HEIDI SYVÄOJA

PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOUR IN ASSOCIATION WITH ACADEMIC PERFORMANCE AND COGNITIVE FUNCTIONS IN SCHOOL-AGED CHILDREN

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ABSTRACT

Syväoja, Heidi
Physical activity and sedentary behaviour in association with academic performance and cognitive functions in school-aged children
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In addition to physical health benefits, physical activity may enhance children's cognitive and academic performance. Excessive sedentary behaviour, in turn, may have harmful effects on cognitive functions and academic achievement in children and adolescents. The purpose of this study was to determine the associations of physical activity and sedentary behaviour with academic achievement and cognitive functions in school-aged children. In addition, this study aimed to evaluate the internal consistency and one-year stability of the seven tests of computerized neuropsychological test battery used to assess children's cognitive functions.

Two hundred seventy-seven children from five schools in the Jyväskylä school district in Finland (58% of the 475 eligible students; mean age 12.2 years; 56% girls) participated in the study in the spring of 2011. Children's physical activity and sedentary behaviour were self-reported and measured objectively using accelerometers. Academic achievement scores (teacher-rated grade point averages) were provided by the education services of the city of Jyväskylä. Cognitive functions were evaluated with Cambridge Neuropsychological Test Automated Battery (CANTAB) using two tests for visual memory, three test for executive functions and two tests for attention. During spring 2012, the follow-up measurements were conducted among 74 children.

Self-reported physical activity had an inverse curvilinear association with academic achievement, and total screen time had a linear negative association with academic achievement, whereas objectively measured physical activity or sedentary time had no association with academic achievement. High levels of objectively measured physical activity were associated with good performance in attentional reaction time test. High levels of objectively measured sedentary time was associated with good performance in sustained attention test. Objectively measured physical activity or sedentary time had no association with other domains of cognitive functioning. Self-reported physical activity, total screen time or TV viewing had no association with assessed cognitive functions. High self-reported time spent in video game play and computer use was associated with poor performance in the tests measuring visuospatial working memory and shifting and flexibility of attention, respectively. The one-year stability of most cognitive tests was moderate-to-good, but the internal consistency was below an acceptable level for most of the tests, highlighting the need to confirm the psychometric characteristics of the computerized tests among target populations.

The results of this study showed that physical activity was positively – and screen time negatively – associated with academic achievement and certain cognitive functions in children. In addition, the positive association with objectively measured sedentary time and sustained attention shows that sedentary time also includes activities that may benefit certain cognitive functions. The results highlight the importance of promoting a physically active lifestyle.

Keywords: Physical activity, sedentary behaviour, academic achievement, cognitive functions, internal consistency, stability, children.

TIIVISTELMÄ

Syväoja, Heidi
Liikunnan ja liikkumattomuuden yhteydet lasten kognitiiviseen toimintaan ja koulumenestykseen
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Liikunta saattaa terveyshyötyjensä lisäksi vaikuttaa myönteisesti myös lasten kognitiiviseen ja akateemiseen suoriutumiseen. Liiallinen ruutuaika voi puolestaan heikentää lasten ja nuorten kognitiivista toimintaa ja koulumenestystä. Tämän tutkimuksen tarkoituksena oli selvittää liikunnan ja liikkumattomuuden yhteyksiä koulumenestykseen ja kognitiiviseen toimintaan kouluikäisillä lapsilla. Lisäksi selvitettiin lasten kognitiivisten toimintojen mittaamiseen käytetyn neuropsykologisen testipatteriston seitsemän eri testin luotettavuutta ja pysyvyyttä.

Tutkimukseen osallistui 277 lasta viidestä eri Jyväskylän alueen koulusta (58 prosenttia kutsutuista; keski-ikä 12,2 vuotta; 56 prosenttia tyttöjä) keväällä 2011. Lapset täyttivät liikuntaa ja ruutuaikaa koskevan kyselyn. Liikunnan ja liikkumattoman ajan määrää mitattiin myös objektiivisesti kiihtyvyysanturilla. Lasten koulumenestystiedot (todistuksen arvosanat) kerättiin Jyväskylän kaupungin opintorekisteristä. Kognitiivisia toimintoja mitattiin tietokonepohjaisella CANTAB-testipatteristolla (Cambridge Neuropsychological Test Automated Battery), johon valittiin kaksi testiä mittaamaan muistia, kolme testiä mittaamaan toiminnanohjausta ja kaksi testiä mittaamaan tarkkaavaisuutta. Osa lapsista (n=74) osallistui seurantamittauksiin keväällä 2012.

Itseraportoitu liikunta oli myönteisesti ja ruutuaika käänteisesti yhteydessä koulumenestykseen, kun taas objektiivisesti mitattu liikunta ja liikkumaton aika eivät olleet yhteydessä koulumenestykseen. Runsas objektiivisesti mitattu liikunta oli yhteydessä parempaan reaktioaikaan tarkkaavaisuustestissä. Runsas objektiivisesti mitattu liikkumaton aika oli yhteydessä parempaan pitkäkestoiseen tarkkaavaisuuteen. Objektiivisesti mitattu liikunta ja liikkumaton aika eivät olleet yhteydessä muihin mitattuihin kognitiivisen toiminnan osa-alueisiin. Runsas itseraportoitu videopelien peluu oli yhteydessä heikompaan suoriutumiseen työmuistitehtävässä ja tietokoneen käyttö heikompaan suoriutumiseen tarkkaavaisuuden joustavuutta mittaavassa testissä. Itseraportoitu liikunta, kokonaisruutuaika tai television katselu eivät olleet yhteydessä mitattuihin kognitiivisen toiminnan osa-alueisiin. Kognitiivisten testien mittaustulosten pysyvyys vuoden välein mitattuna vaihteli kohtalaisesta hyvään, kun taas eri testien sisäinen konsistenssi oli suhteellisen heikko suurimmassa osassa testejä, minkä vuoksi tietokonepohjaisten testipatteristojen psykometriset ominaisuudet tulisi tarkistaa aina kohdejoukossa.

Tulosten mukaan liikunta on myönteisesti ja ruutuaika käänteisesti yhteydessä koulumenestykseen ja tiettyihin kognitiivisen toiminnan osa-alueisiin. Kuitenkaan kaikki liikkumattomuus ei ole samanarvoista kognition kannalta, vaan osa liikkumattomasta ajasta saattaa sisältää toimintoja, jotka ovat kognition kannalta hyödyllisiä. Tutkimus antaa tukea liikunnallisen elämäntavan edistämiseen koulumenestyksen ja kognitiivisen toiminnan näkökulmasta.

Avainsanat: Liikunta, liikkumattomuus, koulumenestys, kognitiivinen toiminta, luotettavuus, pysyvyys, lapset.

No sensible decision can be made any longer without taking into account not only the world as it is but also the world as it will be.

-Isaac Asimov

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Heidi Syväoja

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LIST OF ORIGINAL PUBLICATIONS

The thesis is based on the following original publications, which are referred to in the text by their Roman numerals.

I 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 (11), 2098–2104.
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II Syväoja, H.J., Tammelin, T.H., Ahonen, T., Räsänen, P., Tolvanen, A., Kankaanpää, A. & Kantomaa, M.T. 2014. Internal consistency and stability of the CANTAB neuropsychological test battery in children. Psychological Assessment (Accepted for publication).
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III 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 (7): e103559.
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ABBREVIATIONS

ADHD	attention deficit hyperactivity disorder
B	unstandardized coefficient (in Table 5), estimate (in Table 6)
BDNF	brain-derived neurotrophic factor
Beta	standardized coefficient
CANTAB	Cambridge Neuropsychological Test Automated Battery
CFI	comparative fit index
CI	confidence interval
CRF	cardiorespiratory fitness
FIML	full information maximum likelihood
GPA	grade point average
HBSC	Health Behaviour in School-aged Children
HRR	heart rate reserve
ICC	intra-class correlations
IED	Intra-Extra Dimensional Set Shift
IRT	item response theory
MET	metabolic equivalent
MLR	robust standard errors
MPA	moderate physical activity
MVPA	moderate to vigorous physical activity
OR	odds ratio
p	p-value
PA	physical activity
PACER	Progressive Aerobic Cardiovascular Endurance Run
PE	physical education
PRM	Pattern Recognition Memory
RCT	randomized controlled trial
RMSEA	root mean square error of approximation
RTI	Reaction Time
RVP	Rapid Visual Information Processing
SD	standard deviation (in Tables 1–3)
SE	standard error (in Tables 5–6)
SOC	Stockings of Cambridge
SRM	Spatial Recognition Memory
SRMR	standardized root-mean-square residual
SSP	Spatial Span
TLI	Tucker–Lewis Index
UK	United Kingdom
US	United States
VPA	vigorous physical activity
WHO	World Health Organization
ΔR2	change in R square

CONTENTS

1 INTRODUCTION

Along with numerous societal changes over the past few decades, our lifestyle has become increasingly sedentary. This phenomenon is not only found among adults, but also in children (Nelson et al. 2006), who on average spend 4–8 hours per day being sedentary (Pate et al. 2011). In addition, only one-third of children are sufficiently active according to current physical activity recommendations (Ekelund, Tomkinson & Armstrong 2011). In Finland, about one half of primary school pupils and only one sixth of lower secondary school pupils fulfill the minimum recommendation for physical activity (Tammelin, Laine & Turpeinen 2013).

Lack of physical activity is seen as one of the increasing risk factors for lifestyle diseases: physical inactivity is associated with higher levels of obesity, metabolic and cardiovascular risk factors, depression symptoms, and lower physical fitness in children, whereas adequate physical activity may benefit all of these risk factors (Mountjoy et al. 2011, Tremblay et al. 2011b, Ekelund et al. 2012). Children's physical fitness has decreased and obesity has increased globally during the past couple decades (Tomkinson & Olds 2007, Lakshman, Elks & Ong 2012), including in Finland (Kautiainen et al. 2002, Huotari et al. 2010).

Along with convincing research evidence on the significance of regular physical activity for health, the idea that physical activity may enhance and support learning has also emerged in recent years. There is evidence that physical activity enhances cognitive functions, especially executive functions in the elderly (Hillman, Erickson & Kramer 2008, Guiney & Machado 2013). In addition, there is a recent increase in research suggesting that physical activity benefits children's cognitive functions and academic performance (Donnelly et al. 2009, Davis et al. 2011, Fisher et al. 2011, Kamijo et al. 2011, Chaddock-Heyman et al. 2013, Ardoy et al. 2014). In turn, excessive sedentary behaviour, especially screen-based sedentary behaviour, has been linked to poorer academic performance (Sharif & Sargent 2006, Mößle et al. 2010) and elevated risk of attention and learning difficulties (Swing et al. 2010, Weis & Cerankosky 2010).

Physical activity may have an underestimated and underused potential to support learning. However, evidence of the favourable effects of physical activity and the harmful effects of sedentary behaviour on cognitive functions and academic achievement in healthy children and adolescents is still inconsistent and based on scarce research data. Moreover, most of the previous studies have used self-reported measures of physical activity and sedentary behaviour, with only a few using objectively measured physical activity or sedentary time in connection with educational outcomes and cognitive functions.

As the rates of childhood physical inactivity are increasing worldwide, systematic research on the effects of physical activity and sedentary life on cognitive functions and academic performance is needed for both practitioners and policy makers to promote learning, education and health. This study aims to determine how subjectively and objectively measured physical activity and sedentary behaviour are associated with academic performance and cognitive functions in elementary school-aged children.

1.1 Physical activity and sedentary behaviour among school-aged children

According to traditional definition, physical activity is any bodily movement, which is produced by the contraction of skeletal muscle and increases energy expenditure above a basal level (Caspersen, Powell & Christenson 1985). Physical activity can be classified according to intensity using metabolic equivalent (MET) as a reference. One MET refers to the rate of energy expenditure while sitting at rest (US Department of Health and Human Services & US Department of Health and Human Services 2008). Therefore, moderate to vigorous physical activity (MVPA) is activity that increases the rest energy expenditure threefold (≥3 METs) (World Health Organization 2010), while small-to-large increases in breathing and heart-rate are caused by such activities as brisk walking, bicycling, running and swimming (US Department of Health and Human Services & US Department of Health and Human Services 2008).

In addition to energy expenditure, physical activity can be defined as biocultural behaviour: it occurs in many forms and contexts that are strongly influenced by culture (Malina 2001). Exercise is a subcategory of physical activity. It is planned, structured and repetitive bodily movement that aims to improve or maintain one or more components of physical fitness (Caspersen, Powell & Christenson 1985).

Sedentary behaviour can be defined as any waking behaviour requiring low levels of energy expenditure (≤ 1.5 METs) while in a sitting or reclining posture (Barnes et al. 2012). Sedentary behaviour includes many different activities, such as watching television, playing video games, computer use, reading, desk-based work, doing homework, and sitting while socializing. Sedentary behaviour and physical activity are independent constructs, as a person can have a great amount of sedentary time, but still meet the physical activity guidelines (Pate et al. 2011, Pate, O'Neill & Lobelo 2008).

Physical activity guidelines for health benefits state that children (aged 5–11 years) and youth (aged 12–17 years) should accumulate at least 60 minutes of MVPA per day, including vigorous-intensity activities at least three days per week and activities that strengthen muscle and bone at least three days per week (World Health Organization 2010, Tremblay et al. 2011c). In addition, recent American guidelines for physical activity during school day, state that children should have opportunity to accomplish more than half of the recommended 60 minutes per day of MVPA during regular school hours provided by school district, administrators, teachers and parents (Kohl & Cook 2013). Furthermore, Canadian guidelines on sedentary behaviour recommend that children and youth should minimize the time spent being sedentary each day and especially limit recreational screen time to no more than two hours per day (Tremblay et al. 2011a). Finnish physical activity recommendations for school-aged children are consonant with these international guidelines (Tammelin & Karvinen 2008). As indicated before, the majority of children and youth both internationally and nationally do not meet these recommendations (Ekelund, Tomkinson & Armstrong 2011, Salmon et al. 2011). Exacerbating these issues, physical activity continues to decrease and sedentary time continues to increase from childhood to adolescence (Troiano et al. 2008).

Traditionally, physical activity and sedentary behaviour have been measured subjectively with self-reported questionnaires or diaries. For children and youth, physical activity questionnaires typically assess specific types of physical activity, but also recreational physical activity, mostly expressed as duration of physical activity, time spent in MVPA or estimates of energy expenditure (Ekelund, Tomkinson & Armstrong 2011). Questionnaires have been accepted as being capable of ranking inter-individual differences in physical activity and demonstrating correlations between physical activity and other variables (Strath et al. 2013, Shephard 2014). However, one of the main weaknesses of self-reports is accuracy, especially among children (Ekelund, Tomkinson & Armstrong 2011). Children may overestimate their physical activity levels, compared to objectively measured physical activity (Corder et al. 2010).

Questionnaires used to evaluate sedentary behaviour have usually assessed the time spent in screen-based sedentary behaviour, especially time spent watching television (Tremblay et al. 2011b). In addition, non-screen-based sedentary behaviour such as educational sedentary behaviour, sedentary hobbies and social sedentary behaviours have been measured in self-reports (Pate et al. 2011). Recollection is also a potential issue for self-reports of sedentary behaviour. However, according to Pate et al. (2011), the estimated times spent in sedentary behaviour are similar between self-reports and objectively measured studies.

Objective measurements of physical activity and sedentary time have improved the ability to accurately determine the volume, intensity, duration and frequency of children's physical activity (Ekelund, Tomkinson & Armstrong 2011, Strath et al. 2013), eliminating bias caused by issues of recollection and social desirability and overcoming challenges caused by language and literacy difficulties (Evenson et al. 2006). Accelerometers are the most commonly used tools for objectively measuring physical activity and sedentary time (Ekelund, Tomkinson & Armstrong 2011).

Accelerometers record acceleration and deceleration of the body. Raw accelerometer data is often converted into other units, such as activity counts (Strath et al. 2013). Activity counts can be used to determine the intensity of activity by using thresholds, which have been developed by calibrating activity counts with measurements of oxygen consumption. (Evenson et al. 2006). There is ongoing debate about the thresholds for different intensity categories (sedentary, light, moderate or vigorous) and how the lack of consensus influences interpretation of data (Ekelund, Tomkinson & Armstrong 2011, Strath et al. 2013). In addition, accelerometers cannot track all activities, such as cycling or actions that require lifting a load (Strath et al. 2013); this is one weakness of accelerometers.

Usually, both questionnaires and objective measurements assess the total amount (frequency, duration and intensity) of physical activity and sedentary behaviour, not content or context. In this study, both self-report and accelerometer measurements were used to assess the amount of children's physical activity and sedentary behaviour when determining the relationship of physical activity and sedentary behaviour with academic performance and cognitive functions.

1.2 Academic achievement and cognitive functions

1.2.1 Academic achievement

Learning may be seen as a life-sustaining and an inevitable part of human growth and development. It is an active and interactive process, which results in changes in behaviour, but also in the skills, knowledge and emotional reactions underlying behaviour. Learning occurs in a specific cultural and social context. Many theories have been advanced over the years to understand how people learn. The social theory of learning was chosen to form the basis of this thesis. According to the social theory of learning, learning is seen as social participation (Bandura & McClelland 1977). This participation shapes who we are, what we do and how we interpret what we do (Figure 1) (Wenger 1998, 3–11, Wenger 2000).

