habitual PA levels were measured only once, while PA levels tend to decrease during the adolescent period (Kimm et al., 2002; Ruiz et al., 2011). In addition, the accelerometers used were placed on the participants' hip, a place which limits capturing activities with little upper-body movement such as cycling (Chillon et al., 2011). Also, differences in adolescents' PA levels between weekdays and weekend days (Comte et al., 2013) were not taken into account. This might be an important limitation, because adolescents have a habit to be more active on weekdays than on weekend days, particularly on Sunday (Van Dijk, De Groot, Savelberg, Van Acker, & Kirschner, 2014). Therefore, non-inclusion of active weekdays or inactive weekend days might over- or underestimate adolescents' PA levels.

In the current longitudinal study in healthy Dutch adolescents, PA, cognitive performance and academic achievement were measured objectively at baseline and one-year follow-up. The goal of this study was threefold. Firstly, it was investigated whether objectively measured habitual PA levels changed over one-year time. Secondly, the association of change in PA with change in cognitive performance and academic achievement was investigated. Thirdly, sex and academic year differences were explored. Based on previous results (Van Dijk et al., 2014), several significant covariates such as sex, nationality, and educational level were taken into account.

Methods

Participants

The study sample comprised participants from The GOALS (Grootschalig Onderzoek naar Activiteiten van Limburgse Scholieren [Large-scale Research of Activities in Dutch Students]) Study. This study was conducted between October 2011 and May 2013 at a secondary school in the South of the Netherlands. The study was approved by the local Ethical Committee of the Open University in the Netherlands.

All students (N = 526) in grades 7 and 9 of senior general secondary education (SGSE) or university preparatory education (UPE) were invited to participate. A sample of 440 adolescents (83.7%) was willing to participate at baseline. Of these, 24 were excluded from analyses because of health or concentration problems, illness or injuries throughout the entire week and measurement failures of the accelerometer during the data collection week. Also, 88 participants were excluded because they did not wear the accelerometer for at least four valid days including both weekend days. Of the remaining 328 participants, 96 did not participate at one-year follow-up. At follow-up, 7 participants were injured or ill and 58 did not wear the accelerometer at least four valid days including both weekend days. In addition, 19 participants had missing data at either baseline or follow-up in one of the cognitive tests or school grades. As a result, 151 participants with complete data on both baseline and follow-up were included in analyses.

Procedures

At baseline, habitual PA levels of the participants were measured by wearing an accelerometer continuously for one full week, 24 hours/day. Cognitive performance was measured by two neuropsychological tests. This took place in a classroom under supervision of two trained assistants. At the end of the academic year, school grades for Dutch, mathematics and English throughout the entire academic year were provided by the school. After finishing the study and by full participation, participants received a gift voucher of 15 euro. All procedures at baseline were also executed at one-year follow-up using the same protocols. A comprehensive description of the procedures of this study on baseline has been published elsewhere (Van Dijk et al., 2014).

Measures

Habitual PA levels. Accelerometers (model ActivPAL3™; Paltechnologies, Glasgow, UK) were used to measure habitual PA levels. Previous research showed that the ActivPAL3™ accelerometer is a valid, useful and user-friendly instrument to investigate PA in adolescent girls (Dowd, Harrington, & Donnelly, 2012) and young adults (Berendsen et al., 2014). Data were downloaded and processed with ActivPAL™ Professional software (version 6.4.1). Data output used in the current study was the number of accelerometer steps, which was computed at 15 second intervals (epochs).

Habitual PA levels were based on at least four valid days including both weekend days. A valid day was considered to be a day that the student wore the accelerometer the whole day (24 hours). The total number of accelerometer steps per week was used as measure of habitual PA level (Total PA). Detailed calculations of Total PA have been published in Van Dijk et al. (2014). Change of Total PA over time was calculated by the delta (i.e., difference) score of Total PA between follow-up and baseline (ΔPA).

Cognitive performance. The Symbol Digit Modalities Test (SDMT) was used as measure of information-processing speed (Smith, 2010). The SDMT is widely used in many studies in children and adolescents and has shown to have a good reliability (ICC > .87) in young adults (Hinton-Bayre & Geffen, 2005). This test contains nine numbers coupled with nine symbols in a random order on the top of a page. On the remainder of the page, boxes are presented with symbols only. Participants were asked to fill in as many corresponding numbers as possible within 90 seconds. The total number of digits correctly coupled to symbols was scored. Change of performance on the SDMT over time was calculated by the delta score on the SDMT between follow-up and baseline (ΔSDMT).

The d2 Test of Attention (Brickenkamp & Zillmer, 1998) was used as measure of response inhibition (Budde, Voelcker-Rehage, Pietrabyk-Kendziorra, Ribeiro, & Tidow, 2008), a key component of executive functioning (Alvarez & Emory, 2006), and selective attention (Bates & Lemay, 2004). The d2 Test of Attention is a widely used neuropsychological test and the construct validity has been well supported in European samples (Bates & Lemay, 2004). The d2 Test of Attention consists of 14 rows, each with 47 interspersed “p” and “d” characters. The characters had one to four dashes configured individually or in pairs above and/or below each letter. The target symbol was a “d” with two dashes (hence “d2”), regardless of whether the dashes appeared both above the “d”, both below the “d”, or one above and one below the “d”. The participant’s task was to cross out as many target symbols as possible, moving from left to right, with a limit of 20 seconds/row. No pauses were allowed. An overall performance score was calculated by the total number of correctly crossed-out symbols minus total number incorrectly crossed-out symbols. Change of d2 Test of Attention over time was calculated by the delta score on d2 Test of Attention between follow-up and baseline (ΔTA).

Academic achievement. School grades (ranging from 1.0 = very bad to 10.0 = outstanding) were provided by the school at baseline at the end of academic year

2011-2012 as well as at follow-up at the end of academic year 2012-2013. The mean scores of the school grades for Dutch (native language), mathematics, and English as a modern foreign language were used as measures of academic achievement, according to research of Sigfúsdóttir, Kristjánsson, and Allegrante (2007). Change of academic achievement over time was calculated by the delta score on academic achievement between follow-up and baseline (ΔAC).

Covariates. Several covariates associated with physical activity and cognitive performance or academic achievement were accounted for. Sex (coded as -0,5 = boys, 0,5 = girls) and nationality (coded as -0.5 = native Dutch, i.e., both parents/guardians born in the Netherlands and 0.5 = non-native Dutch) were dichotomized. The academic year-cohort at baseline (grade 7 or grade 9) was coded as -0.5 = cohort 7th Graders, the first year of secondary school in the Netherlands, and 0.5 = cohort 9th Graders. Educational level was coded as -0,5 = SGSE, secondary school level preparing for university of applied sciences [HAVO] and 0,5 = UPE, secondary school level preparing for university study [VWO].

Results in academic achievement were controlled for educational changes between baseline and follow-up and for mathematics domain. When students started in UPE on baseline and moved to SGSE on follow-up, covariate 'Educational level DOWN' was coded as 0,5 and in all other cases as -0,5. When students started in SGSE on baseline and progressed to UPE on follow-up, covariate 'Educational level UP' was coded 0,5 and in all other cases as -0,5. When students in Grade 9 on baseline progressed to Grade 10 on follow-up, they had to choose a mathematics domain. In the Netherlands, two mathematics domains are dominant, probability calculation [Wiskunde A] and mathematical equations and geometry [Wiskunde B]. Covariate 'Mathematics domain' was coded as -0,5 = probability calculation [Wiskunde A] and 0,5 = mathematical equations and geometry [Wiskunde B].

Statistics

Statistical Package for Social Sciences (SPSS) for Windows (version 19.0; SPSS, Inc, Chicago, Illinois) was used for paired sample *t* test and ANOVA repeated measures analyses. Structural equation modelling was performed using R: A language and environment for statistical computing (lavaan; An R Package for Structural Equation Modelling, Vienna, Austria). The distributions of the independent and dependent variables at both baseline and follow-up were normal. The level of significance was .05 in all analyses.

Differences in PA, cognitive performance and academic achievement between baseline and one-year follow-up were analysed by paired sample *t* tests. To investigate whether the differences in PA, cognitive performance and academic achievement over one-year time differed between 7th Graders and 9th Graders and between boys and girls, repeated-measures ANOVA was executed. Time (i.e., baseline or follow-up) was defined as within-subjects factor, whereas academic year and sex respectively were defined as between-subjects factor.

Associations between change of PA over time and change in cognitive performance and academic achievement were analysed by structural equation modelling (SEM). SEM was used to simultaneously estimate various associations in the data. Not only the effects on the dependent variables were modelled, but also other relevant correlations between independent variables and covariates were incorporated in the model. The model consisted of one independent variable (ΔPA) and three dependent variables (ΔTA, ΔSDMT, ΔAC). Relations were controlled for baseline levels of PA, cognition and academic achievement, as well as covariates sex, nationality, academic year, educational level, mathematics domain and whether students moved up or down in educational level between baseline and follow-up.

Only complete cases (N = 151) were used in analyses. Analyses were also conducted using moderate-to-vigorous intensity PA (total number of accelerometer steps with a cadence ≥100 steps/minute) as independent variable. These results showed no differences compared to analyses using Total PA as independent variable and are therefore not published.

Results

The descriptive statistics are shown in Table 6.1. Mean age of the participants included in analyses (N = 151) was 13,48 years old at baseline, 37.1% was boy, 88.1% was native-Dutch and 26.5% was of senior general secondary education.

Change in Habitual PA Levels From Baseline to One-year Follow-up

Total PA decreased 15.6% over one-year time (-11,047 ± 19,729 accelerometer steps, p < .001). In addition, Total PA was significantly lower at one-year follow-up for 7th Graders (-20.2%, p <.001), while there was no significant difference for 9th Graders (-4.9%, p = .250), see Figure 6.1. Repeated measures ANOVA revealed that Total PA of 7th Graders decreased significantly harder than Total PA of 9th Graders (F (0,72) = 12.825; p < .001). In other words, the majority of reduction in Total PA during adolescence took place when students progressed from grade 7 to grade 8. There was no significant difference between boys and girls in the change of Total PA from baseline to follow-up (F (0,04) = 0.708; p = .401).

Change in Cognition and Academic Achievement From Baseline to One-year Follow-up

Cognitive performance improved significantly on the SDMT (5,72 ± 8,21 correct digits, p < .001) and d2 Test of Attention (28,38 ± 17,99 crossed-out symbols, p < .001) over one-year time. Academic achievement decreased significantly (-0,33 ± 0,57, p < .001) over one-year time. For 7th Graders, results showed higher performance on the SDMT (+11.6%, p <.001) and d2 Test of Attention (+15.1%, p <.001) and lower academic achievement (-5.1%, p

<.001) at one-year follow-up. In addition, also for 9th Graders, results showed higher performance on the SDMT (+6.0%, p <.001) and d2 Test of Attention (+17.8%, p <.001) and lower academic achievement (-3.6%, p = .002) at one-year follow-up. Repeated measures of ANOVA showed no significant difference between the sexes and academic years in the change in cognitive performance and academic achievement from baseline to follow-up.

Table 6.1 *Descriptive statistics of the study sample*

	All (*N* = 151)		**Cohort 7th Graders (*N* = 101)**		**Cohort 9th Graders (*N* = 50)**	
	Baseline	Follow-up	Grade 7	Grade 8	Grade 9	Grade 10
	M ± SD	M ± SD	M ± SD	M ± SD	M ± SD	M ± SD
Age (years)	13.48 ± 1.09	14.50 ± 1.15	12.75 ± 0.43	13.75 ± 0.40	14.89 ± 0.45	16.02 ± 0.46
Total PA	70904 ± 18087*	59857 ± 16333*	73870 ± 17876*	58929 ± 16031*	64913 ± 17162	61733 ± 16935
Symbol Digit Modalities Test	59.74 ± 10.23*	65.45 ± 10.96*	56,35 ± 8.92*	62,90 ± 9.92*	66.58 ± 9.29*	70.60 ± 11.25*
d2 Test of attention	176.67 ± 25.15*	205.05 ± 33.12*	170.77 ± 22.70*	196.54 ± 30.59*	188.58 ± 25.86*	222.22 ± 31.59*
Academic achievement	7.14 ± .74*	6.81 ± 0.77*	7,27 ± 0.73*	6,90 ± 0.83*	6.88 ± 0.69*	6.63 ± 0.58*

*Note. M = mean, SD = standard deviation, SGSE = senior general secondary education, UPE = university preparatory education, Total PA = total amount of physical activity per week measured by accelerometer. * indicates significant difference between the academic years at p < .05.*

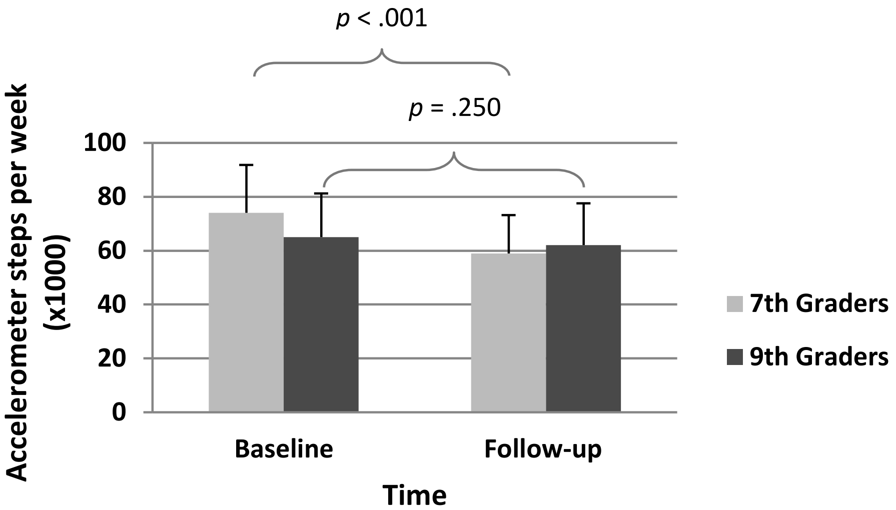

Figure 6.1 *Change in habitual physical activity levels over one-year time. P = significance value (statistically significant difference between baseline and follow-up at p < .05).*

Change in PA Associated With Change in Cognition and Academic Achievement

The structural equation model fitted the data reasonably well as shown by the following fit measures: χ^2 = 58.9, *df* = 42; CFI = .960; TLI = .913, RMSEA = 0.052. The SEM analyses (Table 6.2 and Figure 6.2) indicated no significant association between ΔPA and the cognitive measures ΔSDMT (β = -.05, *p* = .651) and ΔTA (β = -.11, *p* = .292). There was a significantly negative association between ΔPA and ΔAC (β = -.20, *p* = .032). The control variables sex, nationality, academic year and educational level showed no significant effects on the dependent variables and were omitted from Table 6.2 and Figure 6.2 for reasons of parsimony.

Table 6.2 *Structural equation modelling for change in physical activity associated with change in cognition and academic achievement*

	Change in SDMT (ΔSDMT)			**Change in d2 Test of Attention (ΔTA)**			**Change in academic achievement (ΔAC)**		
	β	SE	*p*	β	SE	*p*	B	SE	*P*
Change in Total PA (ΔPA)	-.05	.103	.651	-.11	.105	.292	-.20	.091	.032
Total PA at baseline	-.05	.101	.591	-.14	.103	.172	-.09	.089	.307
SDMT at baseline	-.29	.087	.001						
D2 Test of Attention at baseline				.12	.086	.164			
Academic achievement at baseline							-.22	.081	.007
Mathematics domain							-.20	.082	.017
Educational level UP							-.21	.080	.009
Educational level Down							.25	.074	.001

SDMT = symbol digit modalities test, Total PA = total amount of physical activity per week measured by accelerometer, β = standardized regression coefficients, SE = standard error, p = significance value (statistical significant at p < .05).

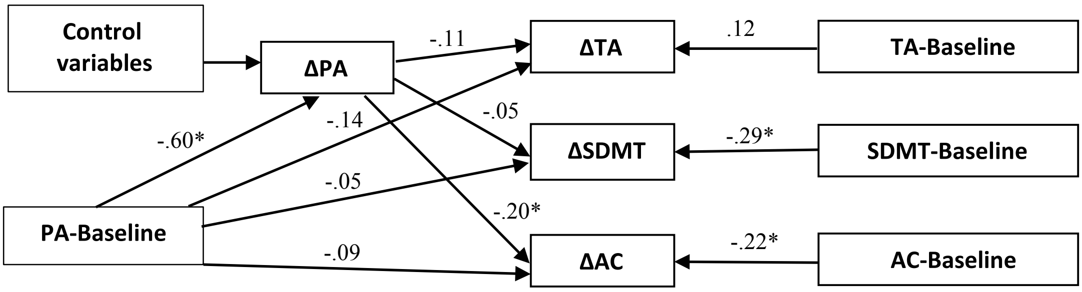

Figure 6.2 *Schematic overview of structural equation modelling for change in physical activity associated with change in cognition and academic achievement. Only most important paths are presented for readability. ΔPA = change in total amount of physical activity between baseline and one-year follow-up. ΔTA = change in performance on the d2 Test of Attention between baseline and one-year follow-up. ΔSDMT = change in performance on the symbol digit modalities test between baseline and one-year follow-up. ΔAC = change in academic achievement between baseline and one-year follow-up. * indicates statistical significance at p < .05.*

Discussion

The main findings of this study indicate that larger reductions in habitual PA levels during adolescence are associated with smaller reductions in academic achievement. To be more clear, the more inactive (i.e., less exhibited PA) adolescents become; the better they relatively perform at school. Change of PA is not significantly associated with change in cognitive performance. To the best of our knowledge, this is the first study in adolescents reporting associations between change in objectively measured PA, cognitive performance and academic achievement on both baseline and follow-up.

Reduction of PA During Adolescence

The results of this study show that habitual PA levels in adolescents decrease over one-year time, which is in line with previous studies (Kimm et al., 2002; Ruiz et al., 2011). Particularly, habitual PA levels decrease mainly during the transition from Grade 7 (age 11-13 years) to Grade 8 (age 12-14 years). Possibly, adolescents meet new friends and take up other - more sedentary - hobbies in Grade 7, the first year of secondary school in the Netherlands. For example, those who are member of a sports club quit their membership and spent more time playing video games. Also, it is possible that in this ‘transition’ year from childhood to adolescence, street play, a physically active activity, is seen as childish and is avoided. To the best of our knowledge, this is the first study showing a sharp decline in objectively measured habitual physical activity levels during the first years of secondary school in Dutch adolescents. Future studies should investigate the nature of the development of a sedentary lifestyle during adolescence and should investigate whether these results can be generalised to other countries.

Change in PA Associated With Change in Cognition and Academic Achievement

Change in PA was negatively associated with change in academic achievement. In other words, the more inactive students became, the better their academic achievement. In addition, however not statistically significant, change in PA was positively associated with change in cognitive performance. In other words, the more inactive students became, the worse their cognitive performance, however not statistically significant. Interestingly, a previous publication using cross-sectional data of The GOALS Study showed a positive association between PA and executive functioning (Van Dijk et al., 2014), while additional analysis using that cross-sectional dataset showed no significant association with cognitive performance (β = .05, *p* = .440). Therefore, the most beneficial effects of PA on cognitive performance seems to be on tasks involving executive functioning. Also results in current study showed a larger effect size in the association between change in PA and change in executive functioning compared to change in cognitive performance, however not statistically significant (see Table 6.2).

The main explanation with respect to the association between PA and academic achievement is that students might have spent less time on PA in favour of time spent devoted to homework and test preparation which might have a positive impact on academic achievement (Tremblay, Inman, & Willms, 2000). Also, those who continued to be physically active might have had less time for homework and test preparation and thus may have scored lower. Additional analyse were performed to investigate whether change in habitual PA level was associated with change in time devoted to homework, however no significant association was found (β = .02, *p* = .832). In addition, it might be that students performing relatively low on baseline decided to spend more time devoted to homework, to the detriment of time spend in physical activities, to improve their academic achievement. However, additional analyses showed no significant association between academic achievement on baseline and change of habitual PA level between baseline and follow-up (β = .11, *p* = .266). Finally, 10 students progressed to a higher educational level (i.e., SGSE to UPE) from baseline to follow-up, and 8 students did the opposite (i.e., UPE to SGSE). Those who progressed to a higher educational level spent more time devoted to homework (47 minutes per day more) and their reduction in PA was correlated with more time devoted to homework (β = .44, *p* = .362), however due to the low number of participants included (N=10) not statistically significant. In addition, those who degraded to a lower educational level spent less time devoted to homework (14 minutes per day less) and their reduction in PA was correlated with less time devoted to homework (β = .26, *p* = .501), but also not statistically significant. Taken together, this implies that the association between change in physical activity and change in academic achievement is very complex due to changes in educational level and time devoted to homework.

With respect to the association between PA and cognitive performance, stringent inclusion criteria were used (i.e., complete PA, cognition and academic achievement data at both baseline and follow-up), resulting in a small sample of 151 included participants in analyses. Consequently, the statistical power was relatively low for the SEM analyses which were used, resulting in non-significant associations between change in PA and change in cognitive performance. In addition, the association between change in PA and change in cognitive performance might be more complex compared to cross-sectional associations between PA and cognitive performance. For example, it might take more time than one-year, the time interval between baseline and follow-up in the current study, before changes in habitual PA levels impact cognitive performance. High PA levels on baseline might benefit cognitive performance on follow-up, also of adolescents who became inactive; the time interval is only one-year and the moment of changed PA behaviour is unknown. On the long term, habitual PA levels might have more beneficial effects on the (frontal) brain, for example by stimulating angiogenesis and neurogenesis (Thomas, Dennis, Bandettini, & Johansen-Berg, 2012). These positive effects of habitual PA levels during many years might result in greater beneficial effects on cognitive performance and academic achievement. Therefore, on the long term, the association between change in PA during adolescence and change in cognitive performance as well as academic achievement might be more clear.