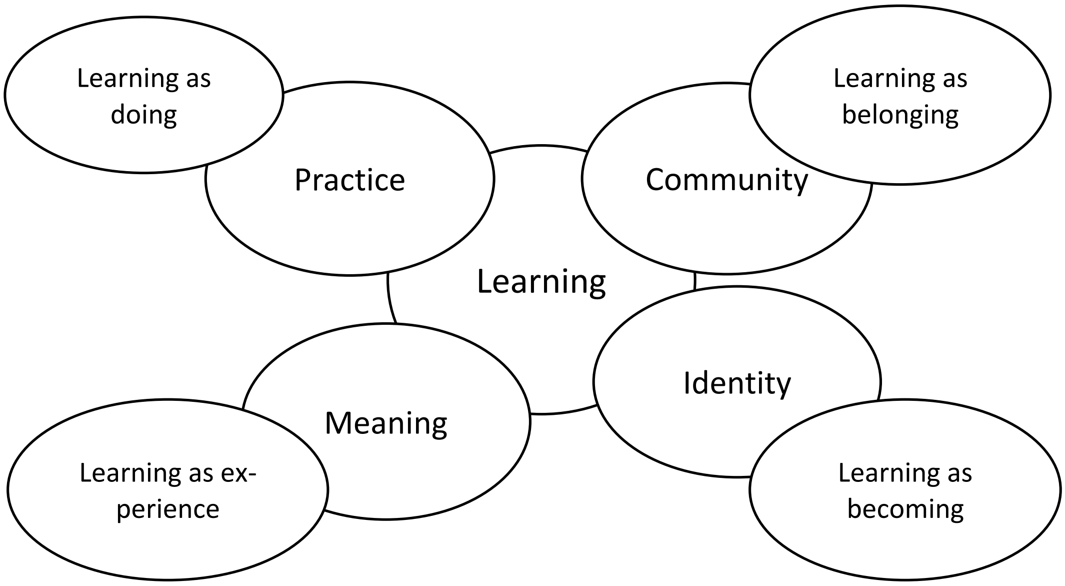

FIGURE 1. Components of the social theory of learning. (Figure modified after Wenger 1998, 5).

At schools, learning is the centre of action. Students' learning is evaluated, monitored and supported. Academic achievement is one way of assessing how well children have achieved their educational goals. The purpose of assessment is to support and enhance learning and teaching. Internationally, different standardized tests – including the disciplines of reading, spelling, arithmetic and science – are used to measure academic achievement, and grades given by teachers at the end of the term are also used. (Rasmussen & Laumann 2013).

In Finland, national standardized tests are not in use in primary or secondary schools. Assessment is based on teacher-rated academic achievement scores, which describe the level of performance in relation to the objectives outlined by the National Core Curriculum for Basic Education (National core curriculum for basic education 2004). Objectives not only include skills and knowledge, but also behaviour and students' working skills, such as the ability to plan, carry out and evaluate their own work. Children's working abilities make up part of the subject-based assessment, but behaviour is assessed separately. Teachers' evaluate children's academic achievements scores independently. (Ouakrim-Soivio 2013).

There is ongoing debate about the best possible method for grading, which is both comparable and commensurable. Grading that strongly depends on standardized achievement tests enables uniform evaluation and comparison between students. Standardized tests are practical, when measuring large group of children quickly, efficiently and affordably. (Ouakrim-Soivio 2013). However, it has been criticized for directing students to rehearse response techniques and for excluding incorrect responses rather than supporting actual knowledge and skills (Koretz & Hamilton 2006, Hamilton, Stecher & Yuan 2012). In addition, standardized tests have been criticized for being unable to measure children's learning comprehensively enough, for example they are not suitable for estimating children's ability to produce own stories (Ansley 1997). Grading, which is administered by the teacher and based on objectives outlined beforehand, enables a more versatile evaluation of children's learning. However, if the objectives of the national curriculum for each grade are not carefully followed in the process of evaluation, a teacher's independent role as evaluator may result in discrepancies in grades between students from different classes or schools with the same level of competence. Inequity and bias in grading weakens the opportunity to directly compare children's academic achievements. (Ouakrim-Soivio 2013).

From a psychological perspective, there are a lot of factors that influence and are associated with academic achievement (Winne & Nesbit 2010). The classic meta-analytic study by Wang, Haertel and Walberg (1994) showed that factors that directly influence children and children's close social interactions had a greater impact on academic achievement than indirect influences. Children's metacognitive and cognitive skills, classroom management, home environment and parental support, and social interactions between students and teachers had the greatest effect on academic achievement (Wang, Haertel & Walberg 1994).

Cognitive processes, especially executive functions (defined later) (Lu et al. 2011, McClelland & Cameron 2011, Weber et al. 2013), have been shown to be strong predictors of academic achievement in elementary school. Motivation, and ultimately, achievement are influenced by people's beliefs about their capability to do different tasks, but also the reasons for doing them (Wigfield & Cambria 2010). When individuals have high self-efficacy beliefs (strong beliefs about their own capabilities) (Caprara et al. 2011, Weber et al. 2013), they are more likely to engage in activities, persist in spite of difficulties, and succeed (Wigfield & Cambria 2010).

Reasons for performing tasks – such as achievement values, goal orientations and interest, and intrinsic value – are also important predictors of achievement outcomes and learning (Wigfield & Cambria 2010, Weber et al. 2013). In addition, parental involvement in their children's education (Karbach et al. 2013) also plays an important role in predicting children's academic achievement.

This study focused on teacher-rated academic scores, on the basis of which grade point averages (GPA) were calculated in order to represent children's overall academic performance.

1.2.2 Cognitive functions

From the neurocognitive perspective, learning is the reconstruction of neuronal networks. These neuronal networks form the biological foundation of cognition, intelligence and learning (Anderson 1997). Intelligence can be defined as an individual's comprehensive cognitive ability to reason, plan, solve problems, think abstractly, understand complex ideas, learn quickly and learn from experience (Neisser et al. 1996, Nisbett et al. 2012). In addition, several specific concepts of cognition have been defined such as executive functions, memory and attention.

Executive functions (also called executive control, the central executive, or cognitive control) are the collection of higher-order cognitive processes that control goal-directed actions. Essential for purposeful behaviour, executive functions regulate cognition, emotion and action. Three core executive functions are inhibition, working memory and mental flexibility. (Diamond 2013). Inhibitory control (inhibition) includes selective attention and the inhibition of inappropriate or interfering responses. In other words, inhibition enables appropriate action by controlling attention, behaviour, thoughts, and emotions to suppress dominant, automatic, or prepotent responses. (Best, Miller & Jones 2009, Diamond 2013). Working memory is defined as the ability to actively retain information in one's mind and mentally manipulate it for brief periods of time. Working memory can be considered as a three-component system involving a control system of limited attentional capacity (a part of executive functions) and two assisting temporary storage systems (Baddeley & Hitch 1974, Baddeley 2012, Diamond 2013). Mental flexibility (shifting), in turn, is defined as the ability to change perspectives and shift between mental states, operations or tasks. These core functions are tightly linked together, and higher executive functions like reasoning, problem-solving and planning are built from these core functions. (Best, Miller & Jones 2009, Diamond 2013).

According to one definition, memory is a lasting representation reflected in thought, experience, or behaviour. It is not a single unitary system, but consists of subsystems called working memory, short-term and long-term memory, which can also be divided into different components. Short-term memory refers to simple temporary storage of information, whereas working memory points to active manipulation of shortly maintained information (Baddeley 2012). As stated above, working memory consists of a supervisory system, which uses two short-term memory systems: one concerning speech and sound (phonological loop) and the other visuospatial information (visuospatial sketchpad) (Baddeley & Hitch 1974, Baddeley 2012, Diamond 2013). Long-term memory includes stored memories and learned knowledge and skills. It can be divided into explicit memory, which includes perceptual, episodic and semantic memories, and implicit memory, which includes implicit knowledge, primed biases and goals as well as highly practised habits and motor skills (Jeneson & Squire 2011, Baddeley 2012).

Attention can be divided into three sub-systems: alerting, orienting and the executive network. Alerting involves achieving and maintaining optimal vigilance during a task, while orienting concerns the ability to prioritize sensory input by selecting a modality or location. The executive network, in turn, is active when processing targets, conflicts and errors (Petersen & Posner 2012, Posner & Rothbart 2014). Attention can be voluntary, goal-directed executive attention or spontaneous bottom-up attention. Executive attention (also called selective or focused attention) enables us to selectively attend to and focus on what we decide, as well as to suppress attention to other stimuli. Spontaneous attention, in turn, is driven by the properties of these stimuli. Due to the selective and controlling nature of executive attention, it can be seen as one executive function, as described above. (Diamond 2013).

Even though many cognitive tests evaluate one specific cognitive function, cognitive functioning is usually a dynamic interactive process of many different functions. For example, paying attention to sensory or internal information is directed by selective attention, after which information becomes available for working memory. Working memory can actively manipulate information, while inhibitory control hinders internal and external distractions. Managing information in working memory is determined by our goals and our existing information (in long-term memory), and attending to selective aspects of the environment. Manipulated information is encoded into long-term memory, and learning takes place. (Baars & Gage 2010, 33–60).

From a developmental perspective, these neurocognitive functions emerge during the early years of life. However, especially the executive functions continue to develop throughout childhood and adolescence, due to protracted development of the brain structures that support them. Different domains of executive functions vary in their developmental trajectories and may not be fully functionally mature by the age of 12 years. (Luciana & Nelson 1998, Luciana & Nelson 2002, Best & Miller 2010). The focus of this thesis is to study associations of physical activity and sedentary behaviour on visual memory, executive functions and attention. Therefore, other domains of cognitive functions will not be discussed further.

1.2.3 Assessments of cognitive functions

Traditionally, cognitive functions have been measured with paper-and-pencil tests to assess specific cognitive ability, for example, the Corsi Blocks test for measuring visuospatial working memory (Milner 1971), Tower of London measuring planning and spatial working memory (Shallice & Shallice 1982, Owen et al. 1990) and the Wisconsin Card Sorting test for measuring mental flexibility (Heaton et al. 1993).

In recent years, the use of computer technology in neuropsychological assessments has increased worldwide, and computer-based test batteries have been used for psychological assessments, for evaluating changes over time, and for evaluating the effects of interventions (Lowe & Rabbitt 1998). Computer technology has made valuable contributions to neuropsychological assessments by increasing efficiency, ease and standardization of administration; reducing errors during scoring; and increasing accuracy of timing and response latencies (Cernich et al. 2007, Parsey & Schmitter-Edgecombe 2013).

In this study, the Cambridge Neuropsychological Test Automated Battery (CANTAB) was used to assess children's cognitive functions. The CANTAB is one of the oldest computer-based test batteries used to evaluate neurocognitive functions, particularly in clinical trials research. CANTAB tests are mainly based on traditional neuropsychological tests. These non-verbal tests measure visual and spatial memory, working memory, planning, different aspects of attention, and other areas of cognition. (Cambridge Cognition Ltd., 2006). According to previous reports, CANTAB has been found suitable for assessing cognitive functions in 4- to 90-year-old individuals (Lowe & Rabbitt 1998, Luciana 2003). In addition, it has been found sensitive to cognitive deficits due to several neuropsychological and psychiatric conditions and diseases, especially in the elderly (e.g. Sahakian et al. 1993, Robbins et al. 1998, Blackwell et al. 2004, Levaux et al. 2007) but also in children (Luciana et al. 1999, Gau & Shang 2010, Rhodes et al. 2011, Fried et al. 2012).

However, earlier studies did not provide adequate information about the reliability of CANTAB tests (Luciana & Nelson 2002). Luciana (2003) reported that internal consistency coefficients for CANTAB tests were high (0.73 – 0.95) in 4–12-year-old children. Furthermore, studies measuring the test-retest reliability of CANTAB have been sparse. Lowe and Rabbit (1998) reported that in an elderly adult population, the test-retest agreement for the CANTAB tests was either moderate, ranging from 0.70 to 0.86, or low, ranging from 0.09 to 0.68. According to Fisher et al. (2011), intra-class correlations for CANTAB subtests, Spatial Span length, and Working Memory errors were quite low (ICC = 0.51 – 0.59) in healthy children. However, Gau and Shang (2010) reported higher intra-class correlations for CANTAB tests (Intra-Extra Dimensional Set Shift, Spatial Span, Spatial Working Memory, Stockings of Cambridge), ranging from 0.55 to 0.94 in a group of 10 children with attention deficit hyperactivity disorder (ADHD).

To our knowledge, there are no other studies that establish the internal consistency agreement or test-retest agreement for CANTAB tests in a child population (Luciana 2003, Henry & Bettenay 2010), while the results of existing studies are, to some extent, inconsistent.

1.3 Associations of physical activity, academic achievement and cognitive functions

Previous studies have shown that physical activity enhances neurocognitive functions and protects against neurodegenerative diseases in the elderly (Kramer & Erickson 2007, Hillman, Erickson & Kramer 2008, Lautenschlager et al. 2008, Erickson et al. 2011). Most typically the effects have been seen in executive functioning, related to selective attention and inhibitory control, mental flexibility and working memory (Guiney & Machado 2013). More recently, physical activity has been linked to better academic performance (Shephard 1997, Trost 2008, Trudeau & Shephard 2008, Trudeau & Shephard 2010, Centers for Disease Control and Prevention. 2010, Singh et al. 2012) and enhanced cognitive functions (Sibley & Etnier 2003, Hillman, Erickson & Kramer 2008, Hillman, Kamijo & Scudder 2011, Guiney & Machado 2013) in children.

Earlier studies have reported that physical activity may benefit (Tuckman & Hinkle 1986, Tremblay, Inman & Willms 2000, Dwyer et al. 2001, Coe et al. 2004, Coe et al. 2006, Fredericks, Kokot & Krog 2006, Hillman et al. 2006, Nelson et al. 2006, Davis et al. 2007, Tremarche, Robinson & Graham 2007) or do not compromise (Low 1990, Sallis et al. 1999, Dollman, Boshoff & Dodd 2006, Yu et al. 2006, Ahamed et al. 2007, Sigfusdottir, Kristjansson & Allegrante 2007) academic and cognitive performance, but conflicting results have also been observed (Themane et al. 2006). In addition, acute exercise during the school day has been shown to have benefits on academic and cognitive performance (McNaughten & Gabbard 1993, Catering & Polak 1999, Maeda & Randall 2003). Moreover, physical fitness (Sollerhed & Ejlertsson 1999, Kim et al. 2003, Grissom 2005, Hillman, Castelli & Buck 2005, Castelli et al. 2007) and participation in sports (Silliker & Quirk 1997, Dexter 1999, Lindner 1999, Stephens & Schaben 2002, Eitle 2005) has been linked to enhanced academic achievement and cognition, but not in all studies (Schumaker, Small & Wood 1986, Hanson & Kraus 1998, Daley & Ryan 2000, Eitle & Eitle 2002, Lindner 2002, Miller et al. 2005).

In 2010, the results of these earlier studies were synthesized and published by the Centers for Disease Control and Prevention. A comprehensive report summarizes the scientific literature (43 articles) published between 1985 and October 2008 that concerns the associations of school-based physical activity and academic performance (Centers for Disease Control and Prevention 2010). School-based physical activity included physical education, physical activity during recess, classroom physical activity and extracurricular activity, while academic performance included academic achievement, academic behaviour and indicators of cognitive skills and attitudes. According to the report, physical activity had a positive association (50.5% of the associations summarized), no association (48% of the associations summarized), or negative association (1.5% of the associations summarized) with academic performance. Moreover, increased physical activity on school days was not associated with attenuated academic performance (Centers for Disease Control and Prevention 2010). The associations of physical activity, academic achievement and cognitive functions observed in studies published in 2008 or later are described in more detail below.

1.3.1 Physical activity in association with academic achievement

A few intervention studies have reported that integrated physical activity in academic lessons (Donnelly et al. 2009, Reed et al. 2010), increased physical education (Ericsson 2008, Spitzer & Hollmann 2013, Ardoy et al. 2014) and aerobic exercise programmes (Davis et al. 2011) benefit children's academic achievement.

In the study of Donelly et al. (2009), academic achievement scores for reading, spelling and math significantly improved from the baseline to three years in children participating in the intervention, compared to control children. In addition, improvements in total academic achievement have been reported (Ardoy et al. 2014), as well as in math (Ericsson 2008, Davis et al. 2011, Spitzer & Hollmann 2013, Ardoy et al. 2014), mother tongue (Ericsson 2008, Spitzer & Hollmann 2013) and social studies (Reed et al. 2010). However, in some of these studies, physical activity had no effect on achievements of reading and language (Reed et al. 2010, Davis et al. 2011, Ardoy et al. 2014), foreign language (Spitzer & Hollmann 2013) or science (Reed et al. 2010).

To summarize the results of these few intervention studies, increasing physical activity to the school week benefits academic achievement in certain school subjects in certain studies, but has no effect on certain subjects. These interventions lasted for about four months with the exception of the intervention of Donelly et al. (2009), which lasted for three years. Davis et al. (2011) speculated that a longer intervention may result in more benefit. Short-term interventions may partly explain the somewhat diverging results.

The associations of physical activity and academic achievement have also been measured by longitudinal studies. In the longitudinal study by Stevens et al. (2008), physical activity, but not physical education, was positively associated with mathematics and reading achievement in both boys and girls. Whereas Carlson et al. (2008) reported that girls who had the highest amount of physical education had better math and reading achievement compared to girls with the lowest physical education exposure, while no effect was realized for boys.

Haapala et al. (2014a) examined the association of different types of physical activities in first grade with reading and arithmetic skills in grades 1–3. According to the results, children who had more physical activity during recess and children who most often commuted actively to school had better reading fluency across grades 1–3. In addition, children who engaged in organized sports had better arithmetic skills. However, the results were slightly different when data was analysed separately for boys and girls. Boys who had more total physical activity and most often commuted actively to school had better reading fluency and reading comprehension. However, among girls, total physical activity was positively associated with reading fluency and arithmetic skills only for girls whose parents had university level education, while the association was inverse in girls whose parents were less educated (Haapala et al. 2014a).

Booth et al. (2014), in turn, examined the associations of objectively measured MVPA at the age of 11 with academic achievement at the age of 11, 13 and 16. MVPA at the age of 11 predicted higher English scores in both sexes at all ages, and higher science scores in females at age of 11 and 16. (Booth et al. 2014). Booth et al. (2014) concluded that MVPA may have a long-term positive influence on academic performance. These results of the longitudinal studies are slightly inconsistent. The authors highlighted factors like intensity and type of physical activity or other factors independent of physical activity such as social development, which may explain the differences (Carlson et al. 2008, Stevens et al. 2008, Booth et al. 2014, Haapala et al. 2014a).

Cross-sectional studies determining the relationship of self-reported physical activity and academic achievement (mostly examined by GPA) in children and adolescents have reported a positive association between physical activity and overall academic achievement (Kristjansson et al. 2009, Vindfeld, Schnohr & Niclasen 2009, Fox et al. 2010, Kantomaa et al. 2010, Kristjansson, Sigfusdottir & Allegrante 2010, Edwards, Mauch & Winkelman 2011, So 2012, Kantomaa et al. 2013, Shi et al. 2013). In addition, reported physical activity was especially associated with math performance in girls (Martínez-Gómez et al. 2012), and in boys (O'Dea & Mugridge 2012).

However, studies using objectively measured physical activity to determine association with academic achievement have not been as unanimous. According to Kwak et al. (2009), objectively measured vigorous physical activity was positively associated with overall academic achievement in girls, but not in boys. In addition, Telford et al. (2012) reported that objectively measured physical activity was associated with better writing scores, but not with reading or math scores. However, LeBlanc et al. (2012) reported that objectively measured MVPA was not associated with performance gains in academic achievement tests in children.

The effects of acute exercise on academic achievement has also been slightly inconsistent. Acute aerobic exercise has been shown to improve reading comprehension (Hillman, Pontifex & Themanson 2009, Duncan & Johnson 2014) and spelling (Duncan & Johnson 2014), have no effect on sentence comprehension (Duncan & Johnson 2014) or spelling and arithmetic (Hillman, Pontifex & Themanson 2009), and attenuate arithmetic (Duncan & Johnson 2014). The timing of the academic testing after an acute bout of exercise may be one factor explaining these conflicting findings. According to Hillman et al. (2009), acute exercise only enhanced reading comprehension, which was measured first, and had no effects on spelling or arithmetic, which were assessed following reading comprehension. This suggests that the benefits of acute exercise may subside over time.

Physical fitness has often been used as a proxy indicator of regular physical activity, when the association of physical activity and academic achievement has been examined. In the longitudinal study by London and Castrechini (2011), persistently fit children had higher English and math test scores compared to persistently unfit children. Similarly, Wittberg, Northrup and Cottrell (2010) reported that students who stayed in the “healthy” fitness zone from fifth to seventh grade had significantly higher academic scores than students who stayed in the “needs improvement” zone.

According to previous cross-sectional studies, good physical fitness has been associated with better performance in literature and math test scores (Chomitz et al. 2009, Blom et al. 2011, Van Dusen et al. 2011). In addition, aerobic fitness in particular has had a positive association with literature and math test scores (Roberts, Freed & McCarthy 2010, Welk et al. 2010, Wittberg et al. 2010, Davis & Cooper 2011, Scudder et al. 2014). In the study by Edwards, Mauch and Winkelman (2011), higher aerobic fitness was related to math scores, but not reading scores. Moreover, Padilla-Moledo et al. (2012) reported a positive association between muscular fitness and academic achievement.

However, there are also studies reporting no associations between physical fitness and academic achievement (Chic & Chen 2011, Wingfield et al. 2011), aerobic fitness and academic skills (Haapala et al. 2014b, Moore et al. 2014), and muscular fitness and math and reading scores (Edwards, Mauch & Winkelman 2011). In addition, in some studies the association between fitness and academic achievement has been different for girls and boys. Eveland-Sayers et al. (2009) reported that aerobic fitness was positively associated with math and reading scores only in girls, while Kwak et al. (2009) reported that cardiovascular fitness was positively associated with GPA only in boys.

To sum up the association between physical activity and academic achievement, it seems that children who are more physically active have better academic achievement. However, the reports to date have generally been weak and inconsistent. Especially, there is no intervention, longitudinal, or cross-sectional studies that have replicated the study design and confirmed the results. In addition, previous studies were conducted in various countries with varying educational systems, which makes it difficult to compare the results. Moreover, most of the previous studies have used self-reported measurements of physical activity and academic performance; only a few have objectively measured physical activity to determine the association with educational outcomes. In conclusion, existing studies only show that certain physical activities are associated with certain academic achievements in certain child populations.

1.3.2 Physical activity in association with cognitive functions

In recent intervention studies, physical activity has been reported to benefit children's cognitive functions. Ardoy et al. (2014) reported that participating in four high-intensity PE lessons per week improved children's overall cognitive performance (including non-verbal and verbal abilities, abstract reasoning, spatial ability, numerical ability and verbal reasoning), compared to two or four hours of normal PE lessons per week. In addition, Reed et al. (2010) reported that intervention integrating physical activity into core curricula at school enhanced performance in fluid intelligence, which is considered to illustrate general intelligence and cognitive ability. Likewise, intervention providing 45 minutes of daily physical education led to improvements in fluid intelligence and perceptual speed (Reed et al. 2013). However, the improvements were only observed in certain sections of the fluid intelligence test and were dependent on age and gender (Reed et al. 2013).

In particular, executive functions have been reported to benefit from physical activity interventions. Different types of interventions like physical education interventions (Fisher et al. 2011, Spitzer & Hollmann 2013, Crova et al. 2014) and school-based physical activity programmes (Davis et al. 2011, Chaddock-Heyman et al. 2013) led to improvements in selective attention and inhibition performance. In addition, aerobically intense physical education intervention and afterschool physical activity programme enhancing aerobic fitness improved children's spatial working memory and temporal working memory, respectively (Fisher et al. 2011, Kamijo et al. 2011). However, in Puder et al.'s (2011) study, a multidimensional physical activity programme enhancing fitness did not affect spatial working memory or selective attention. In addition, physical education programme including cognitively challenging activities had no effect on verbal working memory (Crova et al. 2014). Puder et al. (2011) speculated that the fairly weak reproducibility of the measures in 5-year-old children and the lack of power may explain contradictory results.

Davis et al. (2011) reported that overweight children participating in aerobic exercise programme had higher scores in planning scale assessing strategy generation and application, self-regulation, intentionality and utilization of knowledge, but not in attention, simultaneous or successive sub-scales of the Cognitive Assessment System compared to control children at post-test. They stated that only planning scale measures executive functions, and especially, executive functions are cognitive functions that seems to benefit from physical activity (Davis et al. 2011). However, Fisher et al. (2011), reported that aerobically intense physical education intervention had no effect on any scale of Cognitive Assessment System in healthy children. According to Fisher et al. (2011), intervention was not able to increase time spent in MVPA during physical education lessons enough, which may explain the lack of effect. In addition, the respond to physical activity may differ between lean and overweight children (Davis et al. 2011).

In the study Monti, Hillman and Cohen (2012), there were no differences in relational memory performance between children participating in an aerobic exercise programme and control children after a nine-month after-school intervention promoting fitness. However, compared to the control children, children who participated in the aerobic exercise intervention displayed eye-movement patterns indicative of superior relational memory accuracy (Monti, Hillman & Cohen 2012). This indicates that behavioural test may not been sensitive enough to detect small changes in memory performance.

To sum up the results of these intervention studies, it seems that physical activity enhances children's cognitive functions, and especially executive functions. However, there are only a few intervention studies and hardly any randomized controlled trials. In addition, there have been differences in how physical activity is implemented, what cognitive domains have been assessed and how they have been measured, and the ages of the children have also been varied across studies, making it hard to draw any further conclusions.

The association of physical activity and cognitive functions has also been measured with cross-sectional studies, which supports the results of the intervention studies. In the study by Ruiz et al. (2010), leisure-time physical activity was associated with better cognitive performance, including verbal, numeric and reasoning abilities in adolescents. In addition, Castelli et al. (2011) reported that engagement in vigorous physical activities had a positive association with performance in inhibitory control task.

Besides chronic effects of physical activity, recent studies have also shown that acute physical exercise induces positive changes in free-recall memory performance (Pesce et al. 2009), working memory performance (Hill et al. 2010), and inhibitory control performance (Budde et al. 2008, Hillman, Pontifex & Themanson 2009, Hill et al. 2010, Best 2012, Drollette et al. 2012, Gallotta et al. 2012, Hogan et al. 2013). In addition, in the study by Drollette et al. (2014), the effects of acute aerobic exercise on inhibitory control performance were examined in two groups of children categorized as higher- and lower-performers. Children were divided into two groups according to their inhibitory control performance following the resting session. According to the results, higher-performers maintained their performance, while lower-performers improved their performance in inhibitory control task following exercise. However, acute physical activities have not improved spatial working memory performance (Drollette et al. 2012) or inhibitory control (Stroth et al. 2009) in all studies. According to Stroth et al. (2009), the selected task assessing inhibition was too easy for children, and due to a ceiling effect the effects of acute exercise on inhibition was not revealed. Drollette et al. (2012), in turn, suggested that acute exercise may affect selectively to executive functions enhancing inhibitory control, but not working memory.

As stated before, physical fitness has been used as a proxy measure of regular physical activity. Associations of physical fitness and cognition have been measured with cross-sectional and longitudinal studies. According to the longitudinal study by Chaddock et al. (2012b), children with higher aerobic fitness outperformed less fit children in an inhibitory control task at the initial time of fitness testing, as well as one year later. In addition, children with high aerobic fitness have demonstrated better inhibitory control performance in cross-sectional studies (Buck, Hillman & Castelli 2008, Hillman et al. 2009, Chaddock et al. 2010b, Pontifex et al. 2011, Voss et al. 2011, Wu et al. 2011, Chaddock et al. 2012a, Pontifex et al. 2012, Crova et al. 2014). In addition, Hogan et al. (2013) reported a positive interactive effect of physical fitness level and acute aerobic exercise on inhibitory control: higher fit children had shorter reaction times after exercise compared to a resting condition. However, according to Stroth et al. (2009) and Castelli et al. (2011), aerobic fitness were not associated with inhibitory control.

High aerobic fitness have also been connected to better memory performance (Chaddock et al. 2010a, Chaddock et al. 2011, Raine et al. 2013), planning ability (Davis & Cooper 2011), attentional performance (Davis & Cooper 2011, Wu & Hillman 2013) and arithmetic cognition (Moore et al. 2014). Furthermore, Chaddock et al. (2012c) reported that aerobically more fit children outperformed less fit children in a virtual street-crossing task. More fit children maintained street-crossing performance when distracted, whereas the performance of less fit children attenuated when conversing on a phone. Finally, Åberg et al. (2009) reported that cardiovascular fitness was associated with intelligence in young adulthood. Still, fitness has not always been reported to have an association with cognition. Ruiz et al. (2010) reported that neither aerobic nor muscular fitness was associated with overall cognitive performance. Whereas Davis et al. (2011) reported that fitness was not associated with the Simultaneous (processing with spatial and logical questions) or Successive (analysis/recall of stimuli arranged in sequence) sub-categories of the Cognitive Assessment System.

These apparent inconsistencies in associations between physical activity and cognition suggest that physical activity may selectively affect certain cognitive functions such as executive functions. However, it seems that studies have most often measured the association between physical activity and executive functions. In addition, there are no studies with exactly the same design, which attenuates the interpretation of the results. Furthermore, physical fitness has often been used as a proxy indicator of regular physical activity, without direct measurement of actual physical activity levels. This is particularly important because in childhood habitual physical activity is rarely intensive and lengthy enough to enhance aerobic fitness, and therefore, the relationship between physical activity and fitness may not be meaningful (Armstrong, Tomkinson & Ekelund 2011). This may cause discrepancies in results. For example, Ruiz et al. (2010) and Castelli et al. (2011) reported that physical activity was associated with cognition, while fitness was not.

In summary, it seems that physical activity benefits children's cognitive functions. However, evidence of the favourable effects of physical activity on cognitive functions in healthy children and adolescents is still somewhat inconsistent and based on scarce research data. Especially, the type of physical activity assessed and measurements of physical activity used have varied across studies. Similarly, the assessments of certain cognitive domains have been divergent. Moreover, only a few studies have measured a broad range of cognitive functions. This highlights the need for new studies to clarify the benefits of physical activity on different dimensions of cognitive functions.

1.4 Associations of sedentary behaviour, academic performance and cognitive functions

Since the invention of television, the effects of children's exposure to TV has been discussed in terms of academic achievement and cognitive development (Maccoby 1951). According to these early studies, excessive television viewing may have an unfavourable impact on children's cognitive functions and academic achievement, but the evidence is ambiguous (Gaddy 1986, Gortmaker et al. 1990, Levine & Waite 2000), suggesting that the effects of TV consumption may vary as a function of socioeconomic background, intelligence and other sub-groups of children (Anderson & Collins 1988, Beentjes & Van der Voort, Tom HA 1988, Smith 1992, Cooper et al. 1999). In addition, the association may not be linear, implying that the association turns negative with high amounts of TV viewing (Williams et al. 1982).

Newer studies seem to support this observation by reporting an inverse association between high amounts of TV viewing and lower academic achievement (Chernin & Linebarger 2005, Schmidt & Vandewater 2008, Tremblay et al. 2011b), curvelinearity of the association (Razel 2001) and an association between high amounts of TV viewing and attention problems in school-aged children (Schmidt & Vandewater 2008).

Especially early-childhood TV exposure may have a negative impact on children's development, including language, cognition and attention capacity, and readiness to attend school (Clarke & Kurtz-Costes 1997, Wright et al. 2001, Christakis 2009). In addition, early-childhood TV viewing has been associated with attention problems (Christakis et al. 2004, Zimmerman & Christakis 2007), attenuated cognitive outcomes (Zimmerman & Christakis 2005) and decreased academic achievements (Pagani et al. 2010) at school-age. However, inconsistent results have also been reported in early childhood, showing no association between TV exposure and language or visual motor skills (Schmidt et al. 2009). On the other hand, educational TV viewing has been linked to enhanced academic and cognitive outcomes (Linebarger et al. 2004, Chernin & Linebarger 2005, Kirkorian, Wartella & Anderson 2008, Schmidt & Vandewater 2008).

Besides TV viewing, computer use, video game playing and other screen-based sedentary behaviour have also been linked to cognitive skills and academic achievement. According to recent studies, playing computer or video games may even benefit cognitive functions, especially attentional, visuospatial and problem-solving skills in young adults (Spence & Feng 2010, Granic, Lobel & Engels 2013), as well as in children and adolescents (Subrahmanyam et al. 2001, Schmidt & Vandewater 2008). In addition, computer use has been associated with slightly better academic performance (Subrahmanyam et al. 2001). However, previous results have not been consistent. The associations of screen-based sedentary behaviour, academic achievement and cognitive functions in school-aged children are described more in detail below.

1.4.1 Sedentary behaviour in association with academic achievement

According to recent studies, media use in childhood – especially time spent viewing TV, playing video games, and using the Internet – has a negative association with academic achievement. In a longitudinal study by Sharif, Wills and Sargent (2010), screen-time exposure – including TV viewing, video game playing and the presence of a television in the bedroom – had adverse effects on improvements in overall school performance in children aged 10–14 years.

Similarly, Mößle et al. (2010) reported the results of two studies among primary school students. According to the cross-sectional results among fourth-grade students, the time used for playing computer or video games and watching TV, DVDs and videos was negatively associated with school achievement, including grades in mother tongue, science and math (Mößle et al. 2010). Similarly, in another study that evaluated cross-sectional associations, media use – especially playing computer games – was negatively associated with marks in mother tongue, foreign language and science, but to a lesser extent with marks in math at all measurement occasions in 3rd, 4th and 5th grades. In addition, in longitudinal analysis, negative correlations were observed between the duration of daily computer game playing and academic achievement, while the duration of TV usage had only few negative associations with academic achievements (Mößle et al. 2010).

Especially, frequent TV viewing in childhood and adolescence has been connected to poor reading achievement in childhood (Ennemoser & Schneider 2007), poor academic grades, failure to complete high school, negative attitudes towards school and poor homework completion in adolescence, as well as long-term academic failure (Johnson et al. 2007) and poor educational achievement at the age of 26 (Hancox, Milne & Poulton 2005). In cross-sectional studies, high amounts of television viewing have been shown to have negative associations with math and reading achievement in 6- to 13-year-old children (Shin 2004) and school performance in 5th–8th graders (Sharif & Sargent 2006). Furthermore, children having a TV in their bedroom, the number of television sets at home and the number of hours that televisions are on have been negatively associated with academic achievement (Gentile & Walsh 2002, Borzekowski & Robinson 2005, Espinoza 2009).

Munasib and Bhattacharya (2010), however, reported no association between television viewing and academic achievement in 5–10 years old children after adjusting for socioeconomic determinants, parents' TV-viewing behaviour and parents' role in monitoring children's viewing. Similarly, in a longitudinal study by Bittman et al. (2011), in which two age cohorts (younger cohort aged 0–1 years and older cohort aged 4–5 years at the beginning of the study) were followed for four years, television viewing was not associated with language skills after the parents' involvement in the child's media use was taken into account. In addition, Haapala et al. (2014a) reported that television viewing in first grade was not associated with reading and arithmetic skills in grades 1–3.