Strengths

The major strength of this study is that PA was measured objectively at both baseline and follow-up, which has not been the case in previous studies in the field of PA and cognitive performance or academic achievement (Booth, Leary, et al., 2013; Booth, Tomporowski, et al., 2013; Kwak et al., 2009; Pindus et al., 2014; Syväoja et al., 2013; Syväoja, Tammelin, Ahonen, Kankaanpää, & Kantomaa, 2014). In addition, PA was measured by an accelerometer attached on the thigh, which has been found to be a reliable instrument to investigate PA (Dowd et al., 2012) and capable of measuring activities with little upper-body movement such as cycling (Dahlgren, Carlsson, Moorhead, Hager-Ross, & McDonough, 2010). Second, we calculated PA as weighted mean of two or more weekdays and both Saturday and Sunday, which has also not been the case in previous mentioned studies in this field. This might be an important issue in calculating habitual PA levels, because adolescents' PA levels differ between weekdays and weekend days (Comte et al., 2013). Finally, cognitive performance and academic achievement were measured objectively and for several potential confounders were controlled for.

Limitations

Our study has some limitations. First, the observational design of our study makes it impossible to draw causal relations. Second, data about people who were 'left back (i.e., did not successfully pass the academic year and who were required to repeat the year) are missing, which limits the generalisability of the results. In addition, selection bias might have been present, because inactive adolescents were possibly less inclined to participate a second time than active adolescents who felt more attracted to the research topic. However, additional analyses showed no significant difference in habitual PA levels between students included in current study and those students who participated at baseline only. Finally, results cannot be generalised to the whole Dutch adolescent population, because we used only one secondary school.

Conclusions

Adolescents who become inactive over one-year time perform relatively better at school than their counterparts who stay active. Although the results show an association between change in PA and change in academic achievement, no causal relation can be drawn whether physical inactivity leads to better academic achievement. Future studies should investigate the nature of this, for example whether adolescents spent less time in physical activities in favour of more time devoted to homework. More rigorous longitudinal designs, using large study samples, long (i.e., ≥ two years) time intervals and several measurements are needed in future studies.

Finally, the results of this study show a sharp decline in PA over one-year time, particularly in Grade 7. Habitual PA habits developed during adolescence retain in the transition to adulthood (Kall et al., 2014) and PA has been associated with numerous health benefits across the lifespan (Hillman et al., 2008; Janssen & Leblanc, 2010; Penedo & Dahn, 2005). For these health motives, the results of this study highlight the importance to avoid developing a sedentary lifestyle during adolescence, particularly in Grade 7, the first year of secondary school in the Netherlands.

CHAPTER 7

Decline in Habitual Physical Activity Levels During Adolescence Associated With Change in Mental Health

The majority of studies investigating associations between physical activity and mental health in adolescents used cross-sectional designs. However, as physical activity levels in adolescents tend to decrease, it is better to use longitudinal studies to understand the associations between changes in physical activity and changes in mental health. Few studies have investigated these associations and none has objectively measured physical activity. A total of 158 Dutch adolescents (mean age 13 years, 39% boys, grades 7 and 9 at baseline) participated in this longitudinal study. Habitual physical activity levels decreased 15% over one-year time ($p < .001$), with significant ($p = .001$) greater decreases during grade 7 (21%) than grade 9 (5%). Depressive symptoms decreased (-12%, $p < .001$) over one-year time, while self-esteem did not change significantly (+3%, $p = .066$). Higher levels of depressive symptoms at baseline predicted greater decline in depressive symptoms ($\beta = -.51$, $p < .001$) and higher levels of self-esteem at baseline predicted smaller increase in self-esteem ($\beta = -.48$, $p < .001$). Also, academic year predicted change in self-esteem ($\beta = -.37$, $p < .001$), which indicates larger improvements in self-esteem in students in grade 7 compared to students in grade 9. Decline in physical activity did not seem to predict change in depressive symptoms and self-esteem. The decline in physical activity over one-year time during adolescence is not associated with change in mental health. Further studies in adolescents aiming to investigate whether a change in physical activity is associated with a change in mental health should control for baseline levels of mental health and academic year differences.

This chapter is based on: Van Dijk, M. L., Savelberg, H. H. C. M., Verboon, P., Kirschner, P. A., & De Groot, R. H. M. (2015). Decline in Habitual Physical Activity Levels During Adolescence Associated With Change in Mental Health. Manuscript submitted for publication.

Between 10 and 20% of adolescents have mental health problems (Kieling et al., 2011). Left untreated, these adolescents have an increased risk of isolation, school absenteeism, academic underachievement, substance abuse, and suicide (Egger, Costello, & Angold, 2003; Shaffer et al., 1996; Weissman et al., 1999). Physical activity has been shown to have beneficial effects on mental health (Paluska & Schwenk, 2000). For example, physical activity may alleviate depressive symptoms due to an increased release of β-endorphins, which is related to a positive mood and overall enhanced sense of well-being (Craft & Perna, 2004). In addition, physical activity may directly increase self-esteem (Ekeland, Heian, Hagen, Abbott, & Nordheim, 2004) or indirectly by increasing the perception of physical competence and the level of fitness (Jackson & Marsh, 1986; Weiss & Bredemeier, 1990). Positive associations between physical activity and depressive symptoms or self-esteem have been reported in the majority of studies in adolescents (see reviews (Calfas & Taylor, 1994; Craft & Landers, 1998; Ekeland, Heian, & Hagen, 2005)), however the research designs are often weak (see review of reviews of Biddle and Asare (2011)). Most of the studies used cross-sectional designs (Rothon et al., 2010), however physical activity levels tend to decrease during the adolescent period (Ruiz et al., 2011; Van Mechelen, Twisk, Post, Snel, & Kemper, 2000), therefore longitudinal studies are needed to understand the association between the decline in physical activity during adolescence and change in mental health.

Only three studies have investigated the association between change in physical activity and change in depressive symptoms in adolescents. Motl, Birnbaum, Kubik and Dishman (2004) revealed that an increase in physical activity between the beginning of grade 7 and the end of grade 8 was inversely related to a change in depressive symptoms (i.e., less depressive symptoms). Also, Neissaar and Raudsepp (2011) found in adolescent girls aged 11 to 12 years old that a decrease in physical activity across two years was inversely associated with a change in depressive symptoms (i.e., more depressive symptoms). In contrast, Rothon et al. (2010) found no significant association between a change in physical activity and a change in depressive symptoms in adolescents progressing from grade 7 to grade 9. Also, three studies in adolescents reported associations between baseline levels of physical activity and change in depressive symptoms between baseline and follow-up. Wiles et al. (2008) reported that adolescents aged 11 to 14 years old who participated in at least one-hour of sports activity (e.g., football, tennis, swimming) on a daily basis had fewer emotional problems one-year later. In addition, Stavrakakis, de Jonge, Ormel, and Oldehinkel (2012) reported that high baseline levels of physical activity in 11 and 14 years old adolescents predict a decrease in depressive symptoms, such as depressed mood, low self-worth and loss of pleasure, two years later. In contrast, Clark et al. (2006) found that physical activity levels at baseline were not significantly associated with depressive symptoms two years later in 11 to 14 years old adolescents.

Only one study in adolescents has investigated the association between change in physical activity and change in self-esteem. Lindwall et al. (2014) found no significant association in 14 and 15 years old girls between change in physical activity and change in self-esteem over a three-year follow-up period. Also studies in the field of physical activity and mental health in adolescents using experimental or cross-sectional designs had been published. Boyd and Hrycaiko (1997) examined the effect of a physical activity intervention during six weeks on self-esteem in 9 to 16 years old females. The results indicated that only females in grades 4 and 5 (aged 9 and 10 years old) with low self-esteem benefitted from the intervention. In addition, Tremblay, Inman, and Willms (2000) found that regular participating in physical activities (e.g., sports, active commuting, stretching exercises and strength exercises) was positively associated with self-esteem in adolescents in grade 6. Finally, Schmalz, Deane, Birch, & Krahnstoever Davison (2007) found in 9 and 11 years old girls that higher levels of physical activity as baseline predicted higher levels of self-esteem two years later.

A limitation of all of the above mentioned observational studies was that habitual physical activity levels were subjectively measured using questionnaires. This self-report method has several limitations (Shephard, 2003), such as social desirability (Adams et al., 2005) and recall bias (Duncan, Sydeman, Perri, Limacher, & Martin, 2001). Therefore, it is important to use an objective instrument when investigating associations between changes in physical activity during adolescence and changes in mental health.

The main goal of the current study in adolescents in grades 7 and 9 was to investigate the associations between changes in objectively measured physical activity over one-year and changes in depressive symptoms and self-esteem. Habitual physical activity levels were measured by the ActivPAL3™ accelerometer at baseline and one-year follow-up. Depressive symptoms and self-esteem were measured subjectively by self-report at both moments. Potential confounders were taken into account, such as sex, academic year, socioeconomic status, body mass index, and cardiovascular fitness. Differences in adolescents' habitual physical activity levels between weekdays and weekend days were account for, as well as differences in physical activity levels between students in grade 7 and grade 9 (Van Dijk, De Groot, Savelberg, Van Acker, & Kirschner, 2014).

Methods

Study Design and Participants

The observational-longitudinal GOALS (Grootschalig Onderzoek naar Activiteiten van Limburgse Scholieren [Large-scale Research of Activities in Dutch Students]) Study was originally designed to investigate the associations between physical activity and cognitive performance and academic achievement. This study was conducted at a secondary school in the Netherlands. A sample of 440 students in grades 7 and 9 of senior general secondary education (SGSE) or university preparatory education (UPE) participated. Participants with complete data on both baseline and follow-up (N = 158) were included in current study.

Procedures

Before starting this study, the Ethical Committee of the Open University in the Netherlands approved the research protocol (reference number: U2013/07405/HVM). Before starting data collection, information about the background behind, goals of, and procedures used in the study was distributed to students of the selected classes. Also, parents and/or guardians were invited to a presentation about the study. Parents and/or guardians signed an objection form in case they did not agree with the participation of their children or in case the students themselves did not wish to take part. No written informed consent for participation in the study was obtained from the students or their parents/guardians, which was decided in consultation with the Ethical Committee.

Data collection was executed by research assistants trained with standard protocols and who were given standardized instructions. Habitual physical activity levels of the participants were measured by wearing an accelerometer continuously for one full week, 24 hours/day. Cardiovascular fitness was measured by the shuttle-run test. Experienced feelings of depressive symptoms and self-esteem were self-reported using validated questionnaires. After finishing the study and after full participation, participants received a gift voucher of 15 euro.

Using the same protocols, all baseline procedures were also executed at one-year follow-up. Data collection was conducted between October 2011 and May 2013 at a secondary school in the South of the Netherlands. A comprehensive description of the procedures of this study at baseline has been published elsewhere (Van Dijk et al., 2014).

Measures

Physical activity. Accelerometers (model ActivPAL3™; Paltechnologies, Glasgow, UK) were used to measure habitual physical activity levels. These accelerometers were taped on the midpoint of the anterior part of the right thigh of the participants using Tegaderm™ (3M, St. Paul, MN, US) transparent film. Data were processed with ActivPAL™ Professional software (version 6.4.1).

Habitual physical activity levels were based on at least four valid days (i.e., a day that the student wore the accelerometer 24 hours) including both weekend days. The total physical activity volume per week was calculated by the total number of accelerometer steps per week. Change of physical activity over one-year time (ΔPA) was calculated by the difference score between follow-up and baseline.

Depressive symptoms. Feelings of depressive symptoms were measured by the Center for Epidemiologic Studies Depression Scale (CES-D) designed by Radloff (1977). The CES-D is an appropriate measurement instrument for depression in adolescents, with an internal consistency (Cronbach's alpha) ranging from .78 to .82 (Verhoeven, Sawyer, & Spence, 2013). In this 20-item self-report scale, participants rated the frequency of 20 depressive symptoms over the previous week. The written answers were: (0) Rarely or none of the time (on average less than 1 day), (1) Some or a little of the time (1-2 days), (2) Occasionally or a moderate amount of time (3-4 days), and (3) Most or all of the time

(5-7 days). The positively worded items were reverse-scored. A total severity score was calculated by summing all items, ranging from 0 (not depressed) to 60 (a high amount of depressive symptoms). Change of depressive symptoms over one-year time was calculated by the difference score on the CES-D between follow-up and baseline (ΔDS).

Self-esteem. The Rosenberg Self-Esteem Scale was used to measure self-esteem (Rosenberg, 1979). The Rosenberg Self-Esteem Scale is commonly used in research and a strong indicator of an adolescent's global self-esteem (Hagborg, 1993). The scale consists of ten statements dealing with general feelings about the participant's own self. The statements were answered by: (0) Strongly agree, (1) Agree, (2) Disagree, (3) Strongly Disagree. The negatively worded items were reverse-scored. The self-esteem score is calculated by summing all items and ranges from 0 (minimum score of self-esteem) to 30 (maximum score of self-esteem). Change of self-esteem over one-year time was calculated by the difference score on the Rosenberg Self-Esteem Scale between follow-up and baseline (ΔSE).

Covariates. Sex was coded as -0,5 = boys and 0,5 = girls. Academic year was coded as -0.5 = 7^{th} Graders (i.e., the first year of secondary school in the Netherlands) and 0.5 = 9^{th} Graders. Nationality was coded as -0.5 = native Dutch (i.e., both parents/guardians born in the Netherlands) and 0.5 = non-native Dutch. Socioeconomic status was measured by the highest educational level of the parents/guardians. If the parents/guardians had at most a secondary vocational education level, socioeconomic status was coded as 'low-medium' = -0.5, in all other cases socioeconomic status was coded as 'high' = 0.5 following the Dutch national classification (Dutch Ministry of Public Health, Welfare and Sport, 2011).

Body mass index and cardiovascular fitness were objectively measured and included in the analyses as baseline covariates (i.e., baseline levels) and change covariates (i.e., difference score between follow-up and baseline). Weight in kg (rounded above) and height in meters (two decimals) were measured in light clothing without shoes. The body mass index was then calculated by dividing the weight by the height squared. Change of body mass index over one-year time was calculated by the difference score of body mass index between follow-up and baseline (ΔBMI). Maximum oxygen consumption (VO_2 max) was used as indication of cardiovascular fitness and estimated by the 20m shuttle-run test (Leger, Mercier, Gadoury, & Lambert, 1988). A comprehensive description of the 20m shuttle-run test and calculation of the VO_2 max has been published elsewhere (Van Dijk et al., 2014). Change of cardiovascular fitness over one-year time was calculated by the difference score on the 20m shuttle-run test between follow-up and baseline (ΔCF).

Statistics

Statistical Package for Social Sciences (SPSS) for Windows (version 19.0; SPSS, Inc, Chicago, Illinois) was used for paired sample *t* tests and independent sample *t* tests. Structural equation modelling was performed in R (R Core Team 2013) with the package

Lavaan (Rosseel, 2012). The distributions of the independent and dependent variables at both baseline and follow-up were normal. The level of significance was .05 in all analyses.

Differences in habitual physical activity levels, depressive symptoms and self-esteem between baseline and one-year follow-up were analysed by paired sample *t* tests.

Associations between change of physical activity over time and change in depressive symptoms and self-esteem were analysed by structural equation modelling (SEM). SEM was used to simultaneously estimate various associations in the data. Not only the effects on the dependent variables were modelled, but also other relevant correlations between independent variables and covariates were incorporated in the model. The model consisted of one independent variable (ΔPA) and two dependent variables (ΔDS and ΔSE). Relations were controlled for physical activity at baseline (PA_Baseline), depressive symptoms at baseline (DS_Baseline) and self-esteem at baseline (SE_Baseline), as well as covariates sex, nationality, academic year, socioeconomic status, body mass index and cardiovascular fitness.

Only complete cases (N = 158) were used in analyses. Analyses were also conducted using moderate-to-vigorous intensity physical activity as independent variable. Moderate-to-vigorous intensity physical activity was calculated by the total number of accelerometer steps with a cadence ≥100 steps/minute in accordance with many studies (Dall, McCrorie, Granat, & Stansfield, 2013). These results showed no relevant differences compared to analyses using the total physical activity volume per week as independent variable and are therefore not published.

Results

The descriptive statistics are shown in Table 7.1. The structural equation model, built to test whether decline in physical activity was related to change in mental health, fitted the data well (χ^2 = 23.5, df = 12; CFI = .97; TLI = .92; RMSEA = .078).

Change in Physical Activity

Habitual physical activity levels decreased 15.3% (10,679 ± 18,965 accelerometer steps) over one-year time (paired *t* test, p < .001). SEM analyses (Figure 7.1) revealed that the change in physical activity was mainly predicted by the baseline level of physical activity (β = -.68, p < .001). Higher physical activity levels at baseline predicted sharper decreases after one-year. The 9th Graders (73,672 ± 18,208 accelerometer steps per week) were less active at baseline than the 7th Graders (63,759 ± 18,223 accelerometer steps per week, p < .001). Also, the 9th Graders (-5.0%) showed less decrease in physical activity after one-year than the 7th Graders (-20.7%, p = .001). Decline in physical activity did not differ significantly between boys (-17.4%) and girls (-13.8%, p = .910).

Table 7.1 *Descriptive statistics of the study sample*

	All (N=158)		**Cohort 7th Graders (N=98)**		**Cohort 9th Graders (N=60)**	
	Baseline	**Follow-up**	**Baseline (Grade 7)**	**Follow-up (Grade 8)**	**Baseline (Grade 9)**	**Follow-up (Grade 10)**
Age (years)	13.60 ± 1.13	14.62 ± 1.20*	12.79 ± 0.45	13.75 ± 0.42*	14.92 ± 0.47	16.04 ± 0.48*
Sex						
Boys	61 (38.6%)		38 (38.8%)		23 (38.3%)	
Girls	97		60		37	
Nationality						
Native Dutch	140 (88.6%)		88 (89.8%)		52 (86.7%)	
Non-native	18		10		8	
Educational level						
SGSE	40 (25.3%)		31 (31.6%)		9 (15.0%)	
UPE	118		67		51	
SES						
Low/medium	34 (21.9%)		21 (21.9%)		13 (22.0%)	
High	121		75		46	
Body mass index (kg/m2)	18.75 ± 2.82	19.45 ± 2.83*	17.88 ± 2.81	18.72 ± 2.89*	20.18 ± 2.21	20.65 ± 2.30*
Cardiovascular fitness (VO_2max)	51.53 ± 5.51	51.02 ± 6.14*	51.81 ± 5.72	51.70 ± 6.19	51.06 ± 5.17	49.90 ± 5.94*
Total PA (accelerometer steps)	69908 ± 18786	59229 ± 15021*	73672 ± 18208^B	58405 ± 13809*^{B}	63759 ± 18223^B	60573 ± 16851^B
Depressive symptoms	11.62 ± 9.20	10.21 ± 8.95*	10.99 ± 9.01	9.12 ± 8.03*	12.65 ± 9.49	11.98 ± 10.10
Self-esteem	22.02 ± 5.34	22.65 ± 5.30	22.39 ± 5.27	23.49 ± 4.93*^{B}	21.42 ± 5.45	21.29 ± 5.62^B

SGSE = senior general secondary education; UPE = university preparatory education; Total PA = total amount of physical activity per week measured objectively by accelerometer. VO_2max = maximum oxygen consumption. significantly different from baseline at p < .05. ^{B} indicates significant difference between 7th Graders and 9th Graders*

Change in Mental Health

Overall, depressive symptoms decreased 12.1% (1.41 ± 7.96) over one-year time (paired *t* test, $p = .027$). SEM analyses (Figure 7.1) revealed that change in depressive symptoms was significantly associated with baseline levels of depressive symptoms ($\beta = -.51$, $p < .001$). The higher the baseline levels of depressive symptoms, the greater the decrease over one-year time. There was no significant difference in change of depressive symptoms in 7th Graders (-17.0%) compared to 9th Graders (-5.3%, $p = .083$). In addition, there was no significant difference in change of depressive symptoms between boys (-8.1%) and girls (-14.1%, $p = .580$).

Self-esteem increased by 2.9% (0.64 ± 4.32), however not statistically significant (paired *t* test, $p = .066$). SEM analyses showed that the change in self-esteem was significantly associated with baseline levels of self-esteem ($\beta = -.48$, $p < .001$). The higher the baseline levels of self-esteem, the smaller the increase after one-year. In addition, change in self-esteem was significantly more positive in 7th Graders (+4.9%) than in 9th Graders (-0.6%, $p = .016$). There was no significant difference in change in self-esteem between boys (+3.0%) and girls (+2.8%, $p = .052$).

Change in Physical Activity Associated With Change in Mental Health Over One-year Time

SEM analyses revealed that change in physical activity did not seem to predict change in depressive symptoms and self-esteem (Figure 7.1). Control variable academic year was found to be significantly associated with change in physical activity and self-esteem (see results above). Cardiovascular fitness appeared to be positively related to physical activity at baseline, but not with the change in physical activity. Other control variables (sex, nationality, socioeconomic status, baseline levels of body mass index, change in body mass index, and change in cardiovascular fitness) were omitted from the analyses because they had no effect on any of the variables of interest.

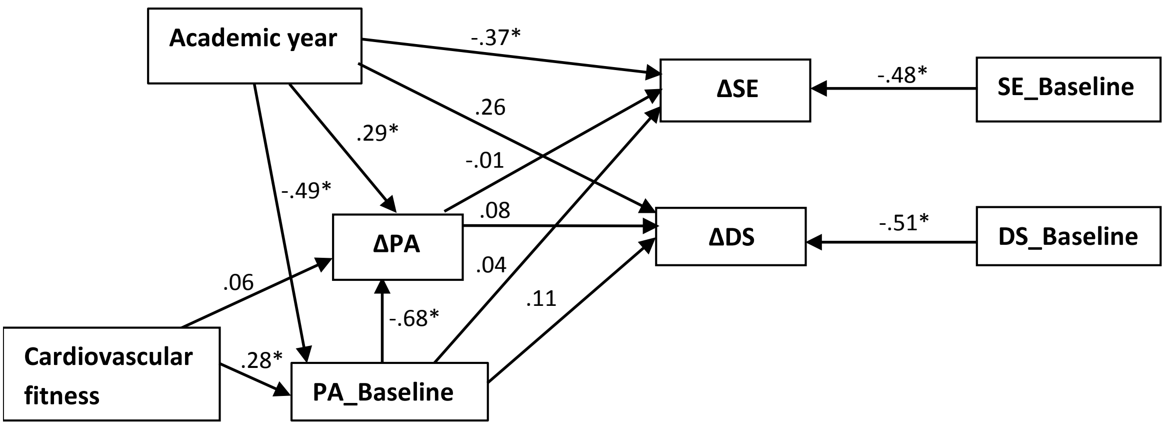

Figure 7.1 *Schematic overview (standardized coefficients) of structural equation modelling for change in objectively measured physical activity (ΔPA) associated with change in self-esteem (ΔSE) and depressive symptoms (ΔDS). Only most important paths are presented for readability. SE_Baseline = baseline levels of self-esteem. DS_Baseline = baseline levels of depressive symptoms. PA_Baseline = baseline levels of physical activity measured objectively by accelerometer. *indicates statistical significance at p < .05.*

Discussion

The main goal of this study was to investigate the associations between changes in habitual physical activity levels and changes in mental health in adolescents. The results indicate no significant overall associations; the decline in physical activity over one-year time is not associated with a change in depressive symptoms or self-esteem in adolescents. In addition, the results make clear that adolescents' habitual physical activity levels decline sharply and that depressive symptoms decrease during the course of a year. Also, changes in depressive symptoms and self-esteem were mainly predicted by baseline levels of depressive symptoms and self-esteem respectively. These results together mean that changes in adolescents' mental health over one-year are mainly explained by other variables than the decline in physical activity, in particular baseline levels of mental health.