Besides TV viewing, computer use and video game playing have been reported to have negative associations with academic achievement. However, these results are more inconsistent: in the intervention study by Weis and Cerankosky (2010), the effects of video game ownership on academic achievement were evaluated in boys aged six to nine. Boys were randomly assigned into two groups: the experimental group received a video game system at the beginning of the four month intervention, whereas the control group received a video game system after follow-up assessments. According to the results at the post-test, children with video games spent more time playing them and received lower reading and writing scores, but not math scores, compared to control children (Weis & Cerankosky 2010).

In a longitudinal study by Jackson et al. (2011), video game playing was associated with lower academic achievement, especially lower GPAs in 12-year-old children. Similarly, according to the study by Bittman et al. (2011) presented earlier, the ownership of game consoles was negatively associated with literature achievements in the older cohort (children aged 8 years). However, in the study by Sharif and Sargent (2006), video game use was not associated with school performance in 5–8 graders. According to Ferguson et al. (2013), violent video game exposure had neither positive nor negative predictive short-term or long-term associations with math achievement in children and youths aged 10–17 years. Similarly, in the longitudinal study by Willoughby (2008), the association between computer game play and academic performance was not significant at the age of 14–16. Haapala et al. (2014a), in turn, reported that high levels of computer use and video game playing in first grade predicted better arithmetic skills among boys in grades 1–3, while no effect was realized for girls.

According to Jackson et al. (2011), Internet use was associated with better reading skills in 12-year-olds, but only in children with initially low reading skills. The same kind of effect was not realized for math skills (Jackson et al. 2011). Moreover, moderate use of the Internet has been connected to more positive academic performance than non-use or high use in ninth to 12th graders (Willoughby 2008, Kim & So 2012). In the other study by Jackson et al. (2006), those children and youths from low-income families who used the Internet more frequently achieved higher reading (but not math) test scores and higher grade point averages 6, 12 and 16 months later, compared to children who used the Internet less frequently. In addition, Bittman et al. (2011) reported that computer use was associated with higher developed language skills. Likewise, Borzekowski and Robinson (2005) reported that computer access and use were positively associated with academic achievement.

In conclusion, the association between screen-based sedentary behaviour and academic achievement is still somewhat inconsistent. The association seems to depend on the type of screen-based behaviour assessed, the age of the children, and other factors like socioeconomic status. For instance, media use may be more controlled in small children, and the effects of screen time on academic achievement may become emphasized in older children (Gortmaker et al. 1990). In addition, the amount of time spent in front of the screen (non-use vs. moderate use vs. high use) and content of screen time may be critical factors affecting the association between screen time and academic achievement. Screen time – such as playing video games or using the Internet – may be beneficial when the use is light or moderate, but may be harmful when the use is excessive. However, the literature concerning screen-based sedentary time in association with academic achievement is divergent and there are no replicated study designs, so more research is needed to clarify the association. Besides, to our knowledge, no one has studied the association between objectively measured sedentary time and academic performance.

1.4.2 Sedentary behaviour in association with cognitive functions

Extensive screen time has been linked to an elevated risk of attention and learning difficulties. In the study by Swing et al. (2010), high amounts of screen time were associated with attention problems. The association of screen time and attention problems was similar for both TV viewing and video game playing, as well as for both age groups (6–12 years and 18–32 years) (Swing et al. 2010). In addition, a high amount of TV viewing in both childhood and adolescence has been associated with frequent attention difficulties in adolescence. (Johnson et al. 2007, Landhuis et al. 2007). However, in the intervention study by Weis and Cerankosky (2010), where 6–9-year-old boys were randomly assigned to an experimental group receiving a video game system at the beginning of the four-month intervention or a control group receiving a video game system after the follow-up, the ownership and playing of video games did not affect attention problems. On the other hand, Weis and Cerankosky (2010) observed higher learning problems in boys with the video game system compared to control childen.

Excessive screen time has also been connected to weaker executive functions in some studies, but not in the others. Mizuno et al. (2013) reported that high amounts of television viewing were associated with a weaker ability for adolescents to divide attention (mean age 13 years). In the study by Dye, Green and Bavelier (2009), the inhibitory control skills of action-game players and a non-playing control group aged 7 to 22 years were compared. The results, however, showed that action-game playing was associated with enhanced attention skills (Dye et al. 2009).

Video game playing has been linked to decreased verbal memory performance (Dworak et al. 2007). Drowak et al. (2007) studied the effects of excessive television and video game exposure on the visuospatial and verbal memory performance of 13-year-old children. According to the results, excessive video game playing, but not television viewing, decreased verbal memory performance compared to the basal condition. Visuospatial memory performance was not affected by either television or video game exposure (Dworak et al. 2007). In turn, Ferguson et al. (2013) reported that violent video game exposure had neither positive nor negative predictive short-term or long-term association with visuospatial cognition in children and youths aged 10–17 years. In addition, in the study of Ruiz et al. (2010), television viewing and video game playing were not associated with overall cognitive performance, including verbal, numeric and reasoning abilities in adolescents.

Differing research results based on scarce and heterogeneous research data, indicates that the association between sedentary behaviour and cognition is more complicated than previously believed and needs clarification. In addition, to our knowledge, no previous studies have examined the associations of objectively measured overall sedentary time on cognitive functions in children.

1.5 Summary of literature

In sum, children today spend excessive amounts of time engaged in sedentary activities and not enough time in physical activities. Low levels of physical activity have raised concerns over the effects of a physically inactive lifestyle on children's physical health and, recently, also on children's learning. Learning is an active and interactive process, which results in changes in skills, knowledge and behaviour. At school, academic achievements have been used to monitor and evaluate children's learning. Cognitive functions, especially executive functions, can be seen as prerequisites of learning. According to recent studies, physical activity may benefit children's cognitive functions and academic performance, while sedentary behaviour, especially screen-based sedentary behaviour, may attenuate them.

Although the number of studies examining the association of physical activity and sedentary behaviour with academic and cognitive performance has almost doubled during recent years, research in this area is still in its infancy, and the evidence is somewhat inconsistent. In particular, the definitions, patterns and measurements of cognitive functions, academic performance and physical activity have varied across different studies. In previous studies, physical activity has often been measured with self-reports or physical fitness has been used as a proxy measure of regular physical activity instead of measuring physical activity levels directly. Likewise, sedentary behaviour has usually been assessed with self-reports of screen time and, especially in earlier studies, with self-reports of the time spent viewing TV.

Furthermore, the use of computerized test batteries to measure cognitive functions has increased worldwide, but the psychometric properties of such test batteries have not been adequately measured. Future studies are needed to clarify the associations between physical activity, sedentary behaviour, academic performance and cognitive functions in school-aged children.

2 AIMS OF THE STUDY

The purpose of the present thesis was to determine how physical activity and sedentary behaviour are associated with academic performance and cognitive functions in elementary school-aged children. The specific aims were:

Aim 1. To examine the associations of self-reported and objectively measured physical activity and sedentary behaviour with teacher-rated academic performance in children.

Aim 2. To evaluate the internal consistency and the one-year stability of seven tests of the Cambridge Neuropsychological Test Automated Battery (CANTAB) used to measure visual memory, executive function, and attention in children.

Aim 3. To examine how objectively measured and self-reported physical activity and sedentary behaviour are associated with cognitive functions in children.

3 MATERIAL AND METHODS

3.1 Study population and data collection

During spring 2011, 475 5th and 6th graders from five schools in the Jyväskylä school district in Finland were invited to participate in the study, which included a self-reported questionnaire filled out in the classroom, an objective measurement of physical activity for seven days, and cognitive tests. Fifty-eight percent (N=277) of 475 eligible children participated in the study. Children engaged in normal curriculum-based instruction, and the language of instruction was Finnish. They had normal or corrected-to-normal vision. Of the 277 children, 230 were selected to participate in cognitive tests according to successful objective measurement of their physical activity. If a child's physical activity measurement did not succeed, because of technical problems or the child did not remember to wear the accelerometer, they were not invited to the cognitive tests. Seven children (three boys and four girls) were excluded from the analysis of the association of physical activity and cognitive functions because, according to their parents' survey, they had physical disabilities, chronic diseases or severe learning disabilities. During spring 2012, students who had been fifth graders in spring 2011 were invited to participate in follow-up measurements. Seventy-four children (49% of 151 eligible) participated in these follow-up measurements. The sample characteristics of the study are presented in Tables 1–3.

TABLE 1. Sample characteristics concerning explanatory variables.

	Boys		Girls		All		p[a]
Explanatory variables	Mean±SD	N	Mean±SD	N	Mean±SD	N	
Physical activity							
Self-reported MVPA (d/ week with ≥60 min MVPA)	5.2±1.8	121	4.9±1.6	153	5.0±1.7	274	0.049
Objectively measured MVPA (min/day)	59.9±22.3	95	56.3±17.1	125	57.9±19.5	220	0.623
Sedentary behaviour							
Self-reported screen time (h/day)	3.8±2.0	121	3.5±1.9	154	3.6±1.9	275	0.095
TV	1.6±1.0	122	1.6±1.0	154	1.6±1.0	276	0.663
Computer/video games	1.3±0.9	121	0.7±0.8	154	1.0±0.9	275	<0.001
Computer use (other than playing)	0.9±0.7	122	1.2±0.9	154	1.1±0.8	276	0.011
Objectively measured seden-tary time (%/day)	39.6±3.5	95	40.8±3.1	125	40.3±3.3	220	0.006

Abbreviations: SD, standard deviation; MVPA, moderate to vigorous physical activity.
[a] p-values for the gender differences.

TABLE 2. Sample characteristics concerning outcome variables.

	Boys		Girls		All		p[a]
Outcome variables	Mean±SD	N	Mean±SD	N	Mean±SD	N	
Academic performance							
Grade point average (range 4–10)	8.1±0.7	122	8.4±0.6	153	8.2±0.7	275	<0.001
Cognitive function							
Visual memory							
PRM no. of correct responses (max 24)	20.9±2.80	99	20.8±2.3	131	20.9±2.5	230	0.478
SRM no. of correct responses (max 20)	16.5±1.6	99	16.8±1.7	131	16.7±1.7	230	0.152
Executive functions							
SSP span length (max 9)	6.5±1.3	99	6.7±1.3	131	6.6±1.3	230	0.385
SOC no. of problems solved in minimum moves (max 12)	7.7±1.8	99	7.6±1.7	131	7.6±1.8	230	0.746
IED no. of children who completed the test (%)	67	99	67	131	67	230	0.935
Attention							
RTI five-choice movement time (ms)	329±74	99	364±87	131	349±83	230	0.001
RTI five-choice reaction time (ms)	300±36	99	318±32	131	310±35	230	<0.001
RVP A’ (range 0–1)	0.97±0.02	99	0.97±0.03	131	0.97±0.02	230	0.973

Abbreviations: SD, standard deviation; PRM, Pattern Recognition Memory; SRM, Spatial Recognition Memory; SSP, Spatial Span; SOC, Stockings of Cambridge; RTI, Reaction Time; RVP, Rapid Visual Information Processing; IED, Intra-Extra Dimensional Set Shift.
[a] p-values for the gender differences.

TABLE 3. Sample characteristics concerning other variables.

	Boys		Girls		All		p[a]
Other variables	Mean±SD	N	Mean±SD	N	Mean±SD	N	
Age (years)	12.2±0.7	123	12.2±0.6	154	12.2±0.6	277	0.765
Families in which the highest level of parental education was tertiary-level education (%)	80	94	79	126	79	220	0.826
Family income (€)	65319±29443	69	63755±27346	103	64383±28132	172	0.722
Parents, who are married or co-habiting (%)	77	94	75	126	76	220	0.734
Children with learning difficulties (%)	9	91	6	124	7	215	0.371
Children with need for remedial education	19	92	14	126	16	218	0.405
Amount of sleep (h)	9.1±0.8	122	9.0±0.7	154	9.1±0.7	276	0.414
Body mass index	18.9±3.4	121	18.9±3.2	149	18.9±3.3	270	0.997

Abbreviations: SD, standard deviation.
[a] p-values for gender differences.

3.2 Measurements

3.2.1 Self-reported physical activity and screen time

Physical activity and screen time were assessed with a self-reported questionnaire used earlier in the World Health Organization (WHO) Health Behaviour in School-aged Children (HBSC) study (Currie et al. 2012). Self-reported MVPA was measured with the following question: "Over the past 7 days, on how many days were you physically active for a total of at least 60 minutes per day?" The response categories were: 0 days, 1 day, 2 days, … 7 days. There was a short description about what kind of physical activity should be taken into account when answering the question: "In the next question, physical activity is defined as any activity that increases your heart rate and makes you get out of breath some of the time when you are for example exercising, playing with friends, commuting actively to school or in physical education lessons." Examples included running, walking quickly, rollerblading, biking, dancing, skateboarding, swimming, snowboarding, cross-country skiing, soccer, basketball, and Finnish baseball. Test-retest agreement for self-reported MVPA has been very good (ICC=0.82) (Booth et al. 2001, Liu et al. 2010).

Self-reported screen time was evaluated with the question: "About how many hours a day do you usually a) watch television (including videos), b) play computer or video games, or c) use a computer (for purposes other than playing games, for example, emailing, chatting, or surfing the Internet or doing homework) in your free time?" The response options were: not at all, about half an hour per day, about an hour a day, about two hours per day, … about five hours per day or more. Children responded separately for both weekdays and weekends. Test-retest agreement for watching television (ICC=0.72–0.74) and for playing computer or video games (ICC=0.54–0.69) has been substantial, and fair to moderate (ICC=0.33–0.50) for using the computer (Liu et al. 2010). Daily screen-time averages were calculated by adding these three questions together, including weekdays and weekends.

3.2.2 Objective measures of physical activity and sedentary time

Children's physical activity was measured objectively by using the ActiGraph GT1M/GT3X accelerometer with one vertical axle. Children wore the accelerometer on their right hip with an elastic waistband during waking hours for seven consecutive days. During bathing, swimming, and other water activities, it was requested that the monitor be removed, because it was not water-resistant. The ActiLife accelerometer software (ActiLife version 5; http://support.theactigraph.com/dl/ActiLife-software) was used to initialize the monitors and download the data. Epoch length was 10 seconds and non-wearing time 30 minutes. Customized software was used for data reduction and analysis. A cut-off value of 2,296 counts per minute was used for MVPA (Evenson et al. 2006) and 100 counts per minute for sedentary time. Children were included in the analysis if they had valid data for at least 500 minutes per day on two weekdays and on one weekend day. In order to compare children who had worn the accelerometers for different amounts of time per day, objectively measured sedentary time was expressed as the percentage of daily amount of time in which data was being registered.

3.2.3 Academic performance

Academic achievement scores (grades in individual school subjects and GPAs) were provided by the education services of the city of Jyväskylä. Individual grades were assessed in the following school subjects: mother tongue (in most cases Finnish or Swedish), first foreign language (started in 3rd grade), mathematics, physics/chemistry, biology, history, geography, religion or ethics, visual arts, music and physical education. The grades refer to numerical assessment on a scale of 4–10, where 4 denotes a failure (US grade: F) and 10 denotes excellent knowledge and skills (US grade: A). The GPAs were calculated on the basis of the individual grades and were used as a measure of academic achievement in the analysis. A Finnish GPA 5.0–5.9 equals 1.0 in US GPA, 6.0–6.9 equals 2.0, 7.0–8.9 equals 3.0, and 9.0–10.0 equals 4.0, respectively.

3.2.4 Cognitive functions

CANTAB (CANTABeclipse version 3 on a PaceBlade Slimbook P110 tablet PC with a 12-inch touch-screen monitor and Windows XP Professional operating system) was used to assess a broad range of cognitive functions: a) visual memory (Pattern Recognition Memory [PRM] and Spatial Recognition Memory [SRM]), b) executive function (Spatial Span [SSP], Stockings of Cambridge [SOC], Intra-Extra Dimensional Set Shift [IED]), and c) attention (Reaction Time [RTI] and Rapid Visual Information Processing [RVP]) (Table 4). The tests were run individually with the help of a trained research assistant and according to the standard protocol. Standard instructions for the tests were provided in the CANTAB manual and were translated into Finnish. The execution required about 45 minutes. The test battery was administered in a silent room without distractions. A Motor Screening Task measuring simple psychomotor speed and accuracy was used as a training procedure at the beginning of a test session. A more detailed description of the tests can be found in the original study II.

TABLE 4. Summary of the CANTAB tests used to measure different dimensions of cognitive function.

Dimension of cognitive function	Test	Abbreviation
Visual memory	Pattern Recognition Memory	PRM
	Spatial Recognition Memory	SRM
Executive function	Spatial Span	SSP
	Stockings of Cambridge	SOC
	Intra-Extra Dimensional Set Shift	IED
Attention	Reaction Time	RTI
	Rapid Visual Information Processing	RVP

3.2.4.1 Visual memory

Visual memory performance was assessed with PRM and SRM. PRM measures recognition memory for visual patterns and SRM for spatial locations in a two-alternative forced-choice paradigm. In these tests, children had to remember presented geometric patterns (PRM) or the locations of white squares (SRM) and discriminate them from novel patterns and locations. The scores in these tasks are based on the number of correct responses (PRM maximum 24, SRM maximum 20).

3.2.4.2 Executive function

Children's executive functions were assessed with SSP, SOC and IED tests. The SSP is based on the Corsi Blocks task (Milner 1971), which measures the length of visuospatial memory span. In this test, a specified number of white boxes changed their colour one by one and children had to reproduce the same sequence by touching the boxes in the same order that the boxes had changed colour. The score in the task is based on the length of the maximum sequence that the child can reproduce.

The SOC is a computerized version of the Tower of London task (Shallice & Shallice 1982, Owen et al. 1990), measuring spatial planning and spatial working memory. In this test, children had to move coloured balls in the lower part of the screen to the same position in the stockings as they were in the upper part of the screen. Children had a specified number of moves to use. The score in this task is based on the number of problems that the child solves with a minimum number of moves.