Decline in Physical Activity

In the research reported here, habitual physical activity levels of adolescents decline sharply over one-year. This is in line with previous studies of Ruiz et al. (2011) and Van Mechelen et al. (2000), who reported declines in physical activity levels in European and Dutch adolescents respectively. In addition to those studies, our results show that habitual physical activity levels decrease in particular in students in grade 7, the first year of secondary school in the Netherlands. In addition, physical activity decreases more sharply in active students than in inactive students. This sedentary trend should be prevented, because habitual physical activity levels developed during adolescence are maintained in the transition to adulthood (Hallal, Victora, Azevedo, & Wells, 2006). In addition, a physically inactive lifestyle during adolescence has been associated with developing chronic diseases such as cardiovascular diseases and type 2 diabetes later in life (Caspersen, Pereira, & Curran, 2000; Ortega et al., 2013).

Change in Mental Health

Mental health improved over one-year time; self-reported feelings of depressive symptoms decreased significantly and self-esteem improved almost significantly. Our results are in contrast with the majority of literature reporting increases in depressive symptoms during adolescence (Kaplan, Hong, & Weinhold, 1984; Rushton, Forcier, & Schectman, 2002; Saluja et al., 2004). Academic year might have played an important role in the contradiction between our results and those of above-mentioned studies. Our results show that mental health improved mainly in students progressing from grade 7 to grade 8 (see Table 7.1). In the Netherlands, grade 7 is the first year of secondary school, thus students in grade 7 moved from the seemingly familiar and safe environment of the primary school, to the unfamiliar and strange surroundings of the secondary school. In addition, they found themselves repositioned as the youngest in the school and met new teachers and new peers from different social and cultural backgrounds (Pratt & George, 2006). Previous research showed that school transition may negatively impact self-esteem and depressive symptoms (West, Sweeting, & Young, 2010), therefore the transition from primary school to secondary school might have resulted in relatively high levels of depressive symptoms and low levels of self-esteem in grade 7. When these students progressed to grade 8, they became more familiar with the school, the teachers and their peers, resulting in improved mental health.

Another explanation for the improvement in mental health observed in our study sample of adolescents is that participants with mental health problems were more likely to drop out after baseline data collection than those without mental health problems (Frojd, Kaltiala-Heino, & Marttunen, 2011). However, additional analyses of The GOALS Study data showed no significant difference in baseline levels of depressive symptoms and self-esteem between students included in current analyses and those excluded from current analyses. Nevertheless, it is still possible that the students who developed a depression between baseline and follow-up are missing at the follow-up measurement. In additional analyses, adolescents were classified as moderately/severely depressed by a total depressive symptoms severity score ≥24 according to the stratification in adolescents of Rushton, Forcier and Schectman (2002). Chi-square analyses showed that participants with moderately/severely levels of depressive symptoms at baseline (N = 39, 9.0% of the total study sample) did not drop-out more frequently at follow-up (N = 25, 8.5%).

Most studies in adolescents show no change in adolescents' self-esteem over time (Brack, Orr, & Ingersoll, 1988; Chubb, Fertman, & Ross, 1997; Savin-Williams & Demo, 1984). However, other studies reported increases in self-esteem during adolescence (Bachman & O'Malley, 1977; McCarthy & Hoge, 1982), in line with our results. An explanation for the improvement in self-esteem might be that youth with low self-esteem at baseline gain peer approval and avoid rejection by conforming to peer norms and yielding to peer pressure. This might have increase their positive sense of themselves because they feel validated by their peers (Zimmerman, Copeland, Shope, & Dielman, 1997).

Decline in Physical Activity Associated With Change in Mental Health

No significant association was found between the decline in physical activity during adolescence and change in mental health. Our results, in line with findings of Clark et al. (2006), Rothon et al. (2010) and Lindwall et al. (2014), add to these studies by using an objective instrument to determine physical activity. Clark et al. (2006) reported that, in 11 to 14 years old adolescents, baseline levels of physical activity were not significantly associated with depressive symptoms two years later. Clark et al. suggested that the relatively short follow-up period of the study might be due to the lack of a significant association, because the pathways between physical activity and mental health may occur later in adolescence or take longer to develop. Our SEM analyses showed also that baseline levels of physical activity did not significantly predict mental health at follow-up (results not published), which might also be due to the relatively short one-year follow-up period. Future studies should make use of longer (≥ two years) follow-up periods and measurements at multiple time intervals. Rothon et al. (2010) found no significant association between change in physical activity and change in depressive symptoms in adolescents progressing from grade 7 to grade 9. Rothon et al. suggested that their self-reported data may partly account for the lack of a significant association between change in physical activity and change in depressive symptoms. Although we used accelerometers to objectively measure physical activity, our results are in accordance with Rothon et al. In our study, it is thus confirmed that no association consists between a change in physical activity and a change in mental health and that this lack of significance cannot be attributed to subjective measurement. Lindwall et al. (2014) reported that change in physical activity over three years was not significantly associated with change in global self-esteem in 14 and 15 years old girls. Lindwall et al. suggested that physical activity is closer linked to the physical self-esteem in comparison to global self-esteem, which is situated further away from specific behaviour such as physical activity. This suggestion might also explain the lack of a significant association between decline in physical activity and change in self-esteem in our study. Future studies might use measures of both global self-esteem and more specific physical self-esteem to get more insight into the association between change in physical activity and change in self-esteem.

In our study, the total amount of accelerometer steps per week was used as measure of physical activity. This measure gives a reasonable approximation of the total physical activity volume per week (Tudor-Locke et al., 2011), but is no measure of how much time participants spend in (team) sports. Participation in sport and exercise groups might also provide social interaction and promote social support (Sagatun, Sogaard, Bjertness, Selmer, & Heyerdahl, 2007), resulting in improved mental health (Eime, Young, Harvey, Charity, & Payne, 2013). This might explain the difference between our results (i.e., no significant association between baseline levels of physical activity and change in mental health over one-year time, see Figure 7.1) and the results of Wiles et al. (2008), who found that participation in sporting activities (including football and tennis) predicted fewer emotional problems one-year later. It might be possible that a combination of physical activity and social interactions and social support during (team) sports, compared to physical activity only, has more beneficial effects on adolescents' mental health.

Sex-differences might have impact on the associations between physical activity and mental health. For example, Tiggemann and Williamson (2000) found significant, negative relationships between the total amount of physical activity and body satisfaction and self-esteem for young women (mean age 18 years), and positive relationships for young men (mean age 18 years). An explanation for these results is that women exercise more for reasons of weight control, tone, and mood enhancement than men, reasons associated with lower body satisfaction (Tiggemann & Williamson, 2000). Though, SEM analyses showed no significant effects of sex on the associations between change in physical activity and change in mental health in our study sample (results not published).

Physical activity leads to an increase in the availability of brain neurotransmitters such as serotonin and dopamine, which are diminished with depression (Craft & Perna, 2004). Therefore, it might be possible that physical activity benefits in particular those who experience elevated levels of depressive symptoms, particularly the more severely depressed individuals (Craft & Landers, 1998). A total of 16 adolescents (10.1%) was, based on a cut-off score of ≥24 (Rushton et al., 2002), classified as moderately/severely depressed at baseline. Of those, 5 increased their physical activity levels between baseline and follow-up and 4 of them (80.0%) were at follow-up not classified as moderately/severely depressed. In addition, in the 11 moderately/severely depressed adolescents at baseline who decreased their physical activity levels between baseline and follow-up, only 3 (27.2%) were not moderately/severely depressed at follow-up. Therefore, it might be possible that physical activity is particularly beneficial for moderately/severely depressed adolescents. However, additional analyses showed no significant difference between students who increased or decreased their physical activity on change in depression (i.e., moderately/severely depressed or non-depressed) from baseline to follow-up. This non-significant result might be due to the small study sample (N=16) of moderately/severely depressed adolescents. In addition, our research design limits the possibility to draw causal relations, it might also have been the case that those who did not feel depressed anymore at follow-up increased their physical activity levels.

A total score of self-reported self-esteem was calculated, while it might be possible that physical activity benefits in particular those who experience low levels of self-esteem (Barnett, Smoll, & Smith, 1992). There are no absolute cut-off points to determine what constitutes high or low self-esteem (Marsh & Peart, 1988), therefore the 50% cut-off point was used in additional analyses according to studies in adolescents of Boyd and Hrycaiko (1997) and Button, Sonuga-Barke, Davies, and Thompson (1996). A total of 22 adolescents (13.9%) had low levels of self-esteem based on a cut-off score of ≤15. Of those, 9 increased their physical activity levels between baseline and follow-up and 5 of them (55.6%) had no longer low levels of self-esteem at follow-up. In addition, in the 13 adolescents with low levels of self-esteem at baseline who decreased their physical activity levels between baseline and follow-up, 6 (46.1%) had no longer low levels of self-esteem at follow-up. Additional analyses showed no significant difference in students who increased or decreased their physical activity between baseline and follow-up on change in self-esteem (i.e., low versus high levels of self-esteem).

Two methodological limitations might impact the results of our study, resulting in less explained variance and consequently non-significant associations between change in physical activity and change in mental health. First, there is uncertainty about the exact time of changed physical activity habits. Physical activity levels were measured during a normal school week, which gives a good representation of the adolescents' habitual physical activity levels. However, the exact moment that the participants changed their physical activity habits is unknown. Consequently, the time that changed physical activity habits possibly affected mental health is not controlled for, while this period can vary between some days up to one full year. Some beneficial effects of physical activity on mental health act immediately, such as the release of β-endorphins, serotonin or dopamine (Craft & Perna, 2004). Other beneficial effects on mental health may act only when people are physically active for long periods. For example, improvements in perceptions of competence or confidence about the body may be increased through regular physical activity during a long period and this may generalize to mental health (Fox, 1999).

A second methodological limitation, which might have impacted our results, is that both the independent and dependent variables regressed towards the mean. Physical activity levels declined sharper in active students at baseline than in inactive students at baseline, depressive symptoms declined sharper in students with high levels of depressive symptoms at baseline than in non-depressed students at baseline and self-esteem improved less in students with high levels of self-esteem at baseline than in students with low levels of self-esteem at baseline. Regression towards the mean is an important limitation and might be the reason that no significant results have been found in the association between change in physical activity and change in mental health.

In conclusion, the results of our study reveal no significant association between the decline in physical activity during adolescence and change in mental health. Our study adds to a limited number of studies in this field, which reported no significant or in most cases weak associations. Therefore, in our opinion, the relationship between change in physical activity and change in mental health in adolescents is weak at most.

Strengths

The major strength of this study was that physical activity was measured objectively at baseline and follow-up, which has not been the case in previous observational studies in the field of physical activity and mental health in adolescents (Clark et al., 2006; Lindwall et al., 2014; Motl et al., 2004; Neissaar & Raudsepp, 2011; Rothon et al., 2010; Schmalz et al., 2007; Stavrakakis et al., 2012; Tremblay et al., 2000; Wiles et al., 2008). Second, the entire study sample at baseline (N = 440) differed not significantly from our study sample included in current study (N = 158) on physical activity, depressive symptoms, and self-esteem. Therefore, the adolescents included in this study are most likely representative for the association between change in physical activity and change in mental health in our entire study sample of Dutch adolescents. Third, only complete cases with full data of physical activity and mental health at both time intervals were used for analyses. Fourth, results were controlled for several potential confounders.

Limitations

The results of this study have to be interpreted with caution due to some limitations. First, the results cannot be generalised to the whole Dutch adolescent population, because we used only one secondary school. Second, mental health was measured by self-report instead of clinically diagnosed. Third, our longitudinal design is sensitive for regression towards the mean and selection bias. Fourth, the moment that our participants changed their physical activity habits is unknown, thus the students might have been more or less active at follow-up for only a couple of days up to one full-year. This might be a crucial factor in the association between change in physical activity and change in mental health.

Conclusions

Our study in Dutch adolescents shows no significant association between the decline in physical activity over one-year time and change in mental health. We observed that changes in mental health were mainly affected by baseline levels of mental health and also academic year seemed to be an important predictor. Future studies in adolescents should make use of rigorous designs to investigate whether a change in physical activity is associated with a change in mental health. We suggest to make use of longer follow-up periods (i.e., ≥2 years), measurements at multiple time intervals, large study samples and control for academic year differences and transitions from primary school to secondary school.

CHAPTER 8

General Discussion

The main aim of this dissertation was to gain insight into possible associations between objectively measured physical activity (PA), cognitive performance, and academic achievement in adolescents. In addition, associations between active commuting to schools, cognitive performance and academic achievement were investigated, as well as associations between PA and mental health and PA and school absenteeism due to illness. The studies described in this dissertation are part of The GOALS (Grootschalig Onderzoek naar Activiteiten van Limburgse Scholieren [Large-scale Research of Activities in Dutch Students]) Study. This observational longitudinal study in 440 students (mean age 13.8 years, 47% female) was conducted at a secondary school in the Netherlands. Habitual PA levels were measured objectively by an accelerometer attached to the thigh during one full week (24 hours/day). The total PA volume per week was calculated by summing the total number of accelerometer steps. Moderate-to-vigorous intensity PA (MVPA) was determined by the total number of accelerometer steps with a cadence ≥100 steps/minute. Cognitive performance was assessed by the d2 Test of attention (measure of response inhibition, a key component of executive functioning) and the Symbol Digit Modalities Test (measure of information-processing speed, a general cognitive ability). Academic achievement was measured by the means of the school grades for Dutch, English and mathematics throughout the entire academic year. All procedures at baseline (including first and third year students) were also executed at one-year follow-up (students progressed to second and fourth year respectively) using the same protocols.

Main Findings and Conclusions

PA and cognitive performance. The main findings of GOALS show that habitual PA levels in adolescents are positively associated with executive functioning. PA is not significantly associated with information-processing speed, a general cognitive ability (Prins et al., 2005). These results concur with an increasing body of literature suggesting that gains in children's cognitive functioning due to PA are most clearly observed in tasks that involve executive functioning (Guiney & Machado, 2013). Interestingly, active commuting to school is in girls also positively associated with executive functioning, while there is no significant association with information-processing speed. There is also a positive, but not significant, association between change in habitual PA levels and change in executive functioning and information-processing speed. These non-significant results might be due to the relatively short follow-up period of one year, it is possible that these results reach significance over a longer period of time.

PA and academic achievement overall. The main findings of GOALS show no significant linear association between habitual PA levels and academic achievement. This is in contrast with the majority of studies in adolescents reporting positive associations between PA and academic achievement (Coe, Pivarnik, Womack, Reeves, & Malina, 2006; Correa-Burrows, Burrows, Orellana, & Ivanovic, 2014; Fox, Barr-Anderson, Neumark-Sztainer, & Wall, 2010; Kantomaa et al., 2013; Kristjansson, Sigfusdottir, & Allegrante, 2010; Sigfusdottir, Kristjansson, & Allegrante, 2007; So, 2012). In all these studies, PA was subjectively measured by questionnaires and in more than half of the studies academic achievement was also measured subjectively (Fox et al., 2010; Kristjansson et al., 2010; Sigfusdottir et al., 2007; So, 2012). Interestingly, studies carried out using an objective instrument to measure PA associated with academic achievement have reported no significant association or mixed results (Booth, Tomporowski, et al., 2013; Kwak et al., 2009; Syväoja et al., 2014). Methodological limitations might have biased the results of studies using questionnaires to measure PA and academic achievement. For example, measuring PA by questionnaires has been found to have several limitations, such as social desirability (Adams et al., 2005) and overestimation of time spent in MVPA (Chinapaw, Slootmaker, Schuit, Van Zuidam, & Van Mechelen, 2009). It might be possible that some students report higher PA levels and higher school grades than they actually have, resulting in positive associations between PA and academic achievement in most of these studies in adolescents. Studies using an objective instrument to measure PA associated with academic achievement (such as the study in GOALS) are probably more reliable, because these results (no significant association between PA and academic achievement in adolescents) could not have been biased by social desirability and overestimation of time spent in PA.

Results of GOALS show an inverted U-shaped association between MVPA and academic achievement, which indicates that there is a positive association between MVPA and academic achievement up to some optimal level, but too much time spent on MVPA might decrease academic achievement. Very active students might have spent a large amount of time in MVPA, such as physical sport activities, to the detriment of time spent to do their homework, which could result in lower academic achievement (Rees & Sabia, 2010). This might also explain whether an indirect association was found between PA and academic achievement by executive functioning, but no direct association. The mediating role of executive functioning in the association between PA and academic achievement might be offset by time spent devoted to homework; active students might have spent time in physical activities to the detriment of time devoted to homework.

Finally, results of GOALS indicate that the more inactive students become over one-year time, the better their academic achievement. This complex association is impacted by changes in educational level and possibly confounded by time devoted to homework. Students might have spent less time on PA in favour of time spent devoted to homework and test preparation which might have a positive impact on academic achievement.

PA and academic achievement divided by academic year. Results of GOALS show a negative association between PA and academic achievement (mean of the school grades in Dutch, English and mathematics) in first year students and a positive association between PA and mathematics performance in third year students. These results indicate that academic year impacts the association between PA and academic achievement and that PA could have the greatest benefits in the academic domain of mathematics, which is strongly correlated with executive functioning (Bull & Scerif, 2001). The above-described mixed results between PA and academic achievement are in line with previous studies in adolescents using objective measures of PA. These studies reported a positive association in girls, but not in boys (Kwak et al., 2009), no significant association (Syväoja et al., 2013), and a negative association for total PA volume, but a positive association for MVPA as percentage of total PA volume (Booth, Leary, et al., 2013). Interestingly, positive associations between PA and academic achievement have been found on the ages of 14 years (results GOALS), and 16 years (Kwak et al., 2009), while in 12 year old adolescents no association (Syväoja et al., 2013) and a negative association (results GOALS) have been found. The transition from primary school to secondary school (in the Netherlands around the age of 12 years) might be due to this interaction effect of age in the association between PA and academic achievement. It might be that a number of children are not academically prepared for the next school level (Anderson, Jacobs, Schramm, & Splittgerber, 2000) and thus experience some decline in academic achievement after the transition from primary school to secondary school (Blyth, Simmons, & Carlton-Ford, 1983). It might be possible that the most active students in the first year of secondary school experience greatest difficulty because they are not used to combine their active lifestyle with the increased amount of homework at secondary school. This might explain the negative association between PA and academic achievement in first year students (mean age ± 12 years). In addition, the most active third year students (mean age ± 14 years) are familiar with the increased amount of homework and are therefore able to combine an active lifestyle with academic pursuits, resulting in a positive association between PA and academic achievement in this age group. This could be a plausible explanation, however it has to be taken with caution because the results in GOALS show no significant association between PA and time devoted to homework. In conclusion, the association between PA and academic achievement in adolescents is complex. This association might be impacted by academic year, PA volume and intensity, school grade and potential confounders such as time devoted to homework and the transition from primary school to secondary school.

PA and mental health. Results of GOALS indicate a positive association between PA and mental health (i.e., higher levels of self-esteem and lower levels of depressive symptoms), however when controlled for covariates (e.g., sex, academic year, and socioeconomic status), the associations are not significant. It is concluded that the association between PA and mental health tend to be positive, but the effect is small, in line with many studies in this field (Biddle & Asare, 2011). Less is known about the association between a change in PA during adolescence and a change in mental health. Results of GOALS indicate no significant association, while previous studies using subjective instruments to measure PA reported predominantly positive, but weak, associations. Taken together, the association between PA and mental health is weak at most and appears to be complex; genetic factors, socioeconomic status, and other lifestyle habits interact and jointly affect mental health (Stavrakakis et al., 2013).

PA and school absenteeism. Results of GOALS show that PA is not directly associated with school absenteeism due to illness, though PA is indirectly associated with school absenteeism by cardiovascular fitness. The positive mediating role of cardiovascular fitness in the association between PA and school absenteeism might be offset by other factors. An explanation might be that long periods of intensive PA, such as training and competing in physically demanding sports, may result in chronic fatigue and injuries (Brenner, 2007, Taylor & Attia, 2000), and consequently more absence days. However, no statistical evidence was found for an inverted U-shaped association between PA and school absenteeism, therefore this explanation has to be taken with caution. More research is necessary to confirm the results, because this was the first study investigating the association between PA and school absenteeism in adolescents.

Implications

PA should be maintained during the first years of secondary school and stimulated on weekend days. Findings of GOALS show that PA is, alternating strong and weak, generally positively associated with executive functioning and several health outcomes (e.g., higher levels of cardiovascular fitness and mental health, and a lower body mass index). Unfortunately, findings of GOALS show that adolescents' habitual PA levels decrease sharply, in particular during transition from the first to the second year (-20%). This has undesirable consequences; first year students engage in the recommended PA guideline of at least 60 minutes of MVPA per day (Janssen & Leblanc, 2010), based on a cut-off score of 10,000 accelerometer steps/day (Tudor-Locke et al., 2011). When these students reach the second year, they no longer engage in the recommended 60 minutes of MVPA per day and neither students in the third and fourth year engage in the recommended 60 minutes of MVPA per day. These undesirable lifestyle habits should be prevented, because habitual PA levels developed during adolescence are maintained in the transition to adulthood (Kall, Nilsson, & Linden, 2014). In addition, a physically inactive lifestyle during adolescence has been associated with developing chronic diseases such as cardiovascular diseases and type 2 diabetes later in life (Caspersen, Pereira, & Curran, 2000; Ortega et al., 2013). Findings of GOALS also indicate that adolescents engage in the recommended level of at least 60 minutes of MVPA per day on weekdays, but not on weekend days. In particular, adolescents are inactive on Sunday, their PA levels are 40% lower than on weekdays. Adolescents spend on weekdays a large part of their exercise time in active commuting to school, an activity missing on weekend days and accounting for a large part of the difference in PA levels between weekdays and Sunday. Taken together, PA intervention programs in adolescents should preferably focus on maintaining habitual PA levels during the first years of secondary school and stimulating PA on weekend days, in particular on Sunday.

Secondary schools should stimulate PA. Adolescents spend a large part of their time at school and the largest part of their school time is sedentary (i.e., sitting at a table). Therefore, schools can help to prevent the decreasing habitual PA levels during the adolescent period. Schools can simultaneously benefit from stimulating PA, because high levels of habitual PA generate several structural changes in the brain, such as neurogenesis and angiogenesis (Thomas, Dennis, Bandettini, & Johansen-Berg, 2012), which may increase cognitive performance and academic achievement (Etnier, Nowell, Landers, & Sibley, 2006; Voss, Nagamatsu, Liu-Ambrose, & Kramer, 2011). Schools can stimulate PA by adding extra physical education classes to the curriculum. Extra physical education classes directly increase children's habitual PA volume and may simultaneously increase enjoyment of PA and perceived physical competence, resulting in increased out-of-class PA and a sustained physically active lifestyle (Wallhead & Buckworth, 2004). In cases where extra physical education classes are difficult to implement in the school curriculum, for example because of a lack of time or gymnasiums, schools can also stimulate PA in a less radical way. For example, the 'lost time' during pauses or lesson-free hours can be used to implement short exercise sessions.

Active commuting to school should be stimulated. The trend of declining rates of walking or bicycling to school in the past decennia (Bassett, John, Conger, Fitzhugh, & Coe, 2014; Davison, Werder, & Lawson, 2008) should be turned around. Findings of GOALS show that active commuting to school is an important source of daily PA (28% of the total PA volume per week) and positively associated with executive functioning in girls. In addition, for the entire study sample, all the associations between active commuting to school and cognitive performance and academic achievement tend to be positive, however not statistically significant. These results have to be confirmed by experimental studies to draw causal relations. In the absence of such studies, the results serve to strengthen the benefits of active commuting to school on cognitive functioning and academic achievement in adolescents. Furthermore, active commuting to school has been associated with increased cardiovascular fitness (Cooper et al., 2008) and decreased overweight (Bere, Seiler, Eikemo, Oenema, & Brug, 2011). Therefore, parents should promote active commuting to school, for example by providing good and safe bikes, instead of driving their children to school by car, which is the case in about 33% of parents of children in Dutch primary schools (Knowledge Centre Traffic and Transport, 2014) and an extra 3-5% of the parents when it is raining (Knowledge Centre Traffic and Transport, 2013). Also, schools and local communities can promote active commuting to school, for example by creating bike facilities at schools and providing safe traffic environments around schools respectively.

Limitations

The studies in this dissertation have some methodological limitations.

Study sample. The study sample of GOALS was small compared to previous studies in adolescents investigating associations between objectively measured PA and cognition (Booth, Tomporowski, et al., 2013; Pindus et al., 2014) or academic achievement (Booth, Leary, et al., 2013). On the other hand, GOALS estimated habitual PA levels using at least four complete days (24 hours of accelerometer wear time) including both weekend days.

Booth et al. and Pindus et al. did not make a distinction between weekdays and weekend days and used 10 hour wear time per day as inclusion criteria.

Generalisability. Results cannot be directly generalised to the whole Dutch population because only one secondary school was used. Though, 83.7% of the invited students participated in GOALS and this sample was equally divided by sex and the mean body mass index was similar to the overall Dutch population. Nevertheless, more schools in different cities and multiple countries should be investigated to increase the generalisability to the Dutch, European and worldwide population.

Measure of executive functioning. Only one of the three core components of executive functioning was investigated. The d2 Test of attention was used to measure response inhibition (i.e., being able to suppress an internal predisposition), a key component of executive functioning (Alvarez & Emory, 2006), and more broadly selective attention and concentration (Budde, Voelcker-Rehage, Pietrabyk-Kendziorra, Ribeiro, & Tidow, 2008). Mental set shifting, and information updating and monitoring are in general also described as core components of executive functioning (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). The d2 Test of attention test was chosen, because inhibitory processes reflect the maturation of the prefrontal cortex (Bjorklund & Harnishfeger, 1990) and thus inhibition is an adequate measure of the effects of PA on (frontal) brain functioning. A limitation is that the positive associations between both PA and active commuting to school and executive functioning reported in the studies are specific for response inhibition. Whether PA and active commuting to school are positively associated with overall executive functioning in the GOALS study sample of Dutch adolescents is unknown.

Measure of academic achievement. Results show a reasonably clear positive association between PA and executive functioning, while the association between PA and academic achievement is unclear. The association between PA and academic achievement might be more difficult to investigate compared to the association between PA and executive functioning due to two methodological issues. First, executive functioning was measured by a well-validated task using standard protocols in a classroom. Academic achievement was measured by the mean of the school grades for Dutch, English, and mathematics throughout the entire academic year, which also depends on factors not controlled for, such as teacher perception, quality of academic teaching (Seyfried, 1998), peer relationships (Wentzel & Caldwell, 1997), and time devoted to homework (Cooper, Robinson, & Patall, 2006). Second, executive functioning was measured in the same week as the habitual PA levels were measured. Although habitual PA levels were measured during a normal school week, due to unforeseen circumstances it might be possible that this week was not representative for the PA levels throughout the entire academic year. Therefore, the association between PA and academic achievement is sensitive for large changes in habitual PA levels during the academic year, while this could not have been the case for the association between PA and executive functioning (measured both in the same school week).

Suggestions for Future Research

Based upon the results and limitations of the studies in GOALS, as well as the literature described in the introduction, a number of suggestions will be given for further research.

Independent and combined effect of PA and sports (team) participation. The studies in GOALS focused on the total PA volume per week. No distinction was made in social interaction (i.e., alone or together with peers) or content (i.e., competition versus recreational). For example, sports (team) participation may increase students' motivation, self-discipline (Rees & Sabia, 2010) and social norms among team/class mates (Fox, Barr-Anderson, Neumark-Sztainer, & Wall, 2010) resulting in improved academic achievement. Future studies might investigate whether a combination of PA and sports (team) participation might have more beneficial effects on cognitive performance and academic achievement compared to PA only.

Adolescents with concentration problems. Only healthy adolescents were included in GOALS; adolescents with either health or concentration problems were excluded from analyses. Future studies might focus particularly on adolescents with concentration problems, such as attention-deficit/hyperactivity disorder (ADHD). There might be similar or even greater beneficial effects of PA on executive functioning, as well as academic achievement, general cognitive abilities, social behaviour and mental health (Verret, Guay, Berthiaume, Gardiner, & Béliveau, 2012) in children and adolescents with ADHD or other concentration problems, however very little is known about this issue (Ziereis & Jansen, 2015).

The nature and begin of the decline in PA. The results show a 20% reduction in PA during the transition from the first to the second year of secondary school. To prevent this sedentary development, future studies should investigate the nature of this decline in PA. For example, it might be possible that those who are member of a sports club quit their membership and spent more time playing video games or that in this 'transition' year from childhood to adolescence, street play (i.e., a physically active activity) is seen as childish and is avoided. In addition, further studies may investigate whether the decline in habitual PA levels begins already at primary school.

Effects of an acute bout of exercise on learning and school exams. The majority of studies, including the studies of GOALS, have focused on cognitive performance. No study examined the actual process of learning (Hillman, 2014), for example remembering of studied words from other languages. In addition, nearly all studies investigating the association between PA and academic achievement used the school grades on several school subjects during a long period (mainly an entire academic year) as measure of academic achievement. No study investigated the effects of an acute bout of exercise on real school exams. Further studies may investigate whether an acute bout of exercise immediately improves the process of learning or the performance on a real school exam, which might result in practical relevant knowledge for schools and students.

Experimental studies. No causal relation can be drawn about the results of GOALS, experimental studies are needed to investigate the effects of PA on executive functioning and potentially academic achievement and general cognitive abilities in adolescents. Thus far, experimental studies in adolescents, which added extra physical education classes to the school curriculum, reported mixed results (Ardoy et al., 2014; Coe, Pivarnik, Womack, Reeves, & Malina, 2006; Dwyer, Coonan, Leitch, Hetzel, & Baghurst, 1983). A limitation of these studies was that none objectively measured much PA the extra physical education classes actually added to the daily PA volume of the participants. This is an important limitation, because a systematic review of Metcalf, Henley and Wilkin (2012) showed that PA interventions have had only a small effect (i.e., four minutes more walking or running per day) on children's daily activity levels. Children might compensate the extra physical education classes during the rest of the day with extra sedentary activities (Van Sluijs, McMinn, & Griffin, 2007). Therefore, future experimental studies should investigate objectively how much time the extra physical education classes actually add to the daily PA volume of the participants. A practical limitation of such an experimental design might be that extra physical education classes are difficult to implement in the school curriculum, for example because of a lack of time, money, gym teachers and gymnasiums. Alternatively, PA can be stimulated by facilitating active commuting to school and introducing short sessions of exercise during pauses or in lesson-free hours. These short (10 to 20 minutes) sessions of exercise may also immediately increase several cognitive functions and academic achievement (Budde et al., 2008; Etnier et al., 2014; Hillman et al., 2009; Janssen et al. 2014). In addition, adding coordinative exercises (e.g., bouncing two balls simultaneously with both hands) and exercises characterised by high cognitive and social interaction demands (e.g., team games/sports) might result in greater improvements in cognitive performance and academic achievement (Budde et al. 2008, Pesce et al. 2009), however the evidence is still inconclusive and also conflicting results have been shown (Gallotta et al. 2014).

Take Home Messages

- Active adolescents perform better on attentional tasks, though they achieve no higher school grades
- Adolescent girls who walk or bike to school perform better at school
- Physical activity is in adolescents positively associated with several health outcomes, but not with school absenteeism due to illness
- Adolescents are too inactive on weekend days, in particular on Sunday
- Adolescents' habitual PA levels decrease sharply during the first years of secondary school

REFERENCES

Adams, S. A., Matthews, C. E., Ebbeling, C. B., Moore, C. G., Cunningham, J. E., Fulton, J., & Hebert, J. R. (2005). The effect of social desirability and social approval on self-reports of physical activity. *American Journal of Epidemiology, 161*, 389-398.

Ainsworth, B. E., Haskell, W. L., Whitt, M. C., Irwin, M. L., Swartz, A. M., Strath, S. J., . . . Leon, A. S. (2000). Compendium of physical activities: an update of activity codes and MET intensities. *Medicine and Science in Sports and Exercise, 32*(9 Suppl), S498-504.

Alvarez, J. A., & Emory, E. (2006). Executive function and the frontal lobes: a meta-analytic review. *Neuropsychology Review 16*, 17-42.

Anderson, L. W., Jacobs, J., Schramm, S., & Splittgerber, F. (2000). School transitions: beginning of the end or a new beginning? *International Journal of Educational Research 33*, 325-339.

Ardoy, D. N., Fernandez-Rodriguez, J. M., Jimenez-Pavon, D., Castillo, R., Ruiz, J. R., & Ortega, F. B. (2014). A physical education trial improves adolescents' cognitive performance and academic achievement: the EDUFIT study. *Scandinavian Journal of Medicine and Science in Sports, 24*, e52-61.

Bachman, J. G., & O'Malley, P. M. (1977). Self-esteem in young men: a longitudinal analysis of the impact of educational and occupational attainment. *Journal of Personality and Social Psychology, 35*, 365-380.

Barnett, N. P., Smoll, F. L., & Smith, R. E. (1992). Effects of enhancing coach-athlete relationships on youth sport attrition. *Sport Psychologist, 6*, 111-127.

Bassett, D. R., John, D., Conger, S. A., Fitzhugh, E. C., & Coe, D. P. (2014). Trends in physical activity and sedentary behaviors of U.S. youth. *Journal of Physical Activity and Health*. (ePub).

Bassett, D. R., Jr., Cureton, A. L., & Ainsworth, B. E. (2000). Measurement of daily walking distance-questionnaire versus pedometer. *Medicine and Science in Sports and Exercise, 32*, 1018-1023.

Bates, M. E., & Lemay, E. P., Jr. (2004). The d2 Test of attention: construct validity and extensions in scoring techniques. *Journal of the International Neuropsychology Society, 10*, 392-400.

Bere, E., Seiler, S., Eikemo, T. A., Oenema, A., & Brug, J. (2011). The association between cycling to school and being overweight in Rotterdam and Kristiansand. *Scandinavian Journal of Medicine and Science in Sports, 21*, 48-53.

Berendsen, B. A., Hendriks, M. R., Meijer, K., Plasqui, G., Schaper, N. C., & Savelberg, H. H. (2014). Which activity monitor to use? Validity, reproducibility and user friendliness of three activity monitors. *BMC Public Health, 14*, 749.

Berg, I. (1992). Absence from school and mental health. *The British Journal of Psychiatry, 161*, 154-166.

Best, J. R., Miller, P. H., & Naglieri, J. A. (2011). Relations between executive function and academic achievement from ages 5 to 17 in a Large, representative national sample. *Learning and Individual Differences, 21*, 327-336.

Biddle, S. J., & Asare, M. (2011). Physical activity and mental health in children and adolescents: a review of reviews. *British Journal of Sports Medicine, 45*, 886-895.

Bjorklund, D. F., & Harnishfeger, K. K. (1990). The resources construct in cognitive development: Diverse sources of evidence and a theory of inefficient inhibition. *Developmental Review, 10*, 48-71.

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). *Taxonomy of educational objectives: The classification of educational goals. Handbook I: Cognitive Domain. David McKay Company, Inc. New York.*

Blyth, D. A., Simmons, R. G., & Carlton-Ford, S. (1983). The adjustment of early adolescents to school transition. *Journal of Early Adolescence, 3*, 105-120.

Booth, J. N., Leary, S. D., Joinson, C., Ness, A. R., Tomporowski, P. D., Boyle, J. M., & Reilly, J. J. (2013). Associations between objectively measured physical activity and academic attainment in adolescents from a UK cohort. *British Journal of Sports Medicine, 48*, 265-270.

Booth, J. N., Tomporowski, P. D., Boyle, J. M., Ness, A. R., Joinson, C., Leary, S. D., & Reilly, J. J. (2013). Associations between executive attention and objectively measured physical activity in adolescence: Findings from ALSPAC, a UK cohort. *Mental Health and Physical Activity, 6*, 212 - 219.

Borrestad, L. A., Ostergaard, L., Andersen, L. B., & Bere, E. (2013). Associations between active commuting to school and objectively measured physical activity. *Journal of Physical Activity and Health, 10*, 826-832.

Boyd, K. R., & Hrycaiko, D. W. (1997). The effect of a physical activity intervention package on the self-esteem of pre-adolescent and adolescent females. *Adolescence, 32*, 693-708.

Brack, C. J., Orr, D. P., & Ingersoll, G. (1988). Pubertal maturation and adolescent self-esteem. *Journal of Adolescent Health Care, 9*, 280-285.

Brenner, J. S. (2007). Overuse injuries, overtraining, and burnout in child and adolescent athletes. *Pediatrics, 119*, 1242-1245. doi: 10.1542/peds.2007-0887

Brickenkamp, R., & Zillmer, E. (1998). The d2 Test of Attention. Seattle, Washington: Hogrefe & Huber Publishers.

Brisswalter, J., Collardeau, M., & Rene, A. (2002). Effects of acute physical exercise characteristics on cognitive performance. *Sports Medicine, 32*, 555-566.

Brooks-Gunn, J., Warren, M. P., Rosso, J., & Gargiulo, J. (1987). Validity of self-report measures of girls' pubertal status. *Child Development, 58*, 829-841.

Budde, H., Voelcker-Rehage, C., Pietrabyk-Kendziorra, S., Ribeiro, P., & Tidow, G. (2008). Acute coordinative exercise improves attentional performance in adolescents. *Neuroscience Letters, 441*, 219-223.

Bull, R., & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: inhibition, switching, and working memory. *Developmental Neuropsychology, 19*, 273-293.

Button, E. J., Sonuga-Barke, E. J., Davies, J., & Thompson, M. (1996). A prospective study of self-esteem in the prediction of eating problems in adolescent schoolgirls: questionnaire findings. *The British Journal of Clinical Psychology, 35*, 193-203.

Calfas, K. J., & Taylor, W. C. (1994). Effects of physical activity on psychological variables in adolescents. *Pediatric Exercise Science, 6*, 406 -423.

Caspersen, C. J., Pereira, M. A., & Curran, K. M. (2000). Changes in physical activity patterns in the United States, by sex and cross-sectional age. *Medicine and Science in Sports and Exercise, 32*, 1601-1609.

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Reports, 100*, 126-131.

Castelli, D. M., Hillman, C. H., Buck, S. M., & Erwin, H. E. (2007). Physical fitness and academic achievement in third- and fifth-grade students. *Journal of Sport and Exercise Psychology, 29*, 239-252.

Chaddock-Heyman, L., Hillman, C. H., Cohen, N. J., & Kramer, A. F. (2014). The importance of physical activity and aerobic fitness for cognitive control and memory in children. *Monographs of the Society for Research in Child Development, 79*, 25-50.

Chillon, P., Ortega, F. B., Ruiz, J. R., De Bourdeaudhuij, I., Martinez-Gomez, D., Vicente-Rodriguez, G., . . . Sjostrom, M. (2011). Active commuting and physical activity in adolescents from Europe: results from the HELENA study. *Pediatric Exercise Science, 23*, 207-217.

Chillon, P., Ortega, F. B., Ruiz, J. R., Veidebaum, T., Oja, L., Maestu, J., & Sjostrom, M. (2010). Active commuting to school in children and adolescents: an opportunity to increase physical activity and fitness. *Scandinavian Journal of Public Health, 38*, 873-879.

Chinapaw, M. J., Slootmaker, S. M., Schuit, A. J., Van Zuidam, M., & Van Mechelen, W. (2009). Reliability and validity of the Activity Questionnaire for Adults and Adolescents (AQuAA). *BMC Medical Research Methodology, 9*, 58-65.

Chodzko-Zajko, W. J., Schuler, P., Solomon, J., Heinl, B., & Ellis, N. R. (1992). The influence of physical fitness on automatic and effortful memory changes in aging. *International Journal of Aging and Human Development, 35*, 265-285.

Chubb, N. H., Fertman, C. I., & Ross, J. L. (1997). Adolescent self-esteem and locus of control: a longitudinal study of gender and age differences. *Adolescence, 32*, 113-129.

Clark, C., Haines, M. M., Head, J., Klineberg, E., Arephin, M., Viner, R., . . . Stansfeld, S. A. (2006). Psychological symptoms and physical health and health behaviours in adolescents: a prospective 2-year study in East London. *Addiction, 102*, 126-135.

Coe, D. P., Pivarnik, J. M., Womack, C. J., Reeves, M. J., & Malina, R. M. (2006). Effect of physical education and activity levels on academic achievement in children. *Medicine and Science in Sports and Exercise, 38*, 1515-1519.

Colcombe, S. J., & Kramer, A. F. (2003). Fitness effects on the cognitive function of older adults: a meta-analytic study. *Psychological Science, 14*, 125-130.

Comte, M., Hobin, E., Majumdar, S. R., Plotnikoff, R. C., Ball, G. D., & McGavock, J. (2013). Patterns of weekday and weekend physical activity in youth in 2 Canadian provinces. *Applied Physiology, Nutrition, and Metabolism, 38*, 115-119.

Cooper, A. R., Wedderkopp, N., Jago, R., Kristensen, P. L., Moller, N. C., Froberg, K., . . . Andersen, L. B. (2008). Longitudinal associations of cycling to school with adolescent fitness. *Preventive Medicine, 47*, 324-328.

Cooper, H., Robinson, J. C., & Patall, E. A. (2006). Does homework improve academic achievement? A synthesis of research, 1987–2003. *Review of Educational Research, 76*, 1-62.

Corder, K., Van Sluijs, E. M., McMinn, A. M., Ekelund, U., Cassidy, A., & Griffin, S. J. (2010). Perception versus reality awareness of physical activity levels of British children. *American Journal of Preventive Medicine, 38*, 1-8.

Correa-Burrows, P., Burrows, R., Orellana, Y., & Ivanovic, D. (2014). Achievement in mathematics and language is linked to regular physical activity: a population study in Chilean youth. *Journal of Sports Sciences, 32*, 1631-1638.

Cotman, C. W., & Berchtold, N. C. (2002). Exercise: a behavioral intervention to enhance brain health and plasticity. *Trends in Neurosciences, 25*, 295-301.

Cotman, C. W., Berchtold, N. C., & Christie, L. A. (2007). Exercise builds brain health: key roles of growth factor cascades and inflammation. *Trends in Neurosciences, 30*, 464-472.

Craft, L. L., & Landers, D. M. (1998). The effect of exercise on clinical depression and depression resulting from mental illness: A meta-analysis. *Journal of Sport and Exercise Psychology, 20*, 339-357.

Craft, L. L., & Perna, F. M. (2004). The benefits of exercise for the clinically depressed. *Primary Care Companion to the Journal of Clinical Psychiatry, 6*, 104-111.

Crone, E. A., & Dahl, R. E. (2012). Understanding adolescence as a period of social-affective engagement and goal flexibility. *Nature Reviews Neuroscience, 13*, 636-650.

Dahlgren, G., Carlsson, D., Moorhead, A., Hager-Ross, C., & McDonough, S. M. (2010). Test-retest reliability of step counts with the ActivPAL (TM) device in common daily activities. *Gait and Posture, 32*, 386-390.