IED is a computerized analogue of the Wisconsin Card Sorting test and measures rule acquisition and reversal in a set-shifting condition. Specifically, it measures the ability to focus attention on different stimuli within a relevant dimension and shift attention to a previously irrelevant dimension. In this task, there are nine stages with increasing levels of difficulty. The children were instructed to choose one of two different dimensions: one was correct and the other was incorrect. According to immediate feedback, they were expected to choose the correct pattern and learn the rule. The score in this task is based on the number of stages completed.

3.2.4.3 Attention

The children's attention abilities were assessed with RTI and RVP. RTI measures the children's speed of response to an unpredictable visual target. In the unpredictable five-choice scenario, a yellow spot appeared randomly in one of five circles on the screen, and children were asked to respond as soon as possible by touching the correct circle. The scores in this task are based on reaction time (ms) and movement time (ms).

Measuring sustained attention, the RVP is similar to the Continuous Performance Task. In this test, children had to press a button every time they discriminated the target sequence (digits 3, 5, and 7) from the digits appearing in a pseudorandom order at the rate of 100 digits per minute. The score in this task is based on RVP A', which measures how successful the child is at detecting target sequences (range: .00 to 1.00; bad to good).

3.2.5 Potential confounders

The parent or the child's main caregiver filled in a questionnaire concerning family background. The mother's and father's education were measured with the following questions: "What is the highest level of mother's/father's education?" The highest level of parental education (calculated on the basis of the mother's and father's education) were categorized as 1) tertiary-level education and 0) basic or upper secondary education. Family income was measured with the question: "What was your household's total income last year (with taxes)?" Marital status was assessed with the question: "Which of the following best describes the marital status of the child's main caregiver? A) Married or cohabiting with child's mother/father, B) Divorced, single parent, C) Divorced, joint custody, D) Divorced, a new marriage, E) Single, D) Widow." The marital status of the main caregiver was categorized as 1) married or cohabiting with child's mother/father and 0) divorced or single/widow. Children's learning difficulties and need for remedial education were measured with the questions: "Has your child been diagnosed with a learning difficulty?" and "Has your child received remedial education?" Children's learning difficulties and need for remedial education were categorized as 1) yes or 0) no or don't know. Children also reported times when they usually went to sleep and woke up on school days.

3.3 Ethics statement

The study was approved by the Ethics Committee of the University of Jyväskylä, and it followed the principles of the Declaration of Helsinki and the Finnish legislation. Participation in the study was voluntary, and all participants had the right to drop out of the study at any time without any specific reason. Only children with a fully completed consent form (Certificate of Consent signed by a parent/guardian and the child) on the day of the first measurements were included in the study.

3.4 Analytical strategies

3.4.1 Study I

In Study I, the main objective was to examine cross-sectional associations of physical activity and sedentary behaviour with academic achievement. In addition, potential confounding factors were taken into account. These associations were examined with analysis of variance and linear regression analysis using the SPSS 19.0 for Windows statistical package (SPSS (2010) IBM SPSS Statistics 19 Core System User's Guide (SPSS Inc., Chicago, IL)).

For the analysis of variance, children were divided into tertile groups (33% each) according to the amount of objectively measured MVPA (first tertile ≤47.0 min, second tertile 47.1–65.0 min, third tertile ≥65.1 min) and sedentary time (first tertile ≤38.4%, second tertile 38.5–41.4%, third tertile ≥41.5%). In addition, children were classified into groups according to the self-reported MVPA (1=0–2 days/week, 2=3–4 days/week, 3=5–6 days/week, 4=7 days/week) and screen time (1=0.00–

1.99 h/day, 2=2.00–2.99 h/day, 3=3.00–3.99 h/day, 4=4.00–4.99 h/day, 5=≥5.00 h/day).

Before proceeding with multiple regression, the Pearson's correlation coefficients for continuous variables were calculated to estimate associations between single variables and GPA. To investigate whether the associations between self-reported or objectively measured MVPA and GPA are quadratic, quadratic terms were calculated using an equation x^2=((x-mean(x))*(x-mean(x)), where x was logarithmically transformed, self-reported MVPA or logarithmically transformed, objectively measured MVPA. After that, the enter method for the multiple regression was used. To calculate change in R square, the variables of interest were added to the second block one by one, while all other variables of the model (potential confounders and other variables of interest) were added to the first block. The change in R square for all variables of interest was calculated and tested for significance. In order to study whether the assumptions of the regression analysis were fulfilled, we examined the distribution of model residuals.

3.4.2 Study II

In Study II, the main objective was to examine internal consistency and one-year stability of the seven CANTAB tests. The analyses were performed using the SPSS 19.0 for Windows statistical package (SPSS (2010) IBM SPSS Statistics 19 Core System User's Guide (SPSS Inc., Chicago, IL)) and the Mplus statistical package (Version 7; Muthèn & Muthèn, 1998–2012).

The internal consistency of each nonhampering test was estimated with Cronbach's alpha reliability coefficient (α). The reliability could not be determined for hampering tests. As preliminary analysis of stability, Pearson's correlation for continuous variables and tetrachoric correlations for dichotomously scored variables were calculated between the assessments.

To examine the stability of the CANTAB tests, structural equation models were applied. To combine a very large number of measured variables for each latent factor, item parcels were constructed by summing every third pattern into the same parcel (Little et al. 2002). Item parcels were used in order to achieve continuous indicators and not to end up with too large of a model in terms of the ratio of sample size to number of free parameters (Herzog & Boomsma 2009, Christopher Westland 2010). Underlying latent traits were assumed to be unidimensional. The constructed parcels were then used as indicator variables in the confirmatory factor analyses.

The measurement models were first specified at both measurement times to test the association between the observed variables and the underlying factors. After demonstrating the fit of the measurement models, longitudinal confirmatory factor analyses were performed. The baseline stability model was estimated, in which the factor (or factors) in the second assessment (2012) was predicted by the factor (or factors) in the previous measurement point (2011). To detect time invariance in the latent constructs, equality constraints were imposed on the corresponding factor loadings across two time points. Furthermore, if the invariance assumption of a stability model was supported, a more parsimonious model in which all the factor loadings were fixed to be one was estimated.

Full information maximum likelihood (FIML) estimation with robust standard errors (MLR) was used under the assumption of data missing at random. Item response theory (IRT) modelling using FIML estimation was applied to the CANTAB tests with hampering nature. The Satorra–Bentler scaled χ^2-test, the comparative fit index (CFI), the Tucker–Lewis Index (TLI), the root mean square error of approximation (RMSEA) and the standardized root mean square residual (SRMR) were used to evaluate the goodness of fit of the models. The model fits the data well if the p-value for the χ^2-test is non-significant, CFI and TLI values are close to 0.95, the RMSEA value is below 0.06 and the SRMR value is below 0.08 (Hu & Bentler 1999). A Satorra–Bentler scaled χ^2 difference test was conducted for the nested models. If the χ^2-test produces a non-significant loss of fit for the constrained model as compared to the baseline stability model, the equality constraints are supported.

3.4.3 Study III

In Study III, the main focus was to examine the associations of objectively and subjectively measured physical activity, sedentary behaviour and cognitive tests. On the basis of the reliability and stability results of the CANTAB tests, five of seven cognitive tests were chosen. In addition, structural equation modelling was chosen to examine the associations, because it enables estimation of measurement errors and therefore increases the reliability of cognitive tests. The analyses were performed using the SPSS 19.0 for Windows statistical package (SPSS (2010) IBM SPSS Statistics 19 Core System User's Guide (SPSS Inc., Chicago, IL)) and the Mplus statistical package (Version 7; Muthèn & Muthèn, 1998–2012).

In this study also, item parcels (Little et al. 2002) were constructed and then used as indicators for latent variables. Single scores of every problem or level of the cognitive tests were applied instead of the total score. When the outcome was dichotomous, multiple logistic regression was used to examine physical activity and sedentary time in association with cognitive function. Full information maximum likelihood estimation with robust standard errors was used under the assumption of data missing at random.

Gender, the highest level of parental education and the child's need for remedial education were chosen to represent different aspects of potential confounders and were added to the main analysis. In order to avoid multicollinearity, highly correlated objectively measured MVPA and sedentary time were added to the model using a Cholesky factoring of the predictors (de Jong 1999). The Satorra-Bentler scaled χ^2-test, the CFI, the TLI, the RMSEA and the SRMR were used to evaluate the goodness of fit of the models, as described above.

4 AN OVERVIEW AND THE MAIN RESULTS OF THE ORIGINAL STUDIES

4.1 Study I: Physical activity, sedentary behaviour, and academic performance in Finnish children

Purpose of the study. Study I aimed to examine how both objectively measured and self-reported physical activity and sedentary behaviour are associated with teacher-rated academic achievement in children. Based on the previous studies, it was hypothesized that physical activity would have a positive association, while sedentary behaviour would have a negative association with academic performance.

Methods. For this purpose, information on children's academic achievement (GPA) was provided by the education services of the city of Jyväskylä. Children self-reported how many days per week they were physically active (for a total of at least 60 minutes per day) and how many hours per day they spent watching TV, playing video games or computer games, or using a computer for other purposes than play. Children's physical activity and sedentary time were measured objectively by using an ActiGraph GT1M/GT3X accelerometer. Cross-sectional associations were examined using analysis of variance and linear regression analysis.

Results. Our results showed that objectively measured MVPA ($p = 0.955$) and sedentary time ($p = 0.285$) were not associated with GPA (Figure 2). However, self-reported MVPA had an inverse U-shaped curvilinear association with GPA ($p = 0.001$), and screen time had a linear negative association with GPA ($p = 0.002$), after adjusting for gender, children's learning difficulties, the highest level of parental education, and amount of sleep (Table 5). Children who were physically active at least 60 minutes per day 5–6 days per week had the highest GPAs, whereas children who were physically active 0–2 days per week had the lowest GPAs (Figure 2). Children who had less than 2 hours per day of screen time had the highest GPAs, whereas children who had more than 5 hours per day of screen time had the lowest GPAs (Figure 2).

Conclusions. Our finding that self-reported physical activity was directly, and screen time inversely, associated with academic achievement, is consistent with earlier studies (Fox et al., 2010; Kantomaa et al., 2010; Möble et al., 2010; Sharif et al., 2006). However, objectively measured physical activity and sedentary time were not associated with academic achievement. This inconsistency between the subjective and objective measurements suggests that objective and subjective measurements may reflect different constructs and contexts of physical activity and sedentary behaviour in association with academic outcomes.

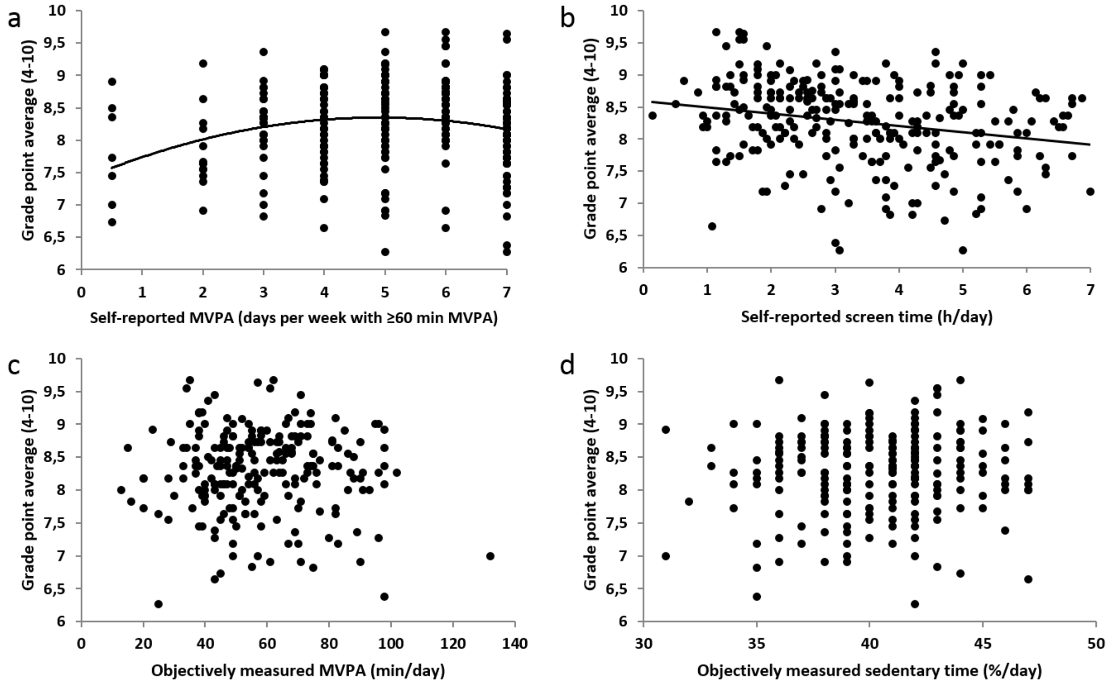

FIGURE 2. Grade point averages according to a) self-reported MVPA, b) self-reported screen time, c) objectively measured MVPA, and d) objectively measured sedentary time. Results from the regression analysis.

TABLE 5. Regression analysis of grade point average (GPA).

	Academic achievement (GPA)			
	Pearson's correla-tions	The regression model		
Variables in the model		B (SE)	Beta (SE)	ΔR^{2f}
Children's learning difficulties[a]	-0.368***	-0.697*** (0.139)	-0.297*** (0.139)	
Highest level of parental education[b]	0.247***	0.307** (0.087)	0.207** (0.087)	
Amount of sleep (h/day)	0.211***	0.114* (0.052)	0.129* (0.052)	
Gender (female)	0.223***	0.176* (0.072)	0.144* (0.072)	
Self-reported MVPA[c]	0.003	0.065 (0.061)	0.067 (0.061)	0.004
Quadratic self-reported MVPA[d]	-0.247***	-0.337** (0.104)	-0.199** (0.104)	0.035**
Self-reported screen time (h/day)[e]	-0.276***	-0.198** (0.062)	-0.193** (0.062)	0.033**
R Square		0.328		
Adjusted R Square		0.305		
N		212		

Abbreviations: B, unstandardized coefficient; Beta, standardized coefficient; SE, standard error; ΔR^{2f}, change in R square.

[a] Parental report of child's diagnosed learning difficulties categorized as 1) yes and 0) no or don´t know.

[b] The highest level of parental education categorized as 1) tertiary-level education and 0) basic or upper secondary education.

[c] Distribution of self-reported MVPA was reflected and transformed logarithmically and reflected again to restore the original order of the variable (-ln((max+1)-y)).

[d] To measure quadratic associations between self-reported physical activity and grade point average, quadratic terms were formed with the equation: Quadratic self-reported MVPA = ((x-mean(x)) * (x-mean(x)), where x was logarithmically transformed self-reported MVPA (-ln((max+1)-y)).

[e] Distribution of self-reported screen time was transformed logarithmically (ln(y)).

[f] The change in R square, Self-reported MVPA, Quadratic self-reported MVPA and Screen time were added to the model one by one.

The level of statistical significance: *** = p<0.001, ** = p<0.01, * = p<0.05.

4.2 Study II: Internal consistency and stability of the CANTAB neuropsychological test battery in children

Purpose of the study. Study II was conducted to ensure the internal consistency and stability of the cognitive tests before examining the associations of physical activity, sedentary behaviour and cognitive functions. The main purpose of Study II was to evaluate the internal consistency and the one-year stability of seven CANTAB tests measuring visual memory, executive function, and attention in elementary school-aged children.

Methods. For this purpose, children participated in cognitive measurements in spring 2011 and again in spring 2012. The CANTAB tests Pattern Recognition Memory (PRM), Spatial Recognition Memory (SRM), Spatial Span (SSP), Stockings of Cambridge (SOC), Intra-Extra Dimensional Set Shift (IED), Reaction Time (RTI) and Rapid Visual Information Processing (RVP) were chosen according to previous studies and hypotheses about the association of physical activity and cognitive functions. In addition, a goal was to test different dimensions of cognitive functions. The internal consistency of the tests was estimated with Cronbach's alpha reliability coefficient (α), while the stability of these tests was examined using structural equation modelling.

Results. In terms of internal consistency, Cronbach's alpha reliability coefficients were 0.65 for the PRM number of correct responses, 0.21 for the SRM number of correct responses, 0.87 for the RTI five-choice movement time, 0.66 for the RTI five-choice reaction time and 0.49 for the RVP A'. For hampering tests (SSP, SOC and IED), Cronbach's alpha could not be determined.

Stability of visual memory tests. The estimation results of the stability model for PRM are presented in Figure 3. The goodness-of-fit statistics of the constrained model for the PRM number of correct responses were good (χ^2 (12) = 17.30, p = 0.14, CFI = 0.96, TLI = 0.95, RMSEA = 0.04, SRMR = 0.13). The stability for the PRM was 0.80. A stability model for SRM could not be determined, because none of the parcels loaded significantly on the hypothesized factor in the cross-sectional measurement models in 2011 and 2012. The correlation for the SRM number of correct responses between 2011 and 2012 was r(72) = 0.30 (p = 0.009).

Stability of executive function tests. The stability model for the SSP could not be determined, because of the nature of the test. The correlation between the SSP span length in 2011 and in 2012 was r(72) = 0.37 (p = 0.001). The cross-sectional IRT models for SOC were estimated, and only 5 of the 12 items loaded significantly on the hypothesized factor in 2011 and only 3 of the 12 items in 2012. According to the results of the estimated baseline stability model, there was no significant association between the latent variables measured in 2011 and 2012. The correlation for SOC problems solved in the minimum number of moves between 2011 and 2012 was r(72) = 0.23 (p = 0.046). Because the latent variables measured by the errors in stages from 3 to 7 and from 8 to 9 of the IED test did not correlate with each other either in 2011 or in 2012, and the regression coefficient between the latent variables measured in consecutive years was significant only for the latter factor (b = 0.68, SE = 0.08, p < 0.001), the stages from 3 to 7 were discarded from further analyses. The tetrachoric correlation for stage 8 between 2011 and 2012 was 0.38 (p = 0.047). For stage 9, it was 0.64 (p < 0.001).