Daley, A. J., & Ryan, J. (2000). Academic performance and participation in physical activity by secondary school adolescents. *Perceptual and Motor Skills, 91*, 531-534.

Dall, P. M., McCrorie, P. R., Granat, M. H., & Stansfield, B. W. (2013). Step accumulation per minute epoch is not the same as cadence for free-Living adults. *Medicine and Science in Sports and Exercise, 45*, 1995-2001.

Davis, C. L., Tomporowski, P. D., Boyle, C. A., Waller, J. L., Miller, P. H., Naglieri, J. A., & Gregoski, M. (2007). Effects of aerobic exercise on overweight children's cognitive functioning: a randomized controlled trial. *Research Quarterly for Exercise and Sport, 78*, 510-519.

Davis, C. L., Tomporowski, P. D., McDowell, J. E., Austin, B. P., Miller, P. H., Yanasak, N. E., . Naglieri, J. A. (2011). Exercise improves executive function and achievement and alters brain activation in overweight children: a randomized, controlled trial. *Health Psychology, 30*, 91-98.

Davison, K. K., Werder, J. L., & Lawson, C. T. (2008). Children's active commuting to school: current knowledge and future directions. *Preventing Chronic Disease, 5*, A100.

De Groot, R. H., Van Dijk, M. L., & Kirschner, P. A. (2015). Cohort profile of the GOALS study: A large-scale research of physical activity in Dutch students. British Journal of Educational Technology. (Published online ahead of print).

De Vriendt, T., Clays, E., Maes, L., De Bourdeaudhuij, I., Vicente-Rodriguez, G., Moreno, L. A.,…Group, H. S. (2012). European adolescents' level of perceived stress and its relationship with body adiposity - The HELENA Study. *European Journal of Public Health, 22*, 519-524.

Dencker, M., & Andersen, L. B. (2011). Accelerometer-measured daily physical activity related to aerobic fitness in children and adolescents. *Journal of Sports Sciences, 29*, 887-895.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*, 135-168.

Dik, M. G., Deeg, D. J., Visser, M., & Jonker, C. (2003). Early life physical activity and cognition at old age. *Journal of Clinical and Experimental Neuropsychology, 25*, 643-653.

Donahoo, W. T., Levine, J. A., & Melanson, E. L. (2004). Variability in energy expenditure and its components. *Current Opinion in Clinical Nutrition and Metabolic Care, 7*, 599-605.

Dowd, K. P., Harrington, D. M., & Donnelly, A. E. (2012). Criterion and concurrent validity of the activPAL professional physical activity monitor in adolescent females. *PloS One, 7*, e47633.

Duncan, G. E., Sydeman, S. J., Perri, M. G., Limacher, M. C., & Martin, A. D. (2001). Can sedentary adults accurately recall the intensity of their physical activity? *Preventive Medicine, 33*, 18-26.

Dunn, M. C., Kadane, J. B., & Garrow, J. R. (2003). Comparing harm done by mobility and class absence: Missing students and missing data. *Journal of Educational and Behavioral Statistics, 28*, 269-288.

Dutch Ministry of Public Health, Welfare and Sport. (2011). Nationale atlas volksgezondheid. Sociaaleconomische status Nederlandse beroepsbevolking. Available from: http://www.zorgatlas.nl/beinvloedende-factoren/sociale-omgeving/ses. Accessed April 10, 2013.

Duvivier, B. M., Schaper, N. C., Bremers, M. A., Van Crombrugge, G., Menheere, P. P., Kars, M., & Savelberg, H. H. (2013). Minimal intensity physical activity (standing and walking) of longer duration improves insulin action and plasma lipids more than shorter periods of moderate to vigorous exercise (cycling) in sedentary subjects when energy expenditure is comparable. *PloS One, 8*, e55542.

Dwyer, T., Coonan, W. E., Leitch, D. R., Hetzel, B. S., & Baghurst, R. A. (1983). An investigation of the effects of daily physical activity on the health of primary school students in South Australia. *International Journal of Epidemiology, 12*, 308-313.

Egger, H. L., Costello, E. J., & Angold, A. (2003). School refusal and psychiatric disorders: a community study. *Journal of the American Academy of Child and Adolescent Psychiatry, 42*, 797-807.

Eime, R. M., Young, J. A., Harvey, J. T., Charity, M. J., & Payne, W. R. (2013). A systematic review of the psychological and social benefits of participation in sport for children and adolescents: informing development of a conceptual model of health through sport. *The International Journal of Behavioral Nutrition and Physical Activity, 10*, 98.

Ekeland, E., Heian, F., & Hagen, K. B. (2005). Can exercise improve self esteem in children and young people? A systematic review of randomised controlled trials. *British Journal of Sports Medicine, 39*, 792-798; discussion 792-798.

Ekeland, E., Heian, F., Hagen, K. B., Abbott, J., & Nordheim, L. (2004). Exercise to improve self-esteem in children and young people. *Cochrane Database of Systematic Reviews,* CD003683.

Ekelund, U., Ward, H. A., Norat, T., Luan, J., May, A. M., Weiderpass, E., . . . Riboli, E. (2015). Physical activity and all-cause mortality across levels of overall and abdominal adiposity in European men and women: the European Prospective Investigation into Cancer and Nutrition Study (EPIC). *The American Journal of Clinical Nutrition, 101*, 613-621.

Ernst, C., Olson, A. K., Pinel, J. P., Lam, R. W., & Christie, B. R. (2006). Antidepressant effects of exercise: evidence for an adult-neurogenesis hypothesis? *Journal of Psychiatry and Neuroscience, 31*, 84-92.

Esteban-Cornejo, I., Gomez-Martinez, S., Tejero-Gonzalez, C. M., Castillo, R., Lanza-Saiz, R., Vicente-Rodriguez, G., ..Martinez-Gomez, D. (2014). Characteristics of extracurricular physical activity and cognitive performance in adolescents. The AVENA study. *Journal of Sports Sciences, 32*, 1596-1603.

Esteban-Cornejo, I., Tejero-Gonzalez, C. M., Sallis, J. F., & Veiga, O. L. (2014). Physical activity and cognition in adolescents: A systematic review. *Journal of Science and Medicine in Sport,* S1440.

Etnier, J., Labban, J. D., Piepmeier, A., Davis, M. E., & Henning, D. A. (2014). Effects of an acute bout of exercise on memory in 6th grade children. *Pediatric Exercise Science, 26*, 250-258.

Etnier, J. L., & Chang, Y. K. (2009). The effect of physical activity on executive function: a brief commentary on definitions, measurement issues, and the current state of the literature. *Journal of Sport and Exercise Psychology, 31*, 469-483.

Etnier, J. L., Nowell, P. M., Landers, D. M., & Sibley, B. A. (2006). A meta-regression to examine the relationship between aerobic fitness and cognitive performance. *Brain Research Reviews, 52*, 119-130.

Fedewa, A. L., & Ahn, S. (2011). The effects of physical activity and physical fitness on children's achievement and cognitive outcomes: a meta-analysis. *Research Quarterly for Exercise and Sport, 82*, 521-535.

Finn, J. D. (1989). Withdrawing from school. *Review of Educational Research, 59*, 117-142.

Forrest, C. B., Bevans, K. B., Riley, A. W., Crespo, R., & Louis, T. A. (2013). Health and school outcomes during children's transition into adolescence. *The Journal of Adolescent Health, 52*, 186-194.

Forwood, M. R., & Burr, D. B. (1993). Physical activity and bone mass: exercises in futility? *Bone and Mineral, 21*, 89-112.

Fox, C. K., Barr-Anderson, D., Neumark-Sztainer, D., & Wall, M. (2010). Physical activity and sports team participation: associations with academic outcomes in middle school and high school students. *Journal of School Health, 80*, 31-37.

Fox, K. R. (1999). The influence of physical activity on mental well-being. *Public Health Nutrition, 2*, 411-418.

Frojd, S. A., Kaltiala-Heino, R., & Marttunen, M. J. (2011). Does problem behaviour affect attrition from a cohort study on adolescent mental health? *European Journal of Public Health, 21*, 306-310.

Frojd, S. A., Nissinen, E. S., Pelkonen, M. U., Marttunen, M. J., Koivisto, A. M., & Kaltiala-Heino, R. (2008). Depression and school performance in middle adolescent boys and girls. *Journal of Adolescence, 31*, 485-498.

Frystyk, J. (2010). Exercise and the growth hormone-insulin-like growth factor axis. *Medicine and Science in Sports and Exercise, 42*, 58-66.

Gale, C. R., Cooper, R., Craig, L., Elliott, J., Kuh, D., Richards, M., . . . Deary, I. J. (2012). Cognitive function in childhood and lifetime cognitive change in relation to mental wellbeing in four cohorts of older people. *PloS One, 7*, e44860.

Gallotta, M. C., Emerenziani, G. P., Franciosi, E., Meucci, M., Guidetti, L., & Baldari, C. (2014). Acute physical activity and delayed attention in primary school students. *Scandinavian Journal of Medicine and Science in Sports*. (ePub).

Garcia-Segura, L. M., Cardona-Gomez, G. P., Chowen, J. A., & Azcoitia, I. (2000). Insulin-like growth factor-I receptors and estrogen receptors interact in the promotion of neuronal survival and neuroprotection. *Journal of Neurocytology, 29*, 425-437.

Guiney, H., & Machado, L. (2013). Benefits of regular aerobic exercise for executive functioning in healthy populations. *Psychonomic Bulletin and Review, 20*, 73-86.

Hagborg, W. J. (1993). The Rosenberg Self-Esteem Scale and Harter's Self-Perception profile for adolescents: a concurrent validity study. *Psychology in the Schools, 30*, 132-136.

Hallal, P. C., Victora, C. G., Azevedo, M. R., & Wells, J. C. (2006). Adolescent physical activity and health: a systematic review. *Sports Medicine, 36*, 1019-1030.

Hartlage, S., Alloy, L. B., Vazquez, C., & Dykman, B. (1993). Automatic and effortful processing in depression. *Psychological Bulletin, 113*, 247-278.

Haugland, S., Wold, B., & Torsheim, T. (2003). Relieving the pressure? The role of physical activity in the relationship between school-related stress and adolescent health complaints. *Research Quarterly for Exercise and Sport, 74*, 127-135.

Hillman, C. H. (2014). Viii. Conclusions and future directions of the research on physical activity and childhood cognitive and brain health. *Monographs of the Society for Research in Child Development, 79*, 149-152.

Hillman, C. H., Erickson, K. I., & Kramer, A. F. (2008). Be smart, exercise your heart: exercise effects on brain and cognition. *Nature Reviews, 9*, 58-65.

Hillman, C. H., Kamijo, K., & Scudder, M. (2011). A review of chronic and acute physical activity participation on neuroelectric measures of brain health and cognition during childhood. *Preventive Medicine, 52,* S21-28.

Hillman, C. H., Pontifex, M. B., Castelli, D. M., Khan, N. A., Raine, L. B., Scudder, M. R., . . . Kamijo, K. (2014). Effects of the FITKids Randomized Controlled Trial on Executive Control and Brain Function. *Pediatrics, 134*, e1063-1071.

Hillman, C. H., Pontifex, M. B., Raine, L. B., Castelli, D. M., Hall, E. E., & Kramer, A. F. (2009). The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. *Neuroscience, 159*, 1044-1054.

Hinton-Bayre, A., & Geffen, G. (2005). Comparability, reliability, and practice effects on alternate forms of the Digit Symbol Substitution and Symbol Digit Modalities tests. *Psychological Assessment, 17*, 237-241.

Howie, E. K., & Pate, R. R. (2012). Physical activity and academic achievement in children: A historical perspective. *Journal of Sport and Health Science, 1*, 160-169.

Ickovics, J. R., Carroll-Scott, A., Peters, S. M., Schwartz, M., Gilstad-Hayden, K., & McCaslin, C. (2014). Health and academic achievement: cumulative effects of health assets on standardized test scores among urban youth in the United States. *The Journal of School Health, 84*, 40-48.

Jaakkola, T., Hillman, C., Kalaja, S., & Liukkonen, J. (2015). The associations among fundamental movement skills, self-reported physical activity and academic performance during junior high school in Finland. *Journal of Sports Sciences*, 1-11.

Jackson, S. A., & Marsh, H. W. (1986). Atheletic or antisocial? The female sport experience. *Journal of Sport Psychology, 8*, 198-211.

Jacobson, B. H., & Aldana, S. G. (2001). Relationship between frequency of aerobic activity and illness-related absenteeism in a large employee sample. *Journal of Occupational and Environmental Medicine, 43*, 1019-1025.

Jago, R., Anderson, C. B., Baranowski, T., & Watson, K. (2005). Adolescent patterns of physical activity differences by gender, day, and time of day. *American Journal of Preventive Medicine, 28*, 447-452.

Janssen, I., & Leblanc, A. G. (2010). Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *International Journal of Behavioral Nutrition and Physical Activity, 7*, 40.

Janssen, M. A., Chinapaw, M. J. M., Rauh, S. P., Toussaint, H. M., Van Mechelen, W., & Verhagen, E. A. L. M. (2014). A short physical activity break from cognitive tasks increases selective attention in primary school children aged 10-11. *Mental Health and Physical Activity, 7*, 129-134.

Jones, R., Hoare, P., Elton, R., Dunhill, Z., & Sharpe, M. (2009). Frequent medical absences in secondary school students: survey and case-control study. *Archives of Disease in Childhood, 94*, 763-767.

Jurado, M. B., & Rosselli, M. (2007). The elusive nature of executive functions: a review of our current understanding. *Neuropsychology Review, 17*, 213-233.

Kall, L. B., Nilsson, M., & Linden, T. (2014). The impact of a physical activity intervention program on academic achievement in a Swedish elementary school setting. *The Journal of School Health, 84*, 473-480.

Kantomaa, M. T., Stamatakis, E., Kankaanpää, A., Kaakinen, M., Rodriguez, A., Taanila, A., . . . Tammelin, T. (2013). Physical activity and obesity mediate the association between childhood motor function and adolescents' academic achievement. *Proceedings of the National Academy of Sciences of the United States of America, 110*, 1917-1922.

Kaplan, G. A., & Keil, J. E. (1993). Socioeconomic factors and cardiovascular disease: a review of the literature. *Circulation, 88*, 1973-1998.

Kaplan, S. L., Hong, G. K., & Weinhold, C. (1984). Epidemiology of depressive symptomatology in adolescents. *Journal of the American Academy of Child Psychiatry, 23*, 91-98.

Kavanagh, J. J., & Menz, H. B. (2008). Accelerometry: a technique for quantifying movement patterns during walking. *Gait and Posture, 28*, 1-15.

Kearney, C. A. (2008). School absenteeism and school refusal behavior in youth: a contemporary review. *Clinical Psychology Review, 28*, 451-471.

Kesse-Guyot, E., Charreire, H., Andreeva, V. A., Touvier, M., Hercberg, S., Galan, P., & Oppert, J. M. (2012). Cross-sectional and longitudinal associations of different sedentary behaviors with cognitive performance in older adults. *PloS One, 7*, e47831.

Kieling, C., Baker-Henningham, H., Belfer, M., Conti, G., Ertem, I., Omigbodun, O., . . . Rahman, A. (2011). Child and adolescent mental health worldwide: evidence for action. *The Lancet, 378*, 1515-1525.

Kimm, S. Y., Glynn, N. W., Kriska, A. M., Barton, B. A., Kronsberg, S. S., Daniels, S. R., . . . Liu, K. (2002). Decline in physical activity in black girls and white girls during adolescence. *The New England Journal of Medicine, 347*, 709-715.

Kirk-Sanchez, N. J., & McGough, E. L. (2014). Physical exercise and cognitive performance in the elderly: current perspectives. *Clinical Interventions in Aging, 9*, 51-62.

Knowledge Centre Traffic and Transport. (2013). Schoolmobiliteit [school mobility]. Available from: http://kpvvdashboard-15.blogspot.nl/2012/12/meer-over-modal-split.html*.* Accessed on May 12, 2015.

Knowledge Centre Traffic and Transport. (2014). 1 op 3 basisschoolkinderen met de auto gebracht [1 in 3 primary school children driven to school by car]. Available from: *http://kpvvdashboard-15.blogspot.nl/.* Accessed on April 15, 2015.

Kogan, S. M., Luo, Z., Brody, G. H., & Murry, V. M. (2005). The influence of high school dropout on substance use among African American youth. *Journal of Ethnicity in Substance Abuse, 4*, 35-51.

Kohl, H. W., 3rd, Craig, C. L., Lambert, E. V., Inoue, S., Alkandari, J. R., Leetongin, G., & Kahlmeier, S. (2012). The pandemic of physical inactivity: global action for public health. *The Lancet, 380*, 294-305.

Kovacs, M., & Goldston, D. (1991). Cognitive and social cognitive development of depressed children and adolescents. *Journal of the American Academy of Child and Adolescent Psychiatry, 30*, 388-392.

Kramer, A. F., Erickson, K. I., & Colcombe, S. J. (2006). Exercise, cognition, and the aging brain. *Journal of Applied Physiology, 101*, 1237-1242.

Kristjansson, A. L., Sigfusdottir, I. D., & Allegrante, J. P. (2010). Health behavior and academic achievement among adolescents: the relative contribution of dietary habits, physical activity, body mass index, and self-esteem. *Health Education and Behavior, 37*, 51-64.

Kuczmarski, R. J., Ogden, C. L., Grummer-Strawn, L. M., Flegal, K. M., Guo, S. S., Wei, R., . . . Johnson, C. L. (2000). CDC growth charts: United States. *Advance Data, 314*, 1-27.

Kwak, L., Kremers, S. P., Bergman, P., Ruiz, J. R., Rizzo, N. S., & Sjostrom, M. (2009). Associations between physical activity, fitness, and academic achievement. *The Journal of Pediatrics, 155*, 914-918.

Leckie, R. L., Oberlin, L. E., Voss, M. W., Prakash, R. S., Szabo-Reed, A., Chaddock-Heyman, L., . . . Erickson, K. I. (2014). BDNF mediates improvements in executive function following a 1-year exercise intervention. *Frontiers in Human Neuroscience, 8*, 985.

Lee, I. M., Shiroma, E. J., Lobelo, F., Puska, P., Blair, S. N., & Katzmarzyk, P. T. (2012). Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *The Lancet, 380*, 219-229.

Leger, L. A., Mercier, D., Gadoury, C., & Lambert, J. (1988). The multistage 20 metre shuttle run test for aerobic fitness. *Journal of Sports Sciences, 6*, 93-101.

Lendt, M., Gleissner, U., Helmstaedter, C., Sassen, R., Clusmann, H., & Elger, C. E. (2002). Neuropsychological outcome in children after frontal lobe epilepsy surgery. *Epilepsy and Behaviour, 3*, 51-59.

Lindwall, M., Asci, H., & Crocker, P. (2014). The physical self in motion: within-person change and associations of change in self-esteem, physical self-concept, and physical activity in adolescent girls. *Journal of Sport and Exercise Psychology, 36*, 551-563.

Maddocks, M., Petrou, A., Skipper, L., & Wilcock, A. (2010). Validity of three accelerometers during treadmill walking and motor vehicle travel. *British Journal of Sports Medicine, 44*, 606-608.

Marais, L., Stein, D. J., & Daniels, W. M. (2009). Exercise increases BDNF levels in the striatum and decreases depressive-like behavior in chronically stressed rats. *Metabolic Brain Disease, 24*, 587-597.

Marsh, H. W., & Peart, N. D. (1988). Competitive and cooperative physical fitness training programs for girls: Effects on physical fitness and multidimensional self-concepts. *Journal of Sport and Exercise Psychology, 10*, 390-406.

Martinez-Gomez, D., Ruiz, J. R., Gomez-Martinez, S., Chillon, P., Rey-Lopez, J. P., Diaz, L. E., . . . Marcos, A. (2011). Active Commuting to School and Cognitive Performance in Adolescents: The AVENA Study. *Archives of Pediatrics and Adolescent Medicine, 165*, 300-305.

Matsuzaka, A., Takahashi, Y., Yamasoe, M., Kumakura, M., Ikeda, A., & Wilk, B. (2004). Validity of the multistage 20-m shuttle-run test for Japanese children, adolescents, and adults. *Pediatric Exercise Science, 16*, 113-125.

McCarthy, J. D., & Hoge, D. R. (1982). Analysis of age effects in longitudinal studies of adolescent self-esteem. *Developmental Psychology, 19*, 372-379.

McCrorie, P. R., Duncan, E., Granat, M. H., & Stansfield, B. W. (2012). The prevalence of upright non-stepping time in comparison to stepping time in 11-13 year old school children across seasons. *Physiological Measurement, 33*, 1901-1912.

Metcalf, B., Henley, W., & Wilkin, T. (2012). Effectiveness of intervention on physical activity of children: systematic review and meta-analysis of controlled trials with objectively measured outcomes. *British Medical Journal, 345*, e5888.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howerter, A. (2000). The unity and diversity of executive functions and their contributions to complex ‘‘frontal lobe’’ tasks: A latent variable analysis. *Cognitive Psychology 41*, 49–100.

Monteggia, L. M., Luikart, B., Barrot, M., Theobold, D., Malkovska, I., Nef, S., . . . Nestler, E. J. (2007). Brain-derived neurotrophic factor conditional knockouts show gender differences in depression-related behaviors. *Biological Psychiatry, 61*, 187-197.

Motl, R. W., Birnbaum, A. S., Kubik, M. Y., & Dishman, R. K. (2004). Naturally occurring changes in physical activity are inversely related to depressive symptoms during early adolescence. *Psychosomatic Medicine, 66*, 336-342.

Neissaar, I., & Raudsepp, L. (2011). Changes in physical activity, self-efficacy and depressive symptoms in adolescent girls. *Pediatric Exercise Science, 23*, 331-343.

O'Malley, P. M., & Bachman, J. G. (1979). Self-esteem and education: Sex and cohort comparisons among high school seniors. *Journal of Personality and Social Psychology, 37,* 1153-1159.

Ortega, F. B., Artero, E. G., Ruiz, J. R., Espana-Romero, V., Jimenez-Pavon, D., Vicente-Rodriguez, G., . . . Castillo, M. J. (2011). Physical fitness levels among European adolescents: the HELENA study. *British Journal of Sports Medicine, 45*, 20-29.