Stability of attention tests. The estimation results of the stability model for RTI reaction time and movement time are presented in Figure 4. The goodness-of-fit statistics of the constrained model for the RTI reaction time and the movement time were good (χ^2 (58) = 78.51 (58) p = 0.04, CFI = 0.96, TLI = 0.95, RMSEA = 0.04, SRMR = 0.15). The stability coefficient for the RTI movement time was 0.67. For the RTI reaction time, it was 0.78. The estimation results of the stability model for RVP A' is presented in Figure 5. The goodness-of-fit statistics of the constrained model for RVP A' were reasonably good (χ^2 (10) = 17.94 (10) p = 0.06, CFI = 0.91, TLI = 0.87, RMSEA = 0.06, SRMR = 0.25. The stability coefficient for RVP A' was 0.62.

Conclusions. Internal consistency was acceptable only in the RTI task. One-year stability was moderate-to-good for the PRM, RTI, and RVP. The SSP and IED showed a moderate correlation between the two measurement points. The SRM and SOC tasks were not reliable or did not provide stable measurements in this study population when comparing two measurements that were conducted one year apart. For research purposes, when using these tests, structural equation modelling is recommended to improve reliability. The results suggest that the reliability and stability of computer-based test batteries should be confirmed in the target population before using them for clinical or research purposes.

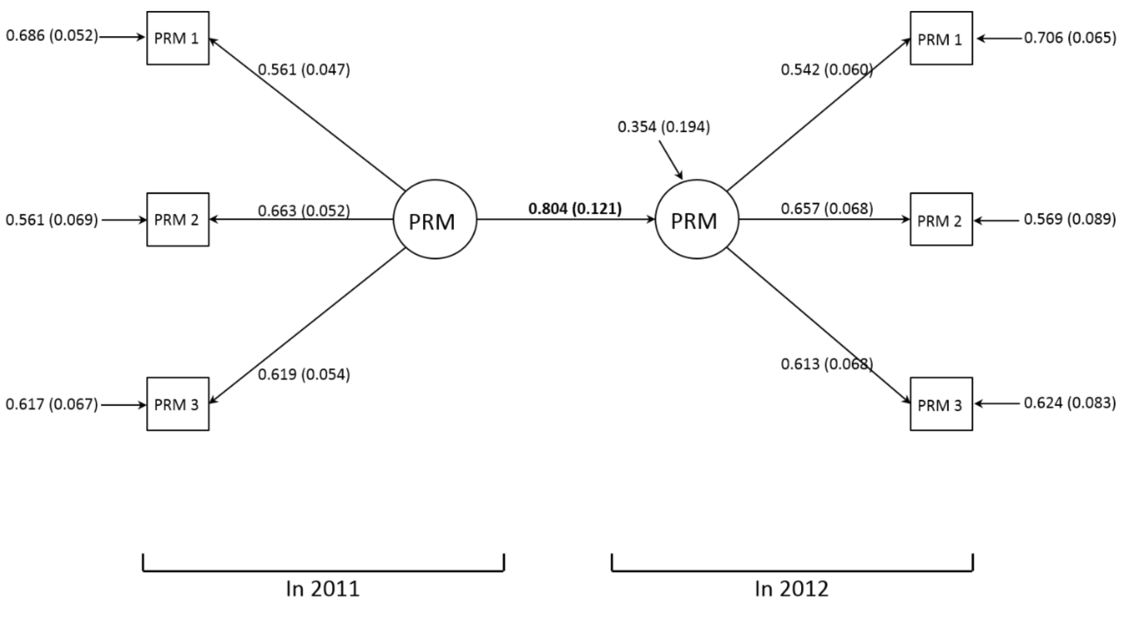

FIGURE 3. Estimation results of the stability model of the Pattern Recognition Memory (PRM) test for 2011 and 2012. Standardized parameter estimates and standard errors are presented. Three parcels from 24 patterns (incorrect/correct response) of the PRM test were constructed and used as indicator variables in the confirmatory factor analyses (PRM 1, PRM 2, PRM 3). All the factor loadings were constrained to be equal to one.

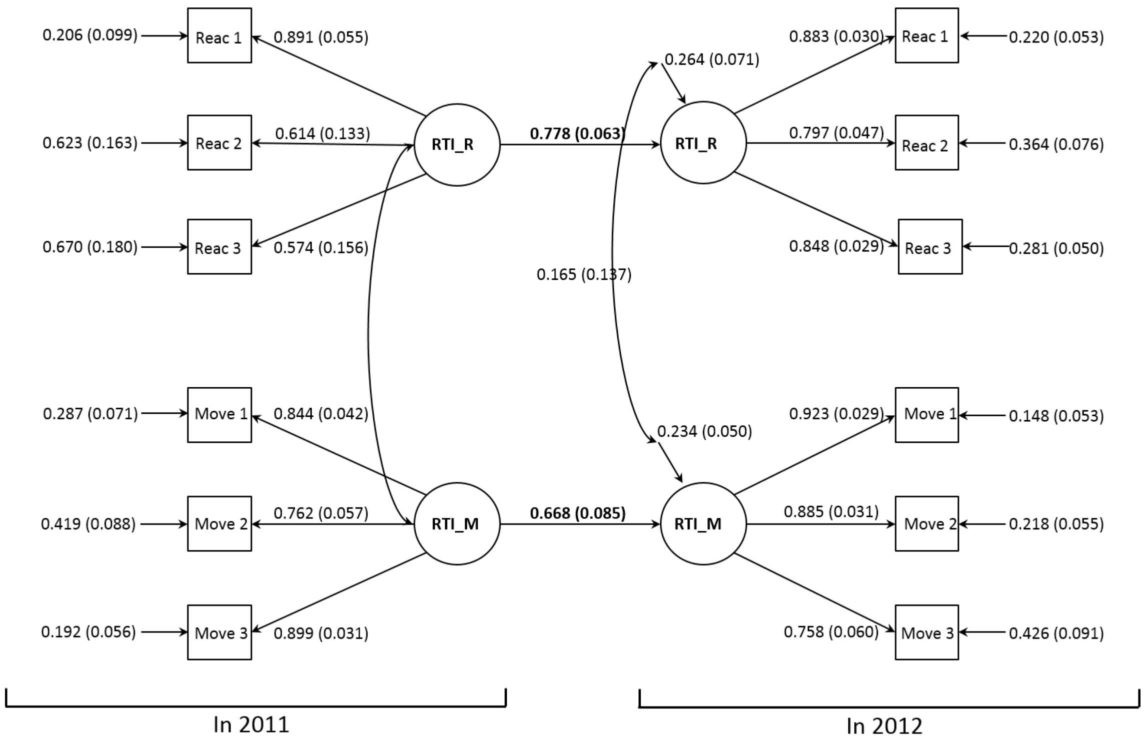

FIGURE 4. Stability model for the Reaction Time (RTI) test for 2011 and 2012. Standardized parameter estimates and standard errors are presented. For structural equation modelling, three sub-categories of the reaction time (Reac 1, Reac 2, Reac 3) and movement time (Move 1, Move 2, Move 3) at both measurement points were formed from 15 patterns of RTI. All the factor loadings were constrained to be equal to one.

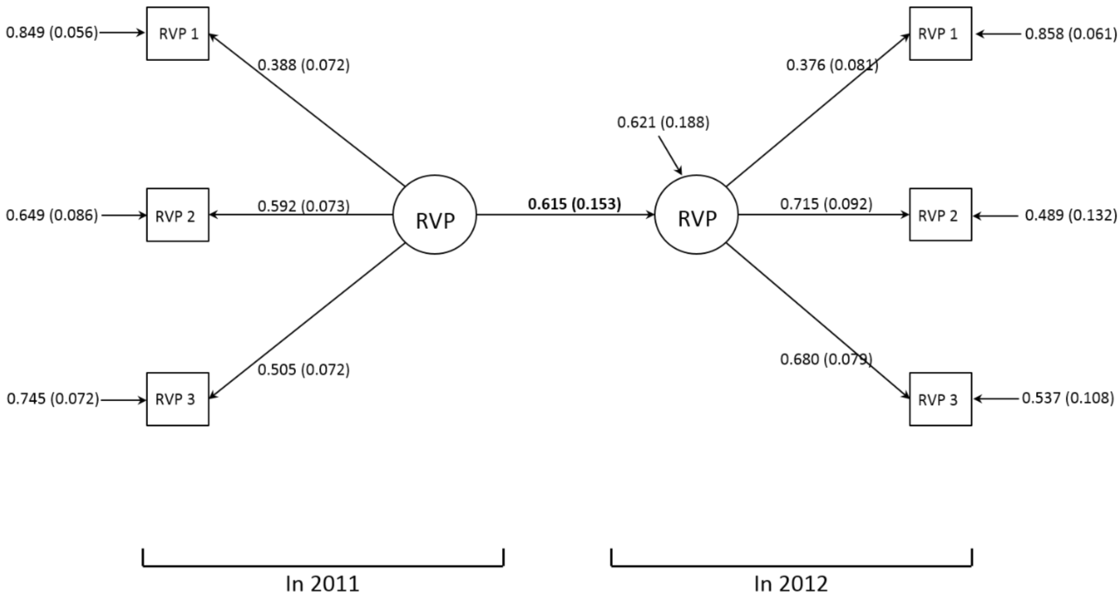

FIGURE 5. Stability model for the Rapid Visual Information Processing (RVP) test for 2011 and 2012. Standardized parameter estimates and standard errors are presented. The RVP (multiplied by 10) of the three blocks of the test (RVP 1, RVP 2, RVP 3) were used as indicator variables in structural equation modelling. Factor loadings were constrained to be equal across time points.

4.3 Study III: The associations of objectively measured physical activity and sedentary time with cognitive functions in school-aged children

Purpose of the study. The main purpose of the Study III was to examine how objectively measured and self-reported physical activity and sedentary behaviour are associated with performance in cognitive tests, measuring visual memory, executive functions and attention in school-aged children. It was hypothesized that physical activity is positively, and sedentary behaviour inversely, associated with cognitive functions.

Methods. On the basis of the results of Study II, which reported the reliability and stability of the CANTAB tests, the following five cognitive tests were chosen for this study: Pattern Recognition Memory (PRM), Spatial Span (SSP), Intra-Extra Dimensional Set Shift (IED), Reaction Time (RTI) and Rapid Visual Information Processing (RVP). The cross-sectional associations of self-reported physical activity and screen time and objectively measured physical activity and sedentary time with cognitive functions were examined with structural equation modelling.

Results. A high level of objectively measured MVPA was associated with good performance in the RTI test (Table 6). A high level of objectively measured sedentary time was associated with good performance in the RVP test (Table 6). Objectively measured MVPA and sedentary time were not associated with other measures of cognitive functions. A high amount of self-reported computer or video game play was associated with weaker performance in the SSP test (Table 6), whereas a high amount of computer use was associated with weaker performance in the IED test (Table 7). Self-reported physical activity, total screen time, and television viewing were not associated with any measures of cognitive functions.

Conclusions. In this study, objectively measured physical activity and sedentary time were positively associated with attentional processes, but not with other measured domains of cognitive functions. Self-reported computer and video game playing was negatively associated with working memory capacity, whereas computer use was negatively associated with shifting and flexibility of attention. Self-reported physical activity and total screen time were not associated with any of the cognitive tests used to measure visual memory, executive functions or attention in children. The results of the present study suggest that physical activity may benefit attentional processes, but excessive video game playing and computer use may have unfavourable effects on cognitive functions.

TABLE 6. Associations between children's cognitive processes and objectively measured physical activity, sedentary time and self-reported screen time.

Explanatory variables	Cognitive test			
	B	SE	95% CI	P[f]
	Reaction Time (RTI)[c]			
Objectively measured MVPA[a]	-0.130	0.062	-0.253, -0.008	0.037
Objectively measured sedentary time[b]	-0.041	0.074	-0.186, 0.104	0.581
	Rapid Visual Information Processing (RVP)[d]			
Objectively measured MVPA	-0.040	0.093	-0.223, 0.143	0.669
Objectively measured sedentary time	0.305	0.078	0.153, 0.457	0.000
	Spatial Span (SSP)[e]			
Self-reported viewing of TV	-0.003	0.067	-0.134, 0.129	0.970
Self-reported playing of computer/video game	-0.179	0.079	-0.333, -0.024	0.023
Self-reported use of computer (other than playing)	0.094	0.068	-0.040, 0.227	0.171

Abbreviations: B, estimate; SE, standard error; CI, confidence interval; p, p-value; MVPA, moderate to vigorous physical activity.

[a] RTI measures children's reaction times and speed of response to a visual target in milliseconds, where faster time indicates better performance.

[b] MVPA measured with the ActiGraph accelerometer using a cut-off value of 2,296 counts per minute and expressed as min/day.

[c] Sedentary time measured by the ActiGraph accelerometer using a cut-off value of 100 counts per minute and expressed as percentage of daily monitoring time (%/day).

[d] RVP measures sustained attention. The score of this task is RVP A', where range is 0.00 to 1.00; bad to good.

[e] SSP measures length of working memory span. The score of this task is the maximum number of items that the child can successfully remember.

[f] P-values for parameter estimates.

Models have been adjusted by gender (female), the highest level of parental education (tertiary) and the child's need for remedial education.

TABLE 7. Associations between children's working memory capacity and self-reported screen time.

	Cognitive test	
	Intra-Extra Dimensional Set Shift (IED) [a]	
Explanatory variables	OR	95% CI
Self-reported viewing of TV (h/day)[b]	0.868	0.623, 1.210
Self-reported playing of computer/video games (h/day)[b]	1.321	0.943, 1.850
Self-reported use of computer (other than playing) (h/day)[b]	0.639	0.421, 0.972

Abbreviations: OR, odds ratio; CI, confidence interval.

[a] IED measures sifting and flexibility of attention and was categorized as 1) children who completed the test and 0) children who did not complete the test.

[b] Self-reported viewing of television, playing of computer/video game and use of computer (other than playing) are treated as continuous variables and expressed as h/day.

Model has been adjusted by gender (female), the highest level of parental education (tertiary) and the child's need for remedial education.

5 DISCUSSION

In the present study, the associations of physical activity and sedentary behaviour with academic achievement and cognitive functions in school-aged children were examined. Self-reported physical activity an inverse U-shaped curvilinear relationship and total screen time had an inverse linear negative relationship with academic achievement (teacher-rated GPA), whereas objectively measured physical activity or sedentary time had no association with academic achievement. High levels of objectively measured physical activity and sedentary time were associated with good attentional performance, but not with other domains of cognitive functions. Self-reported physical activity or total screen time had no association with assessed cognitive functioning. High levels of self-reported computer/video game play was associated with low visuospatial working memory performance, whereas high levels of computer use was associated with low shifting and flexibility of attention performance. Self-reported TV viewing had no association with any domains of cognitive functions.

In addition, the internal consistency and stability of the seven CANTAB tests (PRM, SRM, SSP, SOC, IED, RTI, RVP) measuring visual memory, executive functions and attention were examined. Internal consistency was acceptable only in the RTI test. One-year stability was moderate-to-good for PRM, SSP, IED, RTI and RVP. The SRM and SOC were not reliable or did not provide stable measurements in the present study sample of 12-year-old healthy children.

5.1 Physical activity, academic achievement and cognitive functions

The results of the present study are in line with previous studies reporting that self-reported physical activity is associated with high levels of academic performance (Stevens et al. 2008, Fox et al. 2010, Kantomaa et al. 2010, Kantomaa et al. 2013). In addition, a few previous intervention studies have reported physical activity benefitting academic performance (Donnelly et al. 2009, Davis et al. 2011, Ardoy et al. 2014). However, in the present study the relationship between self-reported MVPA and academic achievement was curvilinear. It seems that 5–6 times/week may be the optimal amount of MVPA for academic achievement. It is possible that some of the most active children spend time engaged in physical activities at the expense of time devoted to homework.

According to the results of the present study, objectively measured MVPA was not associated with academic achievement supporting the study by LeBlanc et al. (2012). In contrast, Kwak et al. (2009) reported that objectively measured vigorous physical activity was positively associated with academic achievement in 16-years-old girls, but not boys. In addition, according to Booth et al. (2014), objectively measured MVPA at the age of 11 predicted increased mother tongue performance at the age of 11, 13 and 16 for both girls and boys, and increased science performance at the age of 11 and 16 for girls. The differences between these studies may be due to slight differences in the age of the study populations and the collection and reduction decisions of objective MVPA data. In addition, in these studies, if children had valid data over a minimum of 2–3 days, they were included in the analysis. Physical activity varies depending on days, whereupon a measurement period of 2–3 valid days may not be long enough to fully capture habitual physical activity. This may partly explain differing results between studies concerning the association with academic achievement. Furthermore, even though Kwak et al. (2009) and Booth et al. (2014) observed significant associations, the effect sizes and β coefficients were quite modest. Booth et al. (2014), however, speculated that results must be interpreted in context. Thus, in the Western world, where the levels of MVPA are quite low, increasing MVPA to reach an average of 60 minutes per day may result in bigger increases in academic achievement (Booth et al. 2014). Reflecting the discussion above to the results of self-reported physical activity, it seems that physical activity is an important factor affecting academic achievement, but it is not the whole story. There are also other factors affecting academic achievement, and the association between physical activity and academic achievement.

According to the present results, a high level of objectively measured physical activity was associated with better performance in attention test measuring reaction time and speed of response to unpredictable stimulus. Previous studies have suggested that physical activity enhances especially inhibitory control of attention (Castelli et al. 2011, Davis et al. 2011, Fisher et al. 2011, Chaddock-Heyman et al. 2013, Spitzer & Hollmann 2013, Crova et al. 2014). However, Puder et al. (2011) reported that physical activity intervention had no effect on children's selective attention. In addition, in the studies of Davis et al. (2011) and Fisher et al. (2011) physical activity had no effect on performance in attention scale of the Cognitive Assessment System, even though physical activity enhanced attentional inhibition performance in the antisaccade task and the Attention Network Test, respectively. Despite the earlier studies have shown that physical activity enhances inhibitory control of attention, our results suggest that physical activity may also affect lower-order levels of attention.

The present results also showed that neither objectively measured nor self-reported physical activity was associated with visual memory, spatial working memory, shifting and flexibility of attention or sustained attention performance. Earlier studies have also reported that physical activity is not necessary associated with all domains of cognitive functioning, but may selectively affect executive functions and especially inhibitory control (Davis et al. 2011, Drollette et al. 2012). However, the study designs with varying age of the children as well as, the definitions, patterns and measurements of cognitive functions and physical activity, which have varied across different studies, potentially contribute to the divergent results.

In the present study, the lack of association between physical activity and performance in cognitive tests may be partly due to the observation that some of the cognitive tests were not able to differentiate healthy 12-year-old children. Especially in the tests of visual memory (PRM), shifting and flexibility of attention (IED) and sustained attention (RVP), on average, children achieved very good performance. Neuropsychological test batteries were originally developed to detect large-scale neurocognitive deficits, and thus, the selected tests may have been too easy to detect subtle differences in health behaviours in healthy children. Stroth et al. (2009) speculated that one reason behind their result of aerobic fitness not being associated with children's performance in cognitive control tasks was the ceiling effect in the selected cognitive tests.

5.1.1 Possible mechanisms explaining the associations between physical activity, academic achievement and cognitive functions

The positive association of physical activity with academic achievement and cognitive functions may be mediated by a few possible mechanisms. Physical activity may induce functional (Davis et al. 2011, Chaddock-Heyman et al. 2013) and structural (Chaddock et al. 2010a, Chaddock et al. 2010b) changes in the brain areas subserving executive functions and memory, such as hippocampus and the basal ganglia, thereby enhancing especially executive functions and memory. Physical activity has also been reported to increase levels of brain-derived neurotrophic factor (BDNF), supporting cellular processes important for learning and memory (Hopkins et al. 2012, Gomez-Pinilla & Hillman 2013). Moreover, physical activity has been shown to enhance cerebrovascular function (Brown et al. 2010).

Motor function has been closely connected to children's cognitive and academic skills and development (Iverson 2010, Davis, Pitchford & Limback 2011, Haapala et al. 2014b), and it may be an important driver in the effects of physical activity on cognitive prerequisites of learning (Kantomaa et al. 2013). In addition, some physical activities are cognitively challenging and may, therefore, facilitate cognitive function and academic performance (Best 2010, Crova et al. 2014). Obesity is another potential mediator: physical inactivity may lead to obesity, and obesity has been linked to poorer academic (Kantomaa et al. 2013) and cognitive performance (Burkhalter & Hillman 2011). Furthermore, unhealthy diet, especially overconsumption of high-caloric foods may attenuate cognitive functions via diminishing BDNF and interfering energy homeostatis (Vaynman & Gomez-Pinilla 2006, Gomez-Pinilla 2011).

Participation in physical activities is often a social phenomenon offering opportunities for interaction with other children and adults, and this interaction may also have a significant impact on children's cognitive development and learning. However, social interaction as a mediator between physical activity and cognitive or academic skills is rarely studied (Hillman, Erickson & Kramer 2008). Finally, different psychosocial factors like school contentment and self-esteem may mediated the association between physical activity and academic achievement (Kristjansson et al. 2009, Kristjansson, Sigfusdottir & Allegrante 2010).

5.1.2 Differences between objectively measured and self-reported physical activity in terms of their association with academic achievement and cognitive functions

In the present study, the associations of self-reported and objectively measured physical activity with academic and cognitive performance were inconsistent. These inconsistencies may be due to differences between subjective and objective measurements of physical activity. Self-reported questionnaires have been accepted as capable of measuring physical activity (Shephard 2014). However, especially when it comes to children, it may be difficult to estimate one's overall physical activity. In the study by Corder et al. (2010), 40% of inactive children aged 10 years old overestimated their physical activity compared to the objective measurement.

On the other hand, accelerometers are not capable of assessing all physical activities, such as swimming and cycling or activities that require lifting any kind of load (Strath et al. 2013). In addition, skill-specific types of physical activities based on body movements are common among children, but may not be seen in activity counts. For example, skateboarding is a skill-specific physical activity requiring balance and agility, yet it hardly accumulates activity counts. Thus, accelerometer-measured MVPA mainly illustrates cardiovascular activity with increased heart rate and respiratory frequency, while self-reported MVPA may represent different constructs and contexts of physical activity. These differences may explain inconsistent results between self-reported and objectively measured MVPA in association with academic achievement and cognitive functions.

5.2 Sedentary behaviour, academic achievement and cognitive functions

The present results, which show a negative association between self-reported screen time and academic achievement, are consistent with those of previous studies (Sharif & Sargent 2006, Mößle et al. 2010, Sharif, Wills & Sargent 2010). In addition, the present results also support some of the earlier studies (Dworak et al. 2007, Swing et al. 2010) by showing that excessive video game play and computer use were associated with weaker performance in cognitive tests measuring working memory and shifting and flexibility of attention. However, in the present study, TV viewing had no association with cognitive functions, contrary to earlier studies in which excessive TV viewing has been connected to attention and learning difficulties (Johnson et al. 2007, Landhuis et al. 2007, Mizuno et al. 2012). In addition, total screen time was not associated with cognition, which is in line with other previous studies reporting no such association (Weis & Cerankosky 2010, Ferguson et al. 2012). However, earlier studies have reported screen time benefitting academic performance (Borzekowski & Robinson 2005, Jackson et al. 2006, Bittman et al. 2011, Jackson et al. 2011, Haapala et al. 2014a) and cognitive functions (Dye, Green & Bavelier 2009, Spence & Feng 2010, Boot, Blakely & Simons 2011, Granic, Lobel & Engels 2013).

In sum, the results of the present study both support and contradict the earlier studies, showing that associations of screen time with cognitive and academic performance are complicated and still need clarification. These inconsistencies may be partly due to the varying designs across the studies. Especially, the age of the children is crucial: the role of screen time may be different for children in different developmental stages. For example, in Haapala et al.'s (2014a) study, television viewing had no association with academic skills and high levels of computer use and video game playing were associated with better academic skills in six to eight years old children. In contrast, in our study, high levels of screen time were associated with lower levels of academic achievement in 11–12-year-old children, suggesting that the effects of screen time on academic achievement may become emphasized in older children. In addition, the amount of screen time may be an important factor: in some studies, screen time (such as video game playing) showed benefits in cognitive functions (Dye et al. 2009). In the present study, some children spent excessive amounts of time in front of screens in their free time: one fifth of the children reported having screen time of about five or more hours per day. Excessive amounts of screen time might partly explain the results suggesting that screen time is harmful to academic achievement and cognition.

Excessive screen time may attenuate academic performance and cognitive functions through different mediators. Shin (2004) reported that television viewing hindered children's academic achievement through three different pathways: time displacement, effort-passivity and attention-arousal. The time displacement theory suggests that time spent in front of a screen takes time away from intellectually demanding activities, such as doing homework and reading books, which may independently affect academic performance. Screen time is more attractive to children than school-related activities displacing comparable activities that involve learning opportunities. The effort-passivity theory hypothesizes that television watching does not require mental effort, which leads to mental laziness and passivity. Thus, children are more likely to find their way in front of television programmes that are entertaining and easy to understand, rather than engaging in activities that require intellectual functions, such as reading, and that this eventually leads to a decrease in academic achievement. The attention-arousal theory proposes that exposure to television programmes leads to superficial intellectual processing and impulsive behaviours, increasing attention difficulties and hindering academic achievement. In sum, Shin (2004) suggests that excessive amounts of screen time may displace activities involving learning opportunities and increase children's impulsive behaviour, with the result of eventually decreasing academic skills.

In addition, according to Sharif, Wills and Sargent (2010), screen exposure has an indirect effect on academic performance through increased sensation-seeking. The sensation-seeking theory touching on the time displacement and attention-arousal theories propose that there may be certain dispositions in media use, especially intense and exciting sensations, which increase desire for these kinds of experiences and are incompatible with concentrated efforts, such as reading and writing. Furthermore, attention difficulties, frequent failure to do homework, negative attitudes toward school, substance use and behaviour problems have been reported to mediate the association between television viewing and academic performance (Johnson et al. 2007, Sharif, Wills & Sargent 2010).

The disadvantages and benefits of screen-based sedentary behaviour on cognitive functions and academic achievement may be explained by content of screen time, as not all types of screen time have an equal role in benefitting or impairing children's cognitive skills and learning (Kirkorian, Wartella & Anderson 2008, Schmidt & Vandewater 2008). This might also explain the divergent results of the studies. According to Ennemoser and Schneider (2007), educational programme viewing was positively correlated with reading speed and comprehension in children, yet entertainment programme viewing was negatively correlated. Feng, Spence and Pratt (2011) reported that action-game training in young adults improved performance and attenuated gender differences favouring males in spatial attention tests, while non-action-game playing among control subjects had no effect on attention performance.

Kühn et al. (2013) reported that video game playing may induce structural brain plasticity in the areas important to spatial navigation, strategic planning, working memory and motor performance, which may explain the positive association between screen time and cognition. On the other hand, according to Drowak et al. (2007), interactive computer game play, but not viewing exciting films, resulted in significant declines in verbal memory performance and slow wave sleep, which is important for memory consolidation. Finally, it should be kept in mind that computer-based cognitive assessments may require similar cognitive skills as video and computer games, which would favour children who play a lot of video and computer games. The skills will develop, which are practised.

To our knowledge, this was the first study that examined associations of objectively measured sedentary time with academic performance and cognitive functions. In the present study, objectively measured sedentary time was not associated with academic achievement, but had a positive association with performance in sustained attention test: children who spent more time being sedentary had higher scores in sustained attention test. This might be due to the objective measurement of sedentary time, which is a summary measure of all kinds of sedentary behaviour – including a range of various activities, such as screen time, reading, homework, interaction with friends, *et cetera* – but is unable to differentiate between types of sedentary behaviour. It is reasonable to suggest that some of these sedentary activities (e.g. homework and reading) benefit learning, cognition and academic achievement.

5.3 Methodological considerations

5.3.1 General strengths and limitations

To our knowledge, this was the first study to examine the associations of both objectively measured and self-reported overall physical activity and sedentary behaviour on teacher-rated academic achievement and cognitive functions. From the perspective of physical activity, our study sample was quite large and representative, and showed comparable levels of physical activity in Finnish school-aged children to those reported in international results (Currie et al. 2012). The study design was cross-sectional and, therefore, conclusions regarding the causality of the observed associations cannot be drawn. Furthermore, pubertal timing, motor skills and fitness were not assessed in this study, which limits the interpretation of the results, especially concerning cognitive functions.

This was also the first study to examine the internal consistency and one-year stability of CANTAB tests in healthy 12-year-old children, and thus it provided valuable and important information on the psychometric characteristics of CANTAB tests in a child population. The number of children in the follow-up measurements in 2012 was limited, which attenuated statistical power. However, there were no significant differences in the CANTAB tests according to socioeconomic status or performance between children with complete data and children who did not participate in the follow-up measurements. In addition, the models were estimated with FIML estimation, which uses all information available and takes missing data into account.

From the perspective of psychometric characteristics, the age-range of the children studied was narrow limiting the generalization of the results to different age groups or developmental stages. Furthermore, the study sample was culturally homogeneous including only Finnish children. It was also not possible to calculate intra-class correlations for the CANTAB tests, because the performance of the children was not measured again immediately after the first measurement. Several measurement points during the year would have given more accurate information on the effects of practice on performance in the tests.

5.3.2 Measurement of physical activity and sedentary behaviour

The questions used in the present study to assess self-reported physical activity and sedentary behaviour were taken from the WHO HBSC study (Currie et al. 2012). These questions have been commonly used. Test-retest agreement has been very good for MVPA (Booth et al. 2001, Liu et al. 2010), substantial for TV viewing and computer and video game playing (Liu et al. 2010), and moderate for computer use (Liu et al. 2010).

One of the main weaknesses of self-reports is accuracy due to recollection and social desirability biases. For example, according to Corder et al. (2010), children overestimated their physical activity levels compared to objectively measured physical activity. In addition, in the present study, self-reported physical activity was assessed with only one question. The question was worded so that it assesses overall MVPA during the day. However, children may not include brief spurts or incidental physical activity in overall MVPA when answering this question. Furthermore, the detailed content of screen-based sedentary behaviour was not assessed, which limits the interpretation of the results regarding screen-based sedentary behaviour. Moreover, time spent doing homework, reading, or performing other activities that may benefit academic achievement and cognition was not investigated, limiting a more precise examination of total sedentary behaviour.

Children's physical activity and sedentary time were also measured objectively with an accelerometer, and accelerometers have been considered to provide more accurate measurement than self-reports (Evenson et al. 2006). However, accelerometers do not measure all kinds of activities, such as swimming, cycling, or similar activities (Strath et al. 2013). Specifically, accelerometers that are worn on the hip, do not capture activities where load-lifting is performed (Strath et al. 2013), and do not differentiate between sitting and standing (Skotte et al. 2014). Furthermore, in the present study, children wore an accelerometer for seven days, which may not have been long enough to capture their normal physical activity.

5.3.3 Measurement of academic achievement

In this study, teacher-rated academic achievement scores were used to assess children's academic performance. Grading given by teachers enables more comprehensive evaluations of children's academic performance, compared to grading that is based solely on standardized tests. At the same time, however, grading by teachers may result in discrepancies in grades between students (from different classes or schools) with the same level of competence. Therefore, a comparison of children's academic achievements is not accurate if the objectives of the national curriculum for each grade are not carefully followed and teachers let their biases affect grading. (Ouakrim-Soivio 2013).

5.3.4 Measurement of cognitive functions – Reliability and stability of cognitive test battery (CANTAB)

Neurocognitive performance of children was assessed with the Cambridge Neuropsychological Test Automated Battery (CANTAB). There are a lot of advantages in computerized testing: computer technology has increased the efficiency, ease, and standardization of administration and saved time and money related to testing. Electronic data capture and automatic results scoring have minimized human errors in scoring and data entry and increased the accuracy of timing and response latencies. (Cernich et al. 2007, Parsey & Schmitter-Edgecombe 2013). Other advantages of computerized technology – particularly for the measurement of attention, motor, and memory functioning – are the availability of almost unlimited alternate forms and an increased number of trials. This minimizes practice effects and allows more assessments at shorter time intervals compared to traditional measures. A large number of trials and accurate assessment of reaction times results in data that is normally distributed and on a true interval scale (Betts et al. 2006). This is particularly important when slight changes in performance across time are assessed.

Computer technology also provides test administration conditions that are accommodating for individuals with particular needs (American Educational Research Association et al. 2014). Touch-screen technology facilitates use by young children and certain clinical groups, and allows more reliable assessment of motor function and processing speed compared to traditional measures using an individual administrator wielding a stopwatch. In addition, non-verbal culture-neutral test stimuli are often used, which allow the application of computerized test batteries (like CANTAB) for individuals from different racial, ethnic, geographic, or sociocultural backgrounds. (Luciana 2003, Henry 2010). CANTAB also has simple standardized test administration; thus, it is easy to use and no previous IT or scientific training is needed to set-up and administer the test (Cambridge Cognition Ltd. 2006). However, there is limited information about the psychometric properties of CANTAB and other computerized batteries.

This study was one of only a few studies to measure the psychometric properties of CANTAB tests, especially in children. Our results, which show that the internal consistency of certain CANTAB tests (PRM, SRM, RVP) was quite low and acceptable only for the RTI test, do not support the study by Luciana et al. (2003), who reported that the internal consistency of CANTAB tests has been uniformly high in 4–12-year-old children. Internal consistency could not be determined for IED or SSP because of the hampering nature of these tests. The results of the present study are in line with previous studies measuring the test-retest stability of CANTAB tests in both children (Gau & Shang 2010, Fisher et al. 2011) and adults (Lowe & Rabbitt 1998, Henry & Bettenay 2010). In this study, one-year stability was moderate in certain tests (PRM, SSP, IED, RTI, RVP). However, earlier studies measured test-retest correlation with a time-interval of a few weeks, whereas in the present study the time-interval was approximately one year. In the present study, SRM and SOC were not reliable or stable measures in healthy 12-year-old children over one year period.

Low internal consistency might be a result of the ceiling effect, especially in the case of PRM and RVP. In these tests, children have been reported to reach ceiling levels by the age of 7 and after 10 years of age, respectively (Halperin et al. 1991, Luciana & Nelson 2002). In addition, in the present study, 12-year-old healthy children reached ceiling levels also in the IED test, which is in line with earlier studies (Luciana & Nelson 1998, Anderson 2002, Luciana & Nelson 2002). Thus, when ceiling levels are reached, the errors the children do may be sparse and random, which may explain why the patterns of the tests do not have a high correlation with each other. It may be problematic to discriminate children with high ability and internal consistency may be affected.