Ortega, F. B., Konstabel, K., Pasquali, E., Ruiz, J. R., Hurtig-Wennlof, A., Maestu, J., . . . Sjostrom, M. (2013). Objectively measured physical activity and sedentary time during childhood, adolescence and young adulthood: a cohort study. *PloS One, 8*, e60871.

Ortega, F. B., Ruiz, J. R., Castillo, M. J., & Sjostrom, M. (2008). Physical fitness in childhood and adolescence: a powerful marker of health. *International Journal of Obesity, 32*, 1-11.

Ottevaere, C., Huybrechts, I., De Bourdeaudhuij, I., Sjostrom, M., Ruiz, J. R., Ortega, F. B.,.. De Henauw, S. (2011). Comparison of the IPAQ-A and Actigraph in relation to VO2max among European adolescents: The HELENA study. *Journal of Science and Medicine in Sport, 14*, 317-324.

Padilla, C., Perez, L., & Andres, P. (2014). Chronic exercise keeps working memory and inhibitory capacities fit. *Frontiers in Behavioral Neuroscience, 8*, 49.

Paluska, S. A., & Schwenk, T. L. (2000). Physical activity and mental health: current concepts. *Sports Medicine, 29*, 167-180.

Pate, R. R., Mitchell, J. A., Byun, W., & Dowda, M. (2011). Sedentary behaviour in youth. *British Journal of Sports Medicine, 45*, 906-913.

Penedo, F. J., & Dahn, J. R. (2005). Exercise and well-being: a review of mental and physical health benefits associated with physical activity. *Current Opinion in Psychiatry, 18*, 189-193.

Pesce, Crova, Cereatti, Casella, & Bellucci. (2009). Physical activity and mental performance in preadolescents: Effects of acute exercise on free-recall memory. *Mental Health and Physical Activity, 2*, 16-22.

Petersen, A. C., Crockett, L., Richards, M., & Boxer, A. (1988). A self-report measure of pubertal status: Reliability, validity, and initial norms. *Journal of Youth and Adolescence, 17*, 117-132.

Pindus, D. M., Davis, R. D., Hillman, C. H., Bandelow, S., Hogervorst, E., Biddle, S. J., & Sherar, L. B. (2014). The relationship of moderate-to-vigorous physical activity to cognitive processing in adolescents: findings from the ALSPAC birth cohort. *Psychological Research*. (ePub).

Plasqui, G., & Westerterp, K. R. (2007). Physical activity assessment with accelerometers: an evaluation against doubly labeled water. *Obesity, 15*, 2371-2379.

Ploughman, M. (2008). Exercise is brain food: The effects of physical activity on cognitive function. *Developmental Neurorehabilitation, 11*, 236-240.

Pratt, S., & George, R. (2006). Transferring friendship: girls' and boys' friendships in the transition from primary to secondary school. *Children and Society, 19*, 16-26.

Preacher, K. J., & Hayes, A. F. (2004). SPSS and SAS procedures for estimating indirect effects in simple mediation models. *Behavior Research Methods, Instruments, and Computers, 36*, 717-731.

Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods, 40*, 879-891.

Prins, N. D., Van Dijk, E. J., Den Heijer, T., Vermeer, S. E., Jolles, J., Koudstaal, P. J., . . . Breteler, M. M. (2005). Cerebral small-vessel disease and decline in information processing speed, executive function and memory. *Brain, 128*, 2034-2041.

Radloff, L. S. (1977). The CES-D Scale: A self-report depression scale for research in the general population. *Applied Psychological Measurement, 1*, 385-401.

R Core Team 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Avaiable from: *http://www.R-project.org.* Accessed March 5, 2013.

Rees, D. I., & Sabia, J. J. (2010). Sports participation and academic performance: Evidence from the National Longitudinal Study of Adolescent Health. *Economics of Education Review, 29*, 751–759.

Reid, K. (2005). The causes, views and traits of school absenteeism and truancy. *Research in Education, 79*, 59-82.

Romeo, R. D., & McEwen, B. S. (2006). Stress and the adolescent brain. *Annals of the New York Academy of Sciences, 1094*, 202-214.

Rosenberg, M. (1965). *Society and the Adolescent Self-Image*: Princeton University Press, Princeton, New Jersey.

Rosenberg, M. (1979). *Conceiving the self*. New York: Basic Books.

Rosseel, Y. (2012). lavaan: An R Package for Structural Equation Modeling. *Journal of Statistical Software, 48*, 1-36.

Rothon, C., Edwards, P., Bhui, K., Viner, R. M., Taylor, S., & Stansfeld, S. A. (2010). Physical activity and depressive symptoms in adolescents: a prospective study. *BMC Medicine, 8*, 32.

Ruiz, J. R., Ortega, F. B., Castillo, R., Martin-Matillas, M., Kwak, L., Vicente-Rodriguez, G., . . . Moreno, L. A. (2010). Physical activity, fitness, weight status, and cognitive performance in adolescents. *The Journal of Pediatrics, 157*, 917-922.

Ruiz, J. R., Ortega, F. B., Martinez-Gomez, D., Labayen, I., Moreno, L. A., De Bourdeaudhuij, I.,..Sjostrom, M. (2011). Objectively measured physical activity and sedentary time in European adolescents: the HELENA study. *American Journal of Epidemiology, 174*, 173-184.

Rushton, J. L., Forcier, M., & Schectman, R. M. (2002). Epidemiology of depressive symptoms in the National Longitudinal Study of Adolescent Health. *Journal of the American Academy of Child and Adolescent Psychiatry, 41*, 199-205.

Ryan, C. G., Grant, P. M., Tigbe, W. W., & Granat, M. H. (2006). The validity and reliability of a novel activity monitor as a measure of walking. *British Journal of Sports Medicine, 40*, 779-784.

Sagatun, A., Sogaard, A. J., Bjertness, E., Selmer, R., & Heyerdahl, S. (2007). The association between weekly hours of physical activity and mental health: a three-year follow-up study of 15-16-year-old students in the city of Oslo, Norway. *BMC Public Health, 7*, 155.

Sallis, J. F., Prochaska, J. J., & Taylor, W. C. (2000). A review of correlates of physical activity of children and adolescents. *Medicine and Science in Sports and Exercise, 32*, 963-975.

Sallis, J. F. (2000). Age-related decline in physical activity: a synthesis of human and animal studies. *Medicine and Science in Sports and Exercise, 32*, 1598-1600.

Saluja, G., Iachan, R., Scheidt, P. C., Overpeck, M. D., Sun, W., & Giedd, J. N. (2004). Prevalence of and risk factors for depressive symptoms among young adolescents. *Archives of Pediatrics and Adolescent Medicine, 158*, 760-765.

Santos, R., Mota, J., Okely, A. D., Pratt, M., Moreira, C., Coelho, E. S. M. J.,..Sardinha, L. B. (2013). The independent associations of sedentary behaviour and physical activity on cardiorespiratory fitness. *British Journal of Sports Medicine*. (ePub).

Savin-Williams, R. C., & Demo, D. H. (1984). Developmental change and stability in adolescent selfconcept. *Developmental Psychology, 20*, 1100-1110.

Schmalz, D. L., Deane, G. D., Birch, L. L., & Krahnstoever Davison, L. (2007). A longitudinal assessment of the links between physical activity and self-esteem in early adolescent non-Hispanic females. *Journal of Adolescence Health, 41*, 559-565.

Seyfried, S. F. (1998). Academic achievement of African American preadolescents: the influence of teacher perceptions. *American Journal of Community Psychology, 26*, 381-402.

Shaffer, D., Gould, M. S., Fisher, P., Trautman, P., Moreau, D., Kleinman, M., & Flory, M. (1996). Psychiatric diagnosis in child and adolescent suicide. *Archives of General Psychiatry, 53*, 339-348.

Shephard, R. J. (2003). Limits to the measurement of habitual physical activity by questionnaires. *British Journal of Sports Medicine, 37*, 197-206.

Shephard, R. J., Lavallee, H., Volle, M., LaBarre, R., & Beaucage, C. (1994). Academic skills and required physical education: The Trois Rivieres experience. *CAHPER Research Supplement, 1*, 1-12.

Shore, S. M., Sachs, M. L., Lidicker, J. R., Brett, S. N., Wright, A. R., & Libonati, J. R. (2008). Decreased scholastic achievement in overweight middle school students. *Obesity, 16*, 1535-1538.

Sibley, B. A., & Etnier, J. L. (2003). The relationship between physical activity and cognition in children: A meta-analysis. *Pediatric Exercise Science, 15*, 243-256.

Sigfusdottir, I. D., Kristjansson, A. L., & Allegrante, J. P. (2007). Health behaviour and academic achievement in Icelandic school children. *Health Education Research, 22*, 70-80.

Singh, A., Uijtdewilligen, L., Twisk, J. W., Van Mechelen, W., & Chinapaw, M. J. (2012). Physical activity and performance at school: a systematic review of the literature including a methodological quality assessment. *Archives of Pediatrics and Adolescent Medicine, 166*, 49-55.

Sirard, J. R., & Slater, M. E. (2009). Compliance with wearing physical activity accelerometers in high school students. *Journal of Physical Activity and Health, 6*, S148-155.

Smith, A. (2010). Symbol Digit Modalities Test. Amsterdam: Hogrefe.

Snoek, H. M., Van Strien, T., Janssens, J. M., & Engels, R. C. (2007). Emotional, external, restrained eating and overweight in Dutch adolescents. *Scandinavian Journal of Psychology, 48*, 23-32.

So, W. (2012). Association between physical activity and academic performance in Korean adolescent students. *BMC Public Health, 12*, 258-264.

Stavrakakis, N., de Jonge, P., Ormel, J., & Oldehinkel, A. J. (2012). Bidirectional prospective associations between physical activity and depressive symptoms. The TRAILS Study. *The Journal of Adolescent Health, 50*, 503-508.

Stavrakakis, N., Roest, A. M., Verhulst, F., Ormel, J., de Jonge, P., & Oldehinkel, A. J. (2013). Physical activity and onset of depression in adolescents: a prospective study in the general population cohort TRAILS. *Journal of Psychiatric Research, 47*, 1304-1308.

Steeves, J. A., Bowles, H. R., McClain, J. J., Dodd, K. W., Brychta, R. J., Wang, J., & Chen, K. Y. (2014). Ability of thigh-worn Actigraph and ActivPAL monitors to classify posture and motion. *Medicine and Science in Sports and Exercise*, *47*, 952-959.

Steinberg, L. (2005). Cognitive and affective development in adolescence. *Trends in Cognitive Sciences, 9*, 69-74.

Strong, W. B., Malina, R. M., Blimkie, C. J., Daniels, S. R., Dishman, R. K., Gutin, B., . . . Trudeau, F. (2005). Evidence based physical activity for school-age youth. *The Journal of Pediatrics, 146*, 732-737.

Stroth, S., Reinhardt, R. K., Thone, J., Hille, K., Schneider, M., Hartel, S.,..Spitzer, M. (2010). Impact of aerobic exercise training on cognitive functions and affect associated to the COMT polymorphism in young adults. *Neurobiology of Learning and Memory, 94*, 364-372.

Stuss, D. T., & Levine, B. (2002). Adult clinical neuropsychology: lessons from studies of the frontal lobes. *Annual Review of Psychology, 53*, 401-433.

Syväoja, H. J., Kantomaa, M. T., Ahonen, T., Hakonen, H., Kankaanpää, A., & Tammelin, T. H. (2013). Physical activity, sedentary behavior, and academic performance in Finnish children. *Medicine and Science in Sports and Exercise, 45*, 2098-2104.

Syväoja, H. J., Tammelin, T. H., Ahonen, T., Kankaanpää, A., & Kantomaa, M. T. (2014). The associations of objectively measured physical activity and sedentary time with cognitive functions in school-aged children. *PloS One, 9*, e103559.

Taras, H., & Potts-Datema, W. (2005). Obesity and student performance at school. *The Journal of School Health, 75*, 291-295.

Tatemichi, T. K., Desmond, D. W., Stern, Y., Paik, M., Sano, M., & Bagiella, E. (1994). Cognitive impairment after stroke: frequency, patterns, and relationship to functional abilities. *Journal of Neurology, Neurosurgery, and Psychiatry, 57*, 202-207.

Taylor, B. L., & Attia, M. W. (2000). Sports-related injuries in children. *Academic Emergency Medicine, 7*, 1376-1382.

Thomas, A. G., Dennis, A., Bandettini, P. A., & Johansen-Berg, H. (2012). The effects of aerobic activity on brain structure. *Frontiers in Psychology, 3*, 86.

Tiggemann, M., & Williamson, S. (2000). The effect of exercise on body satisfaction and self-esteem as a function of gender and age. *Sex Roles, 43*, 119-127.

Tomporowski, P. D., Davis, C. L., Miller, P. H., & Naglieri, J. A. (2008). Exercise and children's intelligence, cognition, and academic achievement. *Educational Psychology Review, 20*, 111-131.

Trautmann, M., & Zepf, F. D. (2012). Attentional performance, age and scholastic achievement in healthy children. *PloS One, 7*, e32279.

Tremblay, M. S., Inman, J. W., & Willms, J. D. (2000). The relationship between physical activity, self-esteem, and academic achievement in 12-year-old children. *Pediatric Exercise Science, 12*, 312-323.

Tremblay, M. S., LeBlanc, A. G., Kho, M. E., Saunders, T. J., Larouche, R., Colley, R. C., . . . Connor Gorber, S. (2011). Systematic review of sedentary behaviour and health indicators in school-aged children and youth. *International Journal of Behavioral Nutrition and Physical Activity, 8*, 98.

Trost, S. G., McIver, K. L., & Pate, R. R. (2005). Conducting accelerometer-based activity assessments in field-based research. *Medicine and Science in Sports and Exercise, 37*, S531-543.

Trudeau, F., & Shephard, R. J. (2008). Physical education, school physical activity, school sports and academic performance. *International Journal of Behavioral Nutrition and Physical Activity, 5*, 10.

Tucker, L. A., Aldana, S. G., & Friedman, G. M. (1990). Cardiovascular fitness and absenteeism in 8.301 employed adults. *American Journal of Health Promotion, 5*, 140-145.

Tudor-Locke, C., Ainsworth, B. E., Adair, L. S., & Popkin, B. M. (2003). Objective physical activity of filipino youth stratified for commuting mode to school. *Medicine and Science in Sports and Exercise, 35*(3), 465-471.

Tudor-Locke, C., Craig, C. L., Beets, M. W., Belton, S., Cardon, G. M., Duncan, S., . . . Blair, S. N. (2011). How many steps/day are enough? for children and adolescents. *International Journal of Behavioral Nutrition and Physical Activity, 8*, 78.

Undheim, A. M., & Sund, A. M. (2005). School factors and the emergence of depressive symptoms among young Norwegian adolescents. *European Children and Adolescents Psychiatry, 14*, 446-453.

Van den Heuvel, S. G., Boshuizen, H. C., Hildebrandt, V. H., Blatter, B. M., Ariens, G. A., & Bongers, P. M. (2005). Effect of sporting activity on absenteeism in a working population. *British Journal of Sports Medicine, 39*, e15.

Van Dijk, M. L., De Groot, R. H., Van Acker, F., Savelberg, H. H., & Kirschner, P. A. (2014). Active commuting to school, cognitive performance, and academic achievement: an observational study in Dutch adolescents using accelerometers. *BMC Public Health, 14*, 799.

Van Dijk, M. L., De Groot, R. H. M., Savelberg, H. C. M., Van Acker, F., & Kirschner, P. A. (2014). The association between objectively measured physical activity and academic achievement in Dutch adolescents: Findings from The GOALS Study. *Journal of Sport and Exercise Psychology, 36*, 460 - 473.

Van Mechelen, W., Twisk, J. W., Post, G. B., Snel, J., & Kemper, H. C. (2000). Physical activity of young people: the Amsterdam Longitudinal Growth and Health Study. *Medicine and Science in Sports and Exercise, 32*, 1610-1616.

Van Sluijs, E. M., McMinn, A. M., & Griffin, S. J. (2007). Effectiveness of interventions to promote physical activity in children and adolescents: systematic review of controlled trials. *British Medical Journal, 335*, 703.

Vaynman, S., Ying, Z., & Gomez-Pinilla, F. (2004). Hippocampal BDNF mediates the efficacy of exercise on synaptic plasticity and cognition. *The European Journal of Neuroscience, 20*, 2580-2590.

Verhoeven, M., Sawyer, M. G., & Spence, S. H. (2013). The factorial invariance of the CES-D during adolescence: are symptom profiles for depression stable across gender and time? *Journal of Adolescence, 36*, 181-190.

Verret, C., Guay, M. C., Berthiaume, C., Gardiner, P., & Béliveau, L. (2012). A physical activity program improves behavior and cognitive functions in children with ADHD: an exploratory study. *Journal of Attention Disorders, 16,* 71-80.

Voss, M. W., Nagamatsu, L. S., Liu-Ambrose, T., & Kramer, A. F. (2011). Exercise, brain, and cognition across the lifespan. *Journal of Applied Physiology*, *111*, 1505-1513.

Wallhead, T. L., & Buckworth, J. (2004). The role of physical education in the promotion of youth physical activity. *Quest, 56*, 285–301.

Warburton, D. E., Nicol, C. W., & Bredin, S. S. (2006). Health benefits of physical activity: the evidence. *Canadian Medical Association Journal, 174*, 801-809.

Weiss, M. R., & Bredemeier, B. J. (1990). Developmental sport psychology: A theoretical perspective for studying children in sport. *Journal of Sport Psychology, 6*, 216-230.

Weissman, M. M., Wolk, S., Goldstein, R. B., Moreau, D., Adams, P., Greenwald, S., . . . Wickramaratne, P. (1999). Depressed adolescents grown up. *Journal of the American Medical Association, 281*, 1707-1713.

Weitzman, M. (1986). School absence rates as outcome measures in studies of children with chronic illness. *Journal of Chronic Diseases, 39*, 799-808.

Wentzel, K. R., & Caldwell, K. (1997). Friendships, peer acceptance, and group membership: relations to academic achievement in middle school. *Child Development, 68*, 1198-1209.

West, P., Sweeting, H., & Young, R. (2010). Transition matters: pupils' experiences of the primary–secondary school transition in the West of Scotland and consequences for well-being and attainment. *Research Papers in Education, 25*, 21-50.

Wigfield, A., Eccles, J. S., Iver, D. M., Reuman, D. A., & Midgley, C. (1991). Transitions during early adolescence: Changes in children's domain-specific-perceptions and general self-esteem across the transition to junior high school. *Developmental Psychology, 27*, 552-565.

Wiles, N. J., Jones, G. T., Haase, A. M., Lawlor, D. A., Macfarlane, G. J., & Lewis, G. (2008). Physical activity and emotional problems amongst adolescents: A longitudinal study. *Social Psychiatry and Psychiatric Epidemiology, 43*, 765-772.

Winter, B., Breitenstein, C., Mooren, F. C., Voelker, K., Fobker, M., Lechtermann, A., . . . Knecht, S. (2007). High impact running improves learning. *Neurobiology of Learning and Memory, 87*, 597-609.

Ziereis, S., & Jansen, P. (2015). Effects of physical activity on executive function and motor performance in children with ADHD. *Research in Developmental Disabilities, 38*, 181-191.

Zimmerman, M. A., Copeland, L. A., Shope, J. T., & Dielman, T. E. (1997). A longitudinal study of self-esteem: Implications for adolescent development. *Journal of Youth and Adolescence, 26*, 117-141.

SUMMARY

Most studies investigating associations between physical activity (PA), cognitive performance and academic achievement have focused on young children or older adults, while little is known about adolescents. Furthermore, the majority of studies in adolescents used questionnaires to investigate PA, a subjective instrument which has several limitations (Shephard, 2003). Only six studies in adolescents used an objective instrument to measure PA related to cognitive performance and academic achievement, and reported mixed results. Therefore, the main aim of this dissertation was to get more insight into the associations between objectively measured PA, cognitive performance and academic achievement in adolescents. In addition, associations between active commuting to school, cognitive performance and academic achievement were investigated, as well as associations between PA and mental health and PA and school absenteeism due to illness.

Chapter 1 describes the background information of the study and starts with a description of the concepts. PA is defined as any bodily movement produced by skeletal muscles that results in energy expenditure and can be categorized by its intensity (light, moderate-to-vigorous and vigorous). Cognition refers to mental abilities involved in knowledge and comprehension, such as attention, information-processing and memory. A special group of cognitive abilities are the executive functions, which refer to control mechanisms that modulate the operation of various cognitive sub-processes. Academic achievement refers to the mean of school grades in school subjects. Adolescence is the transition phase from a dependent child to an autonomous adult. Important characteristics of the adolescence in relation to PA and cognitive performance are the great decline in habitual PA and the rapid development of the frontal brain lobes, which are strongly involved in the regulation of executive functions.

Biological mechanisms underlying a potential association between PA and cognitive performance and academic achievement are described. For example, PA stimulates the formation of new neurons and blood vessels in the brain (Thomas, Dennis, Bandettini, & Johansen-Berg, 2012). Whether these biological mechanisms result in improved cognitive performance and academic achievement in adolescents is unclear. Though, insight into the associations between PA and cognitive performance and academic achievement in adolescents is of high importance, because high levels of cognitive performance and academic achievement during adolescence have been associated with job success (Diamond, 2013) and health during adulthood (Gale et al., 2012).

The lack of a clear association between PA and cognitive performance and academic achievement in adolescents might be due to limitations of the few studies in adolescents using an objective instrument to measure PA. The accelerometers used to measure PA in those studies were worn on the hip, a place which limit capturing activities with little displacement of the upper body, such as cycling (Chillon et al., 2011). Differences in adolescents' activity levels between weekdays and weekend days (Comte et al., 2013) were not taken into account. In addition, adolescents' PA levels tend to decrease (Ruiz et al., 2011), but none of these studies investigated the associations between changes in PA and changes in cognitive performance or academic achievement. In the studies described in this dissertation, habitual PA levels were measured using an accelerometer attached on the thigh, thus activities with little movement of the upper body, such as cycling, were also captured (Steeves et al., 2014). In addition, differences in adolescents' activity levels between weekdays and weekend days were taken into account and PA was measured at baseline and one-year follow-up.

Chapter 2 describes the design of the studies in this dissertation. All data were gathered as part of The GOALS (Grootschalig Onderzoek naar Activiteiten van Limburgse Scholieren [Large-scale Research of Activities in Dutch Students]) Study. This study was conducted at a secondary school in the Netherlands. Data collection took place during normal school weeks from October 2011 to March 2012 and one year later from October 2012 to May 2013. All students in the first and third year of senior general secondary education and university preparatory education were invited to participate (*N* = 526). At baseline a sample of 440 adolescents (mean age 13.8 years, 47% female) was willing to participate (83.7%). Of these, 297 (67.5%) participated also at one-year follow-up. PA was measured objectively by an ActivPal3^{TM} accelerometer during one full week (24 hours/day). Cognitive performance was determined by the Symbol Digit Modalities Test, a measure of information-processing speed, and the d2 Test of attention, a task involving response inhibition (i.e., a key component of executive functioning) and selective attention. Academic achievement was determined using the mean of the school grades in Dutch, English, and Mathematics throughout the entire academic year. Mental health was measured by the Center for Epidemiologic Studies Depression Scale (measure of depressive symptoms) and Rosenberg Self-Esteem Scale (measure of self-esteem). Cardiovascular fitness was measured by the 20-m shuttle-run test. Height and weight were measured to determine the body mass index. Also, information on several covariates such as sex, nationality, and socioeconomic status was collected.

The study described in **Chapter 3** investigated the association between objectively measured PA and academic achievement in adolescents. In addition, the association between PA and executive functioning was examined, as well as the mediating role of executive functioning in the association between PA and academic achievement. Preliminary results showed that PA levels were lower on weekend days than on weekdays, in particular on Sunday (PA levels are 40% lower than on weekdays). In addition, PA was positively associated with cardiovascular fitness and mental health. The main results showed that both total PA volume and moderate-to-vigorous PA (MVPA) were not significantly associated with academic achievement overall. However, there was an interaction effect of academic year. In first year students, the total PA volume was negatively associated with academic achievement, while MVPA was negatively associated with both academic achievement and mathematics performance. In contrast, in third year students, both the total PA volume and MVPA were positively associated with mathematics performance. In addition, the overall association between MVPA and academic achievement followed an inverted U-shaped curve. Finally, the total PA volume was positively associated with executive functioning, while executive functioning in turn mediated the associations between total PA volume and academic achievement and mathematics performance. There was no direct association between PA and academic achievement, therefore the mediating role of executive functioning in the relation between PA and academic achievement might be offset by confounding factors, such as time devoted to homework. It might have been that active students spent less time devoted to homework, resulting in lower academic achievement. It was concluded that the association between PA and academic achievement in adolescents is complex, because this association is impacted by academic year, PA volume and intensity, and school grade.

The study presented in **Chapter 4** examined the associations between active commuting to school, a common activity in Dutch adolescents, and cognitive performance and academic achievement. The total amount of moving time on weekdays between 7:00 a.m. and 8:40 a.m. was used as measure of active commuting to school. Results showed that active commuting to school constituted 28% of the total amount of time spent moving per week. Overall, active commuting to school was not significantly associated with cognitive performance and academic achievement. However, there was a significant interaction between active commuting to school and sex on executive functioning. Active commuting to school was positively associated with executive functioning in girls, but not in boys. Possibly, school-related stress or sex-specific hormones play a role in this interaction effect. It was concluded that the associations between active commuting to school and cognitive performance and academic achievement are weak and might be moderated by sex, while the greatest benefits on cognition due to active commuting to school might be with regard to executive functioning.

The study described in **Chapter 5** investigated the association between habitual PA levels and school absenteeism due to illness in adolescents. In addition, it was examined whether this association was mediated by mental health and cardiovascular fitness. Results showed that PA was not significantly associated with school absenteeism due to illness, though there was an indirect association between PA and school absenteeism by cardiovascular fitness. The mediating role of cardiovascular fitness in the relation between PA and school absenteeism might be offset by other factors. For example, long periods of intensive PA, such as training and competing in intensive physically sports, may result in chronic fatigue and injuries (Brenner, 2007, Taylor & Attia, 2000), and consequently more absence days.

The study presented in **Chapter 6** investigated the associations between change in PA over one-year time and change in cognitive performance and academic achievement. Preliminary results showed a sharp decline in PA over one-year time (-16%). PA levels decreased particularly from the first year to the second year (-20%), the decline from the third year to the fourth year (-5%) was not statistically significant. The main results showed no significant association between change in PA and change in cognitive performance. Change in PA was negatively associated with change in academic achievement; the more inactive adolescents became the better their academic achievement. It might have been that students spent less time on PA in favour of time spent devoted to homework, which might have a positive impact on academic achievement.

The study described in **Chapter 7** examined the associations between changes in PA and changes in mental health. Results showed that the decline in PA did not predict changes in depressive symptoms and self-esteem. These non-significant associations might be explained by the relatively short follow-up period, as associations might become clearer in the long term. In addition, total PA volume per week was used as measure of PA, participation in (team)sport and exercise groups might have greater impact on mental health because it also provides social interaction and promotes social support (Sagatun, Sogaard, Bjertness, Selmer, & Heyerdahl, 2007). It was concluded that the associations between changes in PA and changes in mental health are weak at most.

Chapter 8 discusses the main findings and conclusions and presents practical implications, methodological limitations, and suggestions for further studies.

The first implication is that adolescents should be stimulated to be physically active, because PA is positively associated with executive functioning and several health outcomes (e.g., higher levels cardiovascular fitness). Unfortunately, habitual PA levels in adolescents decrease sharply, in particular during the transition from the first year to the second year of secondary school. In addition, adolescents are less active on weekend days than on weekdays, in particular on Sunday. Therefore, PA programs should preferably focus on maintaining habitual PA levels during the first years of secondary school and stimulating PA on weekend days. The second implication is that secondary schools should stimulate PA, because adolescents spend a large part of their time on school and the largest part of their school time is sedentary. Schools may stimulate PA by adding extra physical education classes to the school curriculum or by implementing short exercise sessions during pauses or free hours. The third implication is that parents, schools and local communities should promote active commuting to school, for example by providing good and safe bicycles, creating bike facilities at schools and providing safe traffic environments around schools respectively. Active commuting to school is an important source of daily PA and has been found to have several health benefits for adolescents.

A limitation of the studies in this dissertation is that results cannot be directly generalised, because only one secondary school was used. Only one key component of executive functioning (response inhibition) was measured, therefore findings are specific for response inhibition instead of overall executive functioning. Results were not controlled for factors related to academic achievement, such as teacher perception, quality of academic teaching, and peer relationships. Habitual PA levels were measured during a normal school week, but due to unforeseen circumstances, it might be possible that this week was not representative for the habitual PA levels throughout the entire academic year. Because academic achievement was measured by the mean of the school grades throughout the entire academic year, the association between PA and academic achievement is sensitive for large changes in habitual PA levels during the academic year.

The studies in this dissertation focused on the total PA volume per week, no distinction was made in social interaction during activities (i.e., alone or together with peers) or context (i.e., competitive versus recreational). Further studies could investigate the independent and combined effect of PA and sports (team) participation on cognitive performance and academic achievement. As only healthy adolescents were included, further studies might focus particularly on adolescents with health or concentration problems. Future studies might investigate the nature of the decline in PA during the first years of secondary school and may investigate whether the development of a sedentary lifestyle begins already at primary school. Nearly all studies have focused on cognitive performance, no study examined the actual process of learning. Further studies might, for example, investigate whether an acute bout of exercise immediately improves remembering of studied words from other languages or the performance on a real school exam. Finally, experimental studies investigating effects of PA on cognition and academic achievement might stimulate PA on school by adding extra physical education classes to the school curriculum or in a less radical way, by facilitating active commuting to school and implementing short sessions of exercise during pauses and in lesson-free hours.

SAMENVATTING

Het grootste deel van de studies die de associaties tussen fysieke activiteit, cognitieve prestaties en schoolprestaties hebben onderzocht, focuste op jonge kinderen of oudere volwassenen. Minder onderzoek is uitgevoerd in de groep adolescenten. Bovendien heeft het grootste deel van de studies in adolescenten gebruik gemaakt van vragenlijsten om fysieke activiteit te meten, een subjectieve methode die vele beperkingen heeft (Shephard, 2003). Slechts zes studies in adolescenten hebben gebruik gemaakt van een objectief instrument om fysieke activiteit te meten in relatie met cognitieve prestaties en schoolprestaties, en deze studies vonden wisselende resultaten. Daarom was het belangrijkste doel van dit proefschrift om meer inzicht te krijgen in de associaties tussen objectief gemeten fysieke activiteit, cognitieve prestaties en schoolprestaties van adolescenten. Daarnaast werden de associaties tussen actief forenzen naar school en cognitieve prestaties en schoolprestaties onderzocht, evenals de associaties tussen fysieke activiteit en mentaal welbevinden en fysieke activiteit en schoolverzuim door ziekte.

Hoofdstuk 1 beschrijft de achtergrondinformatie van het onderzoek en begint met een beschrijving van de belangrijkste concepten. Fysieke activiteit wordt gedefinieerd als iedere vorm van lichaamsbeweging die wordt uitgevoerd door skeletspieren en leidt tot een verhoogd energiegebruik. Cognitie is een verzamelnaam voor vele mentale functies die betrokken zijn bij kennis en begripsvorming, zoals aandacht, informatieverwerking en geheugen. Een speciale groep van cognitieve functies zijn de executieve functies. Dit zijn controlemechanismen die de uitvoering van cognitieve sub-processen aansturen. Schoolprestaties verwijzen naar de behaalde schoolcijfers op bepaalde schoolvakken. Adolescentie is de overgangsfase van een afhankelijk kind naar een zelfstandige volwassene. Belangrijke kenmerken van de adolescentie in relatie tot fysieke activiteit en cognitieve prestaties en schoolprestaties zijn de grote afname in fysieke activiteit en de snelle ontwikkeling van de frontale cortex, welke in sterke mate betrokken is bij de uitvoering van executieve functies.

Biologische mechanismen die ten grondslag kunnen liggen aan de mogelijke associaties tussen fysieke activiteit en cognitieve prestaties en schoolprestaties worden beschreven. Bijvoorbeeld, fysieke activiteit stimuleert de vorming van nieuwe cellen en bloedvaten in het brein (Thomas, Dennis, Bandettini, & Johansen-Berg, 2012). Of deze biologische mechanismen daadwerkelijk leiden tot betere cognitieve prestaties en schoolprestaties in adolescenten is nog onduidelijk. Inzicht in de associaties tussen fysieke activiteit en cognitieve prestaties en schoolprestaties van adolescenten is echter van groot belang, want goede cognitieve prestaties en schoolprestaties tijdens de adolescentie worden geassocieerd met een succesvolle carrière (Diamond, 2013) en gezondheid op latere leeftijd (Gale et al., 2012).

Onduidelijkheid over de associaties tussen fysieke activiteit en cognitieve prestaties en schoolprestaties in adolescenten wordt mogelijk veroorzaakt door beperkingen in de studies die fysieke activiteit objectief hebben gemeten. De versnellingsmeters die in deze studies werden gebruikt om fysieke activiteit te meten werden gedragen op de heup. Activiteiten met weinig beweging van het bovenlichaam, zoals fietsen, worden door de positie op de heup slechts beperkt geregistreerd (Chillon et al., 2011). Ook werden verschillen in fysieke activiteit tussen doordeweekse dagen en weekenddagen (Comte et al., 2013) niet meegenomen. Daarnaast, fysieke activiteit neemt af tijdens de adolescentie (Ruiz et al., 2011), maar geen enkele studie heeft de associaties tussen deze veranderende hoeveelheid fysieke activiteit en mogelijk veranderende cognitieve prestaties en schoolprestaties onderzocht. In de studies die zijn beschreven in dit proefschrift werd de normale hoeveelheid fysieke activiteit van de deelnemers bepaald met een versnellingsmeter bevestigd op het bovenbeen. Deze positie maakt het mogelijk om ook activiteiten met weinig beweging van het bovenlichaam, zoals fietsen, te registreren (Steeves et al., 2014). Daarnaast werden verschillen in fysieke activiteit tussen doordeweekse dagen en weekenddagen meegenomen en werd de normale hoeveelheid fysieke activiteit zowel aan het begin van de studie als aan het einde (na één jaar) gemeten.

Hoofdstuk 2 beschrijft de onderzoeksmethode van de studies in dit proefschrift. Alle gegevens werden verzameld als onderdeel van De GOALS (Grootschalig Onderzoek naar Activiteiten van Limburgse Scholieren) Studie. Deze studie werd uitgevoerd op een middelbare school in Nederland. De dataverzameling vond plaats tijdens normale schoolweken van oktober 2011 tot en met maart 2012 en één jaar later van oktober 2012 tot en met mei 2013. Alle middelbare scholieren uit het eerste en derde jaar van de HAVO en het VWO werden uitgenodigd om deel te nemen (*N* = 526). Aan de beginmeting namen 440 adolescenten (gemiddelde leeftijd 13.8 jaar, 47% vrouw) deel (83.7% van het totaal aantal uitgenodigde scholieren). Hiervan namen 297 adolescenten ook deel aan de eindmeting (67.5% van de deelnemers aan de beginmeting). Fysieke activiteit werd gemeten met de ActivPal3™ versnellingsmeter gedurende een hele week (24 uur per dag). Cognitief functioneren werd gemeten met de Symbol Digit Modalities Test, een test die meet hoe snel iemand informatie kan verwerken. Executief functioneren werd gemeten met de d2 Test of attention. In deze test moet het concentratievermogen heel specifiek worden gebruikt om bepaalde symbolen te herkennen en aan te strepen, de aandacht moet hierbij niet worden afgeleid door afleidende/niet-relevante informatie (een basiscomponent van executief functioneren). Schoolprestatie werd bepaald door het gemiddelde schoolcijfer voor de vakken Nederlands, Engels en wiskunde gedurende het hele schooljaar. Mentaal welbevinden werd gemeten met de Center for Epidemiologic

Studies Depression Scale (vragenlijst over depressieve gevoelens) en Rosenberg Self-Esteem Scale (vragenlijst over gevoelens van eigenwaarde/zelfvertrouwen). Cardiovasculaire fitheid werd gemeten met de 20-m shuttle-run test. Lengte en gewicht werden opgemeten om de body mass index te kunnen bepalen. Daarnaast werd extra informatie verzameld door middel van vragenlijsten, zoals geslacht, nationaliteit, sociaaleconomische status en de puberale ontwikkeling.

De studie beschreven in **Hoofdstuk 3** onderzocht de associatie tussen fysieke activiteit en schoolprestatie van adolescenten. Daarnaast werd de associatie tussen fysieke activiteit en executief functioneren onderzocht, evenals de invloed van executief functioneren op de associatie tussen fysieke activiteit en schoolprestatie. Voorafgaande analyses toonden aan dat de totale hoeveelheid fysieke activiteit lager was op weekenddagen dan op doordeweekse dagen, met name op zondag (dan zijn adolescenten 40% minder actief dan op doordeweekse dagen). Daarnaast was fysieke activiteit positief geassocieerd met cardiovasculaire fitheid en mentaal welbevinden. De hoofdanalyses, voor de hele groep, toonden aan dat fysieke activiteit niet significant geassocieerd was met schoolprestatie. Er werd wel een significante omgekeerde U-vormige associatie gevonden tussen matig tot zware fysieke activiteit en schoolprestatie. Met andere woorden, matig tot zware fysieke activiteit was tot een bepaalde grens positief geassocieerd met schoolprestatie, terwijl te veel matig tot zware fysieke activiteit negatief geassocieerd was met schoolprestatie. Daarnaast was er sprake van een interactie-effect tussen schooljaar en fysieke activiteit op schoolprestatie. In de eerstejaars scholieren werd een negatieve associatie gevonden tussen de totale hoeveelheid fysieke activiteit en de gemiddelde schoolprestatie (gemiddelde schoolcijfer voor de vakken Nederlands, Engels en wiskunde). Daarentegen, in de derdejaars scholieren werd een positieve associatie gevonden tussen de totale hoeveelheid fysieke activiteit en prestatie op wiskunde. Ten slotte werd voor de hele groep een positieve associatie gevonden tussen de totale hoeveelheid fysieke activiteit en executief functioneren, en een positieve associatie tussen executief functioneren en schoolprestatie. Er werd voor de hele groep geen directe associatie gevonden tussen fysieke activiteit en schoolprestatie, dus de positieve invloed die executief functioneren had in de relatie tussen fysieke activiteit en schoolprestatie werd mogelijk teniet gedaan door andere variabelen, zoals de tijdsbesteding aan huiswerk. Mogelijk besteden actieve adolescenten minder tijd aan huiswerk, wat een negatieve invloed heeft op de schoolprestaties. De conclusie was dat de associatie tussen fysieke activiteit en schoolprestatie van adolescenten complex is, want deze associatie wordt beïnvloed door schooljaar, de hoeveelheid en intensiteit van fysieke activiteit en het schoolvak.

De studie in **Hoofdstuk 4** onderzocht de associaties tussen actief forenzen naar school, een gangbare activiteit onder Nederlandse adolescenten, en cognitieve prestaties en schoolprestaties. De totale bewegingstijd op doordeweekse dagen tussen 7:00 uur en 8:40 uur werd gebruikt om actief forenzen naar school te bepalen. De resultaten toonden aan dat actief forenzen naar school 28% bedraagt van de totale hoeveelheid fysieke activiteit per week. Voor de hele groep adolescenten werden geen significante associaties gevonden tussen actief forenzen naar school en cognitieve prestaties en schoolprestaties. Echter, er was sprake van een interactie tussen actief forenzen naar school en geslacht op executief functioneren. Actief forenzen naar school was positief geassocieerd met executief functioneren in meisjes, maar niet in jongens. Mogelijk spelen school gerelateerde stress of geslacht-specifieke hormonen een rol in deze interactie. De conclusie was dat de associaties tussen actief forenzen naar school en cognitieve prestaties en schoolprestaties zwak zijn, terwijl de grootste effecten mogelijk worden gevonden in meisjes en in taken waarbij executieve functies zijn betrokken.

In **Hoofdstuk 5** werd de associatie onderzocht tussen fysieke activiteit en schoolverzuim door ziekte. Daarnaast werd onderzocht of de associatie tussen fysieke activiteit en schoolverzuim door ziekte werd beïnvloed door mentaal welbevinden en cardiovasculaire fitheid. De resultaten toonden aan dat fysieke activiteit niet significant geassocieerd was met schoolverzuim door ziekte. Echter, fysieke activiteit was indirect geassocieerd met schoolverzuim, want fysieke activiteit had een positieve invloed op cardiovasculaire fitheid en cardiovasculaire fitheid was geassocieerd met minder verzuimdagen door ziekte. De positieve invloed die cardiovasculaire fitheid had in de relatie tussen fysieke activiteit en schoolverzuim door ziekte werd mogelijk teniet gedaan door andere factoren. Bijvoorbeeld, een lange, intensieve periode van fysieke activiteit, zoals trainen voor en wedstrijddeelname aan een fysiek intensieve sport, kan resulteren in chronische vermoeidheid en blessures (Brenner, 2007, Taylor & Attia, 2000) en vervolgens meer verzuimdagen op school.

De studie beschreven in **Hoofdstuk 6** onderzocht de associatie tussen verandering in fysieke activiteit na één jaar en veranderingen in cognitieve prestaties en schoolprestaties. De voorafgaande analyses lieten een sterke daling zien in fysieke activiteit na één jaar (-16%). Fysieke activiteit nam hoofdzakelijk af tijdens de overgang van het eerste naar het tweede schooljaar (-20%), de afname van het derde naar het vierde schooljaar (-5%) was niet significant. De hoofdanalyses lieten geen significante associatie zien tussen de verandering in fysieke activiteit en verandering in cognitief functioneren. Er werd wel een significante associatie gevonden tussen verandering in fysieke activiteit en verandering in schoolprestatie; hoe inactiever de adolescenten werden, des te beter werden hun schoolprestaties. Mogelijk besteden adolescenten minder tijd aan fysieke activiteiten om meer tijd te kunnen besteden aan huiswerk, waardoor ze beter gaan presteren op school.

De studie beschreven in **Hoofdstuk 7** onderzocht de associatie tussen verandering in fysieke activiteit en verandering in mentaal welbevinden. De resultaten toonden aan dat de afname in fysieke activiteit niet gerelateerd was aan veranderingen in depressieve gevoelens en gevoelens van eigenwaarde/zelfvertrouwen. Deze associaties waren mogelijk niet significant vanwege de relatief korte periode (één jaar) tussen de beginmeting en eindmeting; de associaties zijn mogelijk duidelijker op een langere termijn. Daarnaast werd de totale hoeveelheid fysieke activiteit per week gebruikt als maat voor fysieke activiteit zonder rekening te houden met deelname aan (team)sportactiviteiten en trainingsgroepen. Deelname aan (team)sportactiviteiten en trainingsgroepen zorgt ook voor sociale interactie en bevordert sociale steun (Sagatun, Sogaard, Bjertness, Selmer, & Heyerdahl, 2007), waardoor dit mogelijk een groter effect heeft op mentaal welbevinden dan alleen de totale hoeveelheid fysieke activiteit. De conclusie was dat er geen of een zwakke associatie bestaat tussen verandering in fysieke activiteit en verandering in mentaal welbevinden in adolescenten.

Hoofdstuk 8 bediscussieert de belangrijkste bevindingen en conclusies en beschrijft praktische implicaties, methodologische beperkingen en suggesties voor toekomstig onderzoek.

De eerste implicatie is dat adolescenten moeten worden gestimuleerd om fysiek actief te zijn, want fysieke activiteit is positief geassocieerd met executief functioneren en verschillende gezondheidsuitkomsten, zoals cardiovasculaire fitheid. Helaas nemen de fysieke activiteiten van adolescenten sterk af, vooral tijdens de eerste jaren van de middelbare school. Ook zijn adolescenten minder actief op dagen in het weekend dan op doordeweekse dagen, met name op zondag. Daarom moeten beweeginterventies zich voornamelijk richten op het behoud van een fysiek actieve leefstijl tijdens de eerste jaren van de middelbare school en het stimuleren van fysieke activiteit in het weekend. De tweede implicatie is dat middelbare scholen fysieke activiteit moeten stimuleren, want adolescenten brengen een groot gedeelte van hun tijd door op school en het grootste deel hiervan zittend. Scholen zouden fysieke activiteit kunnen bevorderen door extra gymlessen in te roosteren of door korte inspanningsactiviteiten te introduceren tijdens pauzes of vrije tussenuren. De derde implicatie is dat actief forenzen naar school moet worden gestimuleerd, want actief forenzen is een belangrijke bron van fysieke activiteit en positief geassocieerd met verschillende gezondheidsuitkomsten. Ouders, scholen en gemeenten kunnen hieraan bijdragen, bijvoorbeeld door te zorgen voor goede en veilige fietsen, een fietsenstalling op school en een veilige verkeerssituatie rond de school.

Een beperking van de studies beschreven in dit proefschrift is dat de resultaten niet direct kunnen worden gegeneraliseerd, want voor het onderzoek is maar één school gebruikt. Daarnaast is er gebruik gemaakt van slechts één basiscomponent van executief functioneren (aandacht specifiek gebruiken en niet laten afleiden door afleidende/niet-relevante informatie), dus de bevindingen in dit proefschrift gelden specifiek hiervoor en niet automatisch voor andere componenten van executief functioneren. De resultaten zijn niet gecontroleerd voor factoren gerelateerd aan schoolprestatie, zoals de perceptie van de leraar, de kwaliteit van het onderwijs en de relaties met klasgenoten. Fysieke activiteit werd gemeten tijdens een normale schoolweek, maar door onvoorziene omstandigheden is het mogelijk dat deze week niet representatief was voor de wekelijkse hoeveelheid fysieke activiteit gedurende het hele schooljaar. Omdat schoolprestatie werd gemeten op basis van de schoolcijfers gedurende het hele schooljaar, is de associatie tussen fysieke activiteit en schoolprestatie gevoelig voor grote veranderingen in fysieke activiteiten tijdens het schooljaar.

De studies beschreven in dit proefschrift focusten op de totale hoeveelheid fysieke activiteit per week, er werd geen onderscheid gemaakt in sociale interactie van de activiteiten (alleen of in een groep bewegen) of context (recreatief of competitief). Verder onderzoek zou het onafhankelijke en gecombineerde effect van fysieke activiteit en (team)sportdeelname op cognitieve prestaties en schoolprestaties kunnen onderzoeken. Alleen gezonde adolescenten zijn meegenomen in de analyses, toekomstige studies zouden zich kunnen richten op adolescenten met aandachts- of gezondheidsproblemen. Verder onderzoek zou de achtergrond van de afname in fysieke activiteit tijdens de eerste jaren van de middelbare school kunnen onderzoeken en zou kunnen onderzoeken of de afname in fysieke activiteit al begint op de basisschool. Geen enkele studie onderzocht dusver het effect van fysieke activiteit op het daadwerkelijke leerproces. Toekomstige studies zouden kunnen onderzoeken of een acute inspanning (bijvoorbeeld 20 minuten hardlopen) een onmiddellijk effect heeft op het onthouden van woorden uit een andere taal of het presteren op een echte schooltoets. Ten slotte, toekomstige experimentele studies in adolescenten kunnen de effecten van een toename in fysieke activiteit op cognitieve prestaties en schoolprestatie onderzoeken. Fysieke activiteit kan worden gestimuleerd door extra gymlessen in te roosteren, of op een minder ingrijpende manier, door het faciliteren van actief forenzen naar school en implementeren van korte inspanningsactiviteiten tijdens pauzes of vrije tussenuren.

DANKWOORD

De finish is gehaald! Een dergelijke titel gebruikte ik ook in het laatste verslag van mijn wereldreis in februari 2009. Ik had een geweldige tijd gehad, veel gezien en meegemaakt en ondertussen mijn afstudeeronderzoek uitgevoerd en scriptie bijna afgerond. Terug in Nederland had ik heel veel zin om aan het werk te gaan. Ik kreeg de kans om werkervaring op te doen als projectmedewerker van De Maastricht Studie, een groot onderzoek naar de ontwikkeling van type 2 diabetes en andere welvaartsziektes. Ik heb hier een heel leerzaam jaar gehad en dit bracht me dichterbij een door mij zeer gewenste promotieplek. Deze vond ik vervolgens bij de Open Universiteit. Bijna vijf jaar later kan ik vol overtuiging zeggen: het is een hele leuke en leerzame periode geweest en ik ben trots op het eindresultaat dat u nu in handen heeft.

Een dankwoord is er niet voor niks. Dit proefschrift zou niet tot stand zijn gekomen zonder de hulp van vele collega’s, betrokkenen, vrienden en familie, dus het is de hoogste tijd om deze personen in het zonnetje te zetten.

Te beginnen met mijn begeleidingsteam. Paul, ik kan me nog goed herinneren dat we het tijdens mijn sollicitatiegesprek hadden over de Mont Ventoux, Lance Armstrong en Max Euwe. Leuk dacht ik, mijn promotor heeft dezelfde interesses als ik. Dat een hoogleraar een drukke agenda heeft en uitgebreide gesprekken over dergelijke onderwerpen dus niet altijd gelegen komen, besefte ik toen nog niet goed. Desondanks kon ik altijd bij je binnenlopen en stond je voor me klaar als ik ‘even’ iets wilde bespreken. Bedankt voor jouw inzet en veelal razendsnelle reacties al die jaren! Renate, ook al was je nog zo druk, ik kon altijd bij je binnen lopen als ik tegen problemen aanliep, wat ik zeker de eerste maanden dan ook dagelijks of vaker deed. Naast de vele overleggen zijn we samen op pad geweest om ons GOALS onderzoek te presenteren op internationale conferenties (van Gent tot San Diego) en hebben we vele leuke etentjes en uitjes gehad. Bedankt voor jouw inzet en de goede samenwerking in al die jaren!

Mijn co-auteurs hebben ontzettend veel tijd gestoken in het kritisch doornemen van de methodes, analyses, resultaten en manuscripten. Dankjewel Hans, Frederik en Peter; zonder jullie hulp had ik dit niet kunnen bereiken.

Dank aan alle collega’s die mij hebben geholpen bij de dataverzameling op het Bernardinuscollege in Heerlen. Een speciaal bedankje aan een aantal collega’s die wel heel vaak, samengepropt in mijn Toyota Starlet uitpuilend van de bewegingsmeters en dozen vol met vragenlijsten, zijn meegegaan naar het Bernardinuscollege: Elise, Jurjen en Ine enorm bedankt voor jullie inzet!

Zeer veel dank aan alle betrokkenen van het Bernardinuscollege. De docenten, conciërge, directie, medewerkers van de ICT en natuurlijk de leerlingen, iedereen heeft mij twee jaar lang geweldig geholpen bij het uitvoeren of ondergaan van het onderzoek.

Joyce, ik vond het heel prettig om met je samen te werken en heel fijn om altijd met alles bij je terecht te kunnen. Ook jij hebt je vele malen (belangeloos) ingezet voor mijn onderzoek, dank daarvoor! Ik ben heel blij dat je mijn paranimf wilt zijn, je kent mijn onderzoek volgens mij ook door en door, dus als ik er tijdens mijn verdediging niet uitkom, dan spring je bij, toch?

Floris, onze wegen kwamen samen tijdens onze studie Gezondheidswetenschappen in Maastricht. We leerden elkaar goed kennen in de ruim zes jaar dat we samenwoonden in ons 'Cadier', een oud klooster net buiten Maastricht waar we met nog een aantal wielrenners een geweldige tijd hebben gehad. Na een carrière als profwielrenner, heb je er vorig jaar voor gekozen om jouw studie weer op te pakken en ambieer je nu een carrière in de wetenschap. Wie nog op zoek is naar een gemotiveerde, sociale en intelligente gezondheidswetenschapper met een ijzersterke discipline, hij staat op 4 september rechts van mij.

Ludo, het was erg leuk om jou als collega te hebben. Vanaf dag één was het duidelijk dat we van dezelfde flauwe humor houden, maar we konden ook goed bomen over onze onderzoeken of andere serieuze onderwerpen. Mede omdat we nu allebei in Eindhoven werken, spreken we elkaar nog heel regelmatig en dat gaan we er ook inhouden! Thomas, door onze gezamenlijke passie voor wielrennen hadden we al snel een klik en genoeg te bespreken tijdens ons wekelijkse koffie-momentje. De leukste herinnering houd ik over aan ons 'bakkie' tijdens de onderzoeksweek in de Irish Pub in Girona. Jérôme, jij bent de collega met wie ik het meeste heb meegemaakt tijdens mijn promotietijd, onder andere conferentiebezoeken in Gent en San Diego en de barbecues met yOUng. De laatste maanden van mijn promotietijd kwamen we bij elkaar in één werkruimte terecht. We hadden door de toenemende drukte vooral 'gesprekken' die niet veel verder kwamen dan "Die Martin toch" of iets diepgaander "Die Jerommeke toch, dat is me er één", maar ontspannend was het wel. Bedankt voor alle gezelligheid en de goede samenwerking die we dikwijls hadden. Je bent een geweldige collega en ik ben er trots op om in november jouw paranimf te mogen zijn bij de verdediging van jouw proefschrift.

Dank aan Leo (†24 juni 2014), mijn oude buurman op de Open Universiteit, die helaas veel te vroeg is overleden. We hadden al heel snel een leuke band, mede door onze gezamenlijke passie voor schaatsen en fietsen (en in het bijzonder fietsen naar het werk). Als ik een keer iets later begon of niet op de fiets was, tikte hij mij (op een leuke manier) op mijn vingers. Mede dankzij hem ben ik al die tijd met veel plezier (op de fiets) naar mijn werk gekomen. Ik heb dan ook veel verdriet gehad toen ik met Leo mijn (fiets)maatje verloor, maar bewaar mooie herinneringen aan hem (met als hoogtepunt onze 80km+ schaatstocht op natuurijs).

Bedankt Ingrid, Audrey, Mieke en Nicole voor de goede secretariële ondersteuning, jullie stonden altijd voor me klaar. Ook dank aan alle collega's die spontaan de deur voor me openhielden als ik ‘s morgens op de racefiets aankwam bij de Open Universiteit. Niemand deed ooit moeilijk als ik mijn fiets mee naar binnen nam, ook niet het laatste jaar, toen ik geen eigen kamer meer had en mijn fiets dus maar pontificaal in de algemene werkruimte neerzette.

Bijna iedere dag ging ik met plezier naar mijn werk en dat had ik mede te danken aan vele fijne collega’s: Milou, Kim, Johan, Iwan, Jaap, Charlotte, Pauline, Suzan, Denise, Inge, Annemarijn, Marije, bedankt voor alle gezellige momenten.

Dank aan een groepje mede-AIO’s die ik nog ken uit mijn studententijd en met wie ik regelmatig een ‘AIO-klaag-etentje’ had. Fijn om even mijn verhaal kwijt te kunnen en, hoe gek het wellicht ook klinkt, lief en leed van anderen te horen. Tijdens deze etentjes kwamen we overigens altijd tot de conclusie dat we het onderzoek toch ook wel erg leuk vonden.

Mijn ouders, die altijd in me hebben geloofd en altijd achter alle keuzes stonden die ik heb gemaakt, bedankt voor jullie onvoorwaardelijke support en nimmer aflatende interesse.

Ten slotte, mijn lieve vriendin Lydia. Ik had nooit kunnen vermoeden dat ik op mijn zevende werkdag bij de Open Universiteit de liefde van mijn leven zou ontmoeten. Het is inmiddels bijna vijf jaar en heel veel fijne momenten en mooie ervaringen later. Bedankt voor jouw support en het aanhoren van al mijn verhalen; je bent er altijd voor me geweest!

CURRICULUM VITAE

Martin van Dijk was born on June 13, 1983 in Naaldwijk, the Netherlands. In 2003, he moved to Maastricht to start his studies in Health Sciences at the Maastricht University. In 2006, he received his bachelor's degree and began working several jobs, including as a research assistant and taxi driver, to earn money for a trip around the world. One year later, he started his master's degree in Physical Activity and Health in Maastricht. He did his graduate research at the University of Wollongong in Australia and investigated the heat dissipation properties of firefighter suits.

Back in the Netherlands in 2009, Martin finished his master's thesis and started working as a project member of The Maastricht Study, the world's largest research project into the development of type 2 diabetes (with 10,000 participants). After one instructive year, Martin started working as a Ph.D. student at the Open University of the Netherlands under the supervision of Prof. Paul Kirschner and Dr. Renate de Groot. His research explored the associations between physical activity, cognitive performance, and academic achievement among adolescents. In order to investigate these associations, he executed a large-scale study at a secondary school called The GOALS (Grootschalig Onderzoek naar Activiteiten van Limburgse Scholieren [Large-scale Research into Activities of Dutch Students]) Study. A total of 440 adolescents of the Bernardinuscollege in Heerlen participated in GOALS. To investigate the physical activity habits of these participants, they each wore an accelerometer, taped on the right thigh, for one full week (24 hours per day). The results of his study were presented at several international conferences and published in three international journals thus far (i.e. *Journal of Sport and Exercise Psychology*, *BMC Public Health*, and *British Journal of Educational Technology*).

In 2014, Martin combined his Ph.D. research with a lecturer position at the Fontys Sporthogeschool [University of Applied Sciences, School of Sport Studies]. He taught courses in exercise physiology, research methodology, and the effects of physical activity on both health and the development of lifestyle diseases. Martin finished his dissertation in 2015, and is currently working as a lecturer and researcher at the Fontys Sporthogeschool.

ICO DISSERTATION SERIES

In the ICO Dissertation Series, the dissertations are published of graduate students from faculties and institutes on educational research within the ICO Partner Universities: Eindhoven University of Technology, Leiden University, Maastricht University, Open University in the Netherlands, University of Amsterdam, University of Twente, Utrecht University, VU University Amsterdam, and Wageningen University, and formerly University of Groningen (until 2006), Radboud University Nijmegen (until 2004), and Tilburg University (until 2002). The University of Groningen, University of Antwerp, University of Ghent, and the Erasmus University Rotterdam have been 'ICO 'Network partner' in 2010 and 2011. From 2012 onwards, these ICO Network partners are full ICO partners, and from that period their dissertations will be added to this dissertation series.

250. Van de Pol, J.E. (28-09-2012). *Scaffolding in teacher-student interaction. Exploring, measuring promoting and evaluating scaffolding.* Amsterdam: University of Amsterdam.
251. Phielix, C. (28-09-2012). *Enhancing collaboration through assessment and Reflection.* Utrecht: Utrecht University.
252. Peltenburg, M.C. (24-10-2012). Mathematical potential of special education students. Utrecht: Utrecht University.
253. Doppenberg, J.J. (24-10-2012). *Collaborative teacher learning: settings, foci and powerful moments.* Eindhoven: Eindhoven University of Technology.
254. Kenbeek, W.K. (31-10-2012). Back to the drawing board. Creating drawing or text summaries in support of system dynamics modelling. Enschede: University of Twente.
255. De Feijter, J.M. (09-11-2012). Learning from error to improve patient safety. Maastricht: Maastricht University.
256. Timmermans, A.C. (27-11-2012). Value added in educational accountability: Possible, fair and useful? Groningen: University of Groningen.
257. Van der Linden, P.W.J. (20-12-2012). A design-based approach to introducing student teachers in conducting and using research. Eindhoven: Eindhoven University of Technology.

258. Noroozi, O. (11-01-2013). *Fostering argumentation-based computer-supported collaborative learning in higher education.* Wageningen: Wageningen University.
259. Bijker, M.M. (22-03-2013). *Understanding the gap between business school and the workplace: Overconfidence, maximizing benefits, and the curriculum.* Heerlen: Open University of the Netherlands.
260. Belo, N.A.H. (27-03-2013). *Engaging students in the study of physics.* Leiden: Leiden University.
261. De Jong, R.J. (11-04-2013). *Student teachers' practical knowledge, discipline strategies, and the teacher-class relationship.* Leiden: Leiden University.
262. Verberg, C.P.M. (18-04-2013). *The characteristics of a negotiated assessment procedure to promote teacher learning.* Leiden: Leiden University.
263. Dekker-Groen, A. (19-04-2013). *Teacher competences for supporting students' reflection. Standards, training, and practice.* Utrecht: Utrecht University.
264. Knol, M.K. (19-04-2013). *Improving university lectures with feedback and consultation.* Amsterdam: University of Amsterdam.
265. Van Diggelen, M.R. (21-05-2013). *Effects of a self-assessment procedure on VET teachers' competencies in coaching students' reflection skills.* Eindhoven: Eindhoven University of Technology.
266. Azkiyah, S.N. (23-5-2013). The effects of two interventions on teaching quality and student outcome. Groningen: University of Groningen.
267. Taminiau, E.M.C. (24-05-2013). Advisory models for on-demand learning. Heerlen: Open University of the Netherlands.
268. De Milliano, I.I.C.M. (24-05-2013). *Literacy development of low-achieving adolescents. The role of engagement in academic reading and writing.* Amsterdam: University of Amsterdam.
269. Vandyck, I.J.J. (17-06-2013). *Fostering community development in school-university partnerships.* Amsterdam: VU University Amsterdam.
270. Hornstra, T.E. (17-06-2013). *Motivational developments in primary school. Group-specific differences in varying learning contexts.* Amsterdam: University of Amsterdam.
271. Keuvelaar-Van den Bergh, L. (26-06-2013). *Teacher feedback during active learning: The development and evaluation of a professional development programme.* Eindhoven: Eindhoven University of Technology.
272. Van Meeuwen, L.W. (06-09-13). *Visual problem solving and self-regulation in training air traffic control.* Heerlen: Open University of the Netherlands.
273. Pillen, M.T. (12-09-2013). *Professional identity tensions of beginning teachers* Eindhoven: Eindhoven University of Technology
274. De Kleijn, R.A.M. (27-09-2013). *Master's thesis supervision. Feedback, interpersonal relationships and adaptivity.* Utrecht: Utrecht University.
275. Bezdan, E. (04-10-2013). *Graphical overviews in hypertext learning environments: When one size does not fit all.* Heerlen: Open University of the Netherlands.

276. Bronkhorst, L.H. (4-10-2013). *Research-based teacher education: Interactions between research and teaching.* Utrecht: Utrecht University.
277. Popov, V. (8-10-2013). *Scripting intercultural computer-supported collaborative learning in higher education.* Wageningen: Wageningen University.
278. Dolfing, R. (23-10-2013). *Teachers' professional development in context-based chemistry education. Strategies to support teachers in developing domain-specific expertise.* Utrecht: Utrecht University.
279 Lucero, M.L. (21-11-2013). *Considering teacher cognitions in teacher professional development: Studies involving Ecuadorian primary school teachers*. Ghent: Ghent University.
280. Kamp, R.J.A. (28-11-2013). *Peer feedback to enhance learning in problem-based tutorial groups.* Maastricht: Maastricht University.
281. Cviko, A. (19-12-2013). *Teacher roles and pupil outcomes in technology-rich early literacy learning.* Enschede: University of Twente.
282. Van Der Zwet, J. (30-1-2014). *Identity, interaction, and power. Explaining the affordances of doctor-student interaction during clerkships*. Maastricht: Maastricht University.
283. De Smet, M.J.R. (31-1-2014). *Composing the unwritten text: Effects of electronic outlining on students' argumentative writing performance.* Heerlen: Open University of the Netherlands.
284. Hagemans, M.G. (07-03-2014). *On regulation in inquiry learning.* Enschede: University of Twente
285. Van Kuijk, M.F. (13-03-2014). *Raising the bar for reading comprehension. The effects of a teacher professional development program targeting goals, data use, and instruction.* Groningen: University of Groningen.
286. Karimi, S (14-3-2014). *Analysing and promoting entrepreneurship in Iranian higher education: Entrepreneurial attitudes, intentions and opportunity identification.* Wageningen: Wageningen University.
287. Frambach, J.M. (26-3-2014). *The cultural complexity of problem-based learning across the world.* Maastricht: Maastricht University.
288. Mascareno, M.N. (11-4-2014). *Learning opportunities in kindergarten classrooms. Teacher-child interactions and child developmental outcomes.* Groningen: University of Groningen.
289. Bakker, M. (16-04-2014). *Using mini-games for learning multiplication and division: A longitudinal effect study.* Utrecht: Utrecht University.
290. Van Loon, M. (8-5-2014). *Fostering monitoring and regulation of learning.* Maastricht: Maastricht University.
291. Coninx, N.S. (28-05-2014). *Measuring effectiveness of synchronous coaching using bug-in-ear device of pre-service teachers.* Eindhoven: Eindhoven University of Technology.

292. Baars, M.A. (6-6-2014). *Instructional strategies for improving self-monitoring of learning to solve problems.* Rotterdam: Erasmus University Rotterdam.
293. Hu, Y. (26-6-2014). *The role of research in university teaching: A comparison of Chinese and Dutch teachers.* Leiden: Leiden University.
294. Rutten, N.P.G. (5-9-2014). *Teaching with simulations.* Enschede: University of Twente.
295. Van Der Rijt, J.W.H. (11-9-2014). *Instilling a thirst for learning. Understanding the role of proactive feedback and help seeking in stimulating workplace learning.* Maastricht: Maastricht University.
296. Khaled, A.E. (7-10-2014). *Innovations in hands-on simulations for competence development. Authenticity and ownership of learning and their effects on student learning in secondary and higher vocational education.* Wageningen: Wageningen University.
297. Gaikhorst, L. (29-10-2014). *Supporting beginning teachers in urban environments.* Amsterdam: University of Amsterdam.
298. Wijnia, L. (14-11-2014). *Motivation and achievement in problem-based learning: The role of interest, tutors, and self-directed study.* Rotterdam: Erasmus University Rotterdam.
299. Gabelica, C. (4-12-2014). *Moving teams forward. Effects of feedback and team reflexivity on team performance.* Maastricht: Maastricht University.
300. Huizinga, T. (12-12-2014). *Developing curriculum design expertise through teacher design teams*. Enschede: University of Twente.
301. Van Strien, J.L.H. (19-12-2014). *Who to trust and what to believe? Effects of prior attitudes and epistemic beliefs on processing and justification of conflicting information from multiple sources.* Heerlen: Open University of the Netherlands.