Stability could also be affected by the ceiling effect and a long test-retest interval. In this study, stability was measured with a one-year interval. It is to be expected that the cognitive abilities of 11-year-old children develop over the course of a year. Therefore, measuring their performance twice – in the beginning with a shorter interval between the measurements – would have enabled calculation of test-retest reliability, thus ruling out developmental effects.

The SOC test, which measures spatial planning and spatial working memory, and is identical to the traditional Tower of London task, did not measure the phenomena it was supposed to with satisfying reliability. Previous studies have also raised questions about the psychometric characteristics of both traditional and CANTAB versions of this test: previous studies have reported low internal consistency (Humes et al. 1997, Ahonniska et al. 2000) and test-retest reliability (Lowe & Rabbitt 1998, Bishop et al. 2001). However, temporal stability has also been reported to be acceptable (Gnys & Willis 1991, Ahonniska et al. 2000, Gau & Shang 2010). Both large intra-individual variation due to different rates of learning and task novelty have been suggested as explanations for low reliability and stability (Lowe & Rabbitt 1998, Ahonniska et al. 2000). Children's performance in the SOC test improves approximately at the age of 11 years due to developmental spurt (Anderson, Anderson & Lajoie 1996). In addition, performance in the tests of executive function can abruptly improve when an individual discovers an optimal strategy, but there is less or no chance in performance if a strategy is not found, and it may even decline if an incorrect strategy is attempted (Lowe & Rabbitt 1998). In the present study, 58% showed improved performance, and 31% showed a decline in performance. These different practice effects may weaken test-retest reliability (Lowe & Rabbitt 1998).

CANTAB tests as well as other computer-based tests are based on traditional neuropsychological tests. However, a few studies have shown that the computerized versions of the tests are not equivalent to traditional ones (Feldstein et al. 1999, Smith et al. 2013). The reason for these findings is unknown, and it can only be speculated that computerized test sessions are more prone to attentional disruptions than manual sessions, or they may not offer similar perceptual characteristics as manual versions.

Despite the potential advantages that computerized technology offers for neuropsychological testing – especially the ease of building ready algorithms for calculating indexes and scores – computer-assisted assessment also produces a risk factor. Due to commercial competitive reasons, the companies providing these tools may not always publish detailed information about these algorithms or the psychometric properties of the tasks. The general characteristics of scoring algorithms and the accuracy of the algorithms as well as technical evidence should be documented and reviewed periodically (American Educational Research Association et al. 2014). According to the Finnish Psychological Test Committee (2013), test batteries (computerized or not) that do not provide a satisfactory level of information about the psychometric properties of the tasks in the technical manual should not be used in clinical practice. Likewise, in clinical practice, an expert (a psychologist or an MD) should always do the interpretation of the test results. There are two reasons for this. First, to use CANTAB or other computerized test batteries, there needs to be a person who supervises and paces the introduction of tests and monitors the assessment process (Luciana 2003, American Educational Research Association et al. 2014). Secondly, the interpretation and the clinical conclusions and decisions made based partly on the test results produce a juridical situation where there needs to be a responsible decision-maker. Most countries do not allow automated decision-making in healthcare.

There will be rapid growth in the usage of computer-assisted test batteries. However, little is known about the psychometric properties of computerized batteries as well as how performance on computerized batteries correlates with traditional neuropsychological measures. In addition, it is also vital to have more information about the reliability and validity of these batteries in all clinical target populations of interest as well as in samples derived from the normal population.

6 CONCLUSIONS

6.1 Summary and main conclusions

The main findings and conclusions of each aim of the study can be summarized as follows:

1. Self-reported (but not objectively measured) physical activity and screen-based sedentary behaviour were associated with academic achievement in school-aged children. Self-reported MVPA had an inverse curvilinear relationship with the grade point averages of school subjects, while self-reported screen time had an inverse linear relationship with grade point averages. Objective and subjective measurements may reflect different constructs and contexts of physical activity and sedentary behaviour in association with academic outcomes.

2. The internal consistency of most of the seven CANTAB tests used in this study was below the accepted level of 0.7. The one-year stability of most tests was moderate-to-good. In addition, in the present study population of 12-year-old healthy children, the ceiling levels were reached in the PRM, IED, and RVP tests. The psychometric characteristics of traditional neuropsychological tests may be lost when converted into computer form; this should be confirmed among target populations before using computer-based test batteries for clinical or research purposes. The results of the present study suggest that the use of structural equation modelling would improve the reliability of these tests when using them in research analysis.

3. High objectively measured physical activity and sedentary time were associated with good performance in the test measuring attentional processes, but not in the tests related to other domains of cognitive functioning. Self-reported physical activity, total screen time or television viewing were not associated with any of the cognitive tests measuring visual memory, executive functions or attention in children. High self-reported time spent in computer or video game play and computer use was associated with poor performance in the tests measuring visuospatial working memory and shifting and flexibility of attention, respectively. The results of the present study suggest that physical activity may benefit some attentional processes. However, excessive video game play and computer use may have an unfavourable influence on some cognitive functions. However, all sedentary time is not harmful to cognition, but may include activities that benefit certain cognitive functions.

6.2 Implications and future directions

This doctoral thesis provide important information about the associations of physical activity and sedentary life with cognitive functions and academic performance in Finnish school-aged children, in order for both practitioners and policy-makers to better develop learning, education and health in the Finnish school system. The topic is highly relevant and currently important. The results suggest that in Finland, which has an educational system of high quality and equality, physical activity may enhance some attentional processes and academic achievement, whereas excessive screen-based sedentary behaviour may attenuate them.

As physical inactivity among children is increasing worldwide, physical activity that benefits both health and learning is becoming an important part of education. The enhancement of physical activity in school settings has recently also been the focus of Finnish Sport policy aimed at improving the health and well-being of young people. Almost every Finnish child conducts their compulsory education in school, spending plenty of time there during the week. Thus, schools play an important role in encouraging children to be more physically active, both at school and outside school hours. As learning is the centre of action at school, research that shows a positive association between physical activity and learning may also pique the interest of parents and teachers who are not into physical activity themselves.

A few studies have also shown that both acute exercise and chronic physical activity enhances cognitive performance, especially in children with ADHD (Verret et al. 2012, Pontifex et al. 2013) and in children with weaker cognitive performance (Reynolds & Nicolson 2007, Drollette et al. 2014). This important observation may significantly contribute to children's learning and well-being in schools. Providing a learning environment where physical activity is implemented in alignment with learning objectives, may establish new opportunities to support learning and individual development.

There are many options when integrating physical activity in the school day. However, it is important that physical activity is implemented in a manner that supports adoption of a physically active lifestyle. This is especially important, because physical activity in childhood and adolescence predicts physical activity in adulthood (Telama et al. 2014). Creating positive physical activity patterns that offer good experiences and support autonomy, competence and relatedness in childhood enhances physical activity over the course of one's entire life (Hirvensalo & Lintunen 2011). Promoting a physically active lifestyle may also support lifelong academic and cognitive performance and learning.

Although, excessive screen time may have unfavourable effect on academic performance and cognition, a reasonable amount of video game play and computer use may benefit them (Bittman et al. 2011, Boot, Blakely & Simons 2011, Jackson et al. 2011, Granic, Lobel & Engels 2013). Today, exergames that combine physical activity and video games are popular, and they are considered to provide one possible way to decrease children's excessive sedentary behaviour (Staiano & Calvert 2011). In addition, exergaming may also enhance cognitive functions, especially executive functions compared to non-players (Staiano, Abraham & Calvert 2012). These kinds of approaches, which combine physical activity and media use, may make important contributions to future learning environments. The advance of comprehensive approaches may support children's physical, psychological and social growth, as well as development and learning.

Although research examining the association of physical activity and sedentary behaviour with academic and cognitive performance has increased during recent years, the studies, including the current thesis, have mainly been cross-sectional. Thus, studies with longitudinal study designs and randomized controlled trials are needed to clarify the causal relationship of these variables.

In addition, it would be valuable in future studies to specify the mechanisms mediating and underlying these associations. The few studies to date concerning these mechanisms have largely focused on physiological and neural mechanisms like cerebrovascular function, levels of growth factors and neural activity in the brain, which are very important factors for explaining the relationship between physical activity and cognition and academic performance. However, in the future, social interaction and context-related factors should also be considered and taken into account. The mechanisms and mediators behind the association between sedentary behaviour and cognitive and academic performance may be even more complicated and in need of clarification.

Furthermore, more information is needed not only on the amount but also the types and contexts of physical activity and sedentary behaviour, which affect academic performance and specific kinds of cognition. It would be important to examine the dose-response relationship of both physical activity and screen-based sedentary behaviour with academic achievement and cognitive functions.

This study provides important insight into inconsistencies between self-reported and objective measurements of physical activity and sedentary time in association with academic and cognitive performance. The results of the present study recommend that future studies use both subjective and objective measurements to examine physical activity, sedentary behaviour, and academic achievement. In addition, a longer period of wearing the accelerometer and, preferably, several measurement points during the school year should be considered.

Only a few studies have measured a broad range of cognitive functions. The associations between physical activity and different dimensions of cognitive functions are somewhat inconsistent, highlighting the need for new studies to clarify the benefits of physical activity on a wide range of cognitive performance. In addition, the definitions, patterns and measurements of cognitive functions have varied across different studies, which makes it difficult to directly compare and summarize the results of these earlier studies and to determine the specific benefits and disadvantages that physical activity and sedentary behaviour may have on cognitive functions.

The use of computerized test batteries to measure cognitive functions is increasing worldwide. As there are hardly any studies that assess the internal consistency and stability of these test batteries in a child population, and the results of the present study suggest that the confirmation of psychometric properties of these test batteries in the target population is highly important, more research is needed to assess the reliability and stability of computerized test batteries. In particular, research on different age groups and developmental stages is needed.

Technology, which is developing with dizzying pace imposes new challenges also for research assessing the effects of screen-bases sedentary time. Children today are more familiar with different media devices than previous generations. In Finland, 95% of 10–12-year-old children are estimated to have access to electronic media at home (Suoninen 2013). This may have an influence on results concerning cognitive functions, especially when computerized test batteries are used. In the future, it might be reasonable to use also other possible alternatives, such as everyday real-world cognitive tasks that could differentiate children's cognitive performance.

In addition, computers, tablets, and smartphones are always available, which makes it difficult to assess how much time is spent in front of the screens. Furthermore, the dynamic nature of screen time and media use makes it difficult to predict the longitudinal effects of screen time. For example, younger and younger children use these technologies daily, so the effects of screen time may be significantly different for those two-year-old children (who develop with technology) when they are of school age, than for school-age children now. Even two-year-old children today have gained different experience from technology than two-year-old children two years ago. The history of screen time may be one important factor to take into account in future studies assessing the association between screen time and cognition.

The results of this study indicate that physical activity is positively associated and screen time inversely associated with academic performance and certain cognitive functions in children, supporting the importance of promoting physical activity in school settings and a physically active lifestyle overall. In the future, research that focuses on specifying, deepening and applying this information is needed.

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APPENDICES

APPENDIX 1. Summary of studies examining the association of physical activity with academic performance and cognitive functions published in 2008 and after.

Authors publication year	Age and number of subjects, design, year, country (if mentioned)	Measurement of PA and fitness, academic achievement and cognitive functions	Main results
Ardoy et al. 2014.	13 y, n=67, a 4-month group-RCT: control group receiving 2 usual PE lessons, experimental group #1 receiving 4 usual PE lessons and experimental group #2 receiving 4 high intensity PE lessons, 2007, Spain.	Academic achievement with grades in the core subjects (Math and Language), average score of others subjects, average score of all subjects and average score excluding PE, cognitive functions with the M (medium) version of the Spanish Overall and Factorial Intelligence Test (IGF-M).	Experimental group #2 improved significantly in average academic achievement (except language achievement), nonverbal and verbal abilities, abstract reasoning, spatial ability, numerical ability and verbal reasoning, compared to control group or experimental group #1. There were no differences between experimental group #1 and control group.
Best et al. 2012.	6–10 y, n=33, a 2 x 2 within-subject experimental design: children's cognitive functions were assessed after PA (physically active video games versus sedentary video activities) and cognitive engagement (challenging and interactive video games versus repetitive video activities), Georgia.	Inhibitory control with a modified flanker task: the Child Attention Network Test (ANT-C).	Children's speed to resolve interference from conflicting visuospatial stimuli was enhanced after PA (exergaming), compared to sedentary activities. Cognitive engagement had no effect on task performance.
Blom et al. 2011.	Grades 3–8, n=2992, cross-sectional, 2007–2008, US.	Physical fitness with FITNESSGRAM® (composite score of PACER, curl-ups, push-ups, trunk lifts, sit and reach test, and skinfold/BMI), academic achievement with the Mississippi Curriculum Test (MCT2) for language arts and mathematics.	Positive correlation between overall physical fitness and language arts and math achievements.
Booth et al. 2014.	11 y at baseline, n=4755, the Avon Longitudinal Study of Parents and Children: 2002–2003→2004–2005→2007–2010, UK.	Objectively measured MVPA with Actigraph AM 7164 2.2 accelerometer (7 days, at least 3 days of 10 h valid data), academic achievement with nationally administered school assessments in mother tongue, math and science.	MVPA predicted increased performance in mother tongue in both sexes at the ages of 11, 13 and 16. MVPA predicted increased performance in math in both sexes at the age of 16, but not at the age of 11 or 13. For females, the MVPA predicted increased science scores at 11 and 16, but not for males.

APPENDIX 1. Continued.

Buck, Hillman & Castelli 2008.	7–12 y, n=74, cross-sectional, US.	CRF with FITNESSGRAM® (PACER), inhibitory control with the Stroop task (word, colour, colour-word).	Greater CRF was associated with better performance in each of the three conditions in the Stroop task.
Budde et al. 2008.	13–16 y, n=115, children's attention performance were measured after a regular school lesson (pre-test) and after 10 min. of coordinative exercise (experimental group) or of a normal sport lesson (control group), Germany.	Attention and concentration with the d2-test.	Both groups had enhanced attention and concentration performance with a significantly higher progression in the experimental group.
Castelli et al. 2011.	8.8 y, n=59, cross-sectional: children participated in a 9-month physical activity programme during which their PA was measured, US.	PA with Polar heart-rate monitors and time below, time at, and time above the target heart rate were recorded, CRF with maximal treadmill test using a modified Balke protocol, cognitive functions with the Stroop Color-Word Test and the Comprehensive Trail-Making Test.	CRF has no correlation with cognitive functions. Mean time above the target hearth zone was associated with high executive function demand (Stroop Color-Word & Trail-Making part B).
Carlson et al. 2008.	From kindergarten to 5th grade, n=5316, the Early Childhood Longitudinal Study, fall 1998→ spring 2004, US.	Classroom teachers measured the time spent in PE (minutes per week), academic achievement with standardized tests for math and reading.	The higher amount of PE was positively associated with math and reading achievement in girls, but not in boys.
Chaddock et al. 2010.	9–10 y, n=49, cross-sectional, US.	CRF with maximal treadmill test using a modified Balke protocol, memory with item and relational memory paradigm.	CRF had a positive association with relational memory task performance, but no association with item memory task performance.
Chaddock et al. 2010.	9–10 y, n=55, cross-sectional, US.	CRF with maximal treadmill test using a modified Balke protocol, inhibitory control with a modified version of the Eriksen flanker task.	More fit children had less percent interference compared to less fit children. CRF fitness had no association with flanker accuracy or reaction time.
Chaddock et al. 2011.	9–10 y, n=46, cross-sectional, US.	CRF with maximal treadmill test using a modified Balke protocol, memory performance with a modified version of a memory task developed by Henke et al.	CRF fitness had a positive association with relational memory accuracy, but had no association with non-relational memory accuracy.

APPENDIX 1. Continued.

Chaddock et al. 2012.	9–10 y, n=32, cross-sectional, US.	CRF with maximal treadmill test using a modified Balke protocol, inhibitory control with a modified version of the Eriksen flanker task.	There were no group differences in congruent accuracy. During incongruent trials, only more fit children maintained accuracy across the blocks. There were no group differences in reaction times.
Chaddock et al. 2012.	9–10 y, n=32, longitudinal: one year follow-up, US.	CRF with maximal treadmill test using a modified Balke protocol, inhibitory control with a modified version of the Eriksen flanker task.	More fit children had higher accuracy than less fit children across compatibility task conditions and test sessions. More fit children maintained accuracy across compatible and incompatible task conditions, whereas less fit children showed lower accuracy in the incompatible condition relative to the compatible condition. More fit children also had faster reaction times at follow-up.
Chaddock et al. 2012.	8–10 y, n=26, cross-sectional, US.	CRF with maximal treadmill test using a modified Balke protocol, cognition with Virtual reality street crossing paradigm.	More fit children maintained performance in street-crossing across all 3 conditions, whereas less fit children showed decreased performance when on the phone, relative to being undistracted or listening to music.
Chaddock-Heyman et al. 2013.	8–9 y, n=23, a RCT: 60+ minutes of PA 5 days per week for 9 months, US.	Inhibitory control with a modified flanker task, including three task condition: neutral, incongruent, and NoGo trials.	Children who participated in the PA programme improved their performance in the inhibitory control task at the level of young adults at post-test, while the control group still differed from the young adults.
Chih et al. 2011.	11–12 y, n=476, cross-sectional, 2006–2010, China.	Physical fitness measured with sit and reach test, bent-knee sit-ups for one minute, 800m run/walk and standing long jump, academic achievement in math and mother tongue.	Physical fitness variables were not associated with academic achievement. PE performance was positively associated with academic achievement.

APPENDIX 1. Continued.

Chomitz et al. 2009.	Grades 4,6,7,8 (mean age 11.7 y), n=1478, cross-sectional, 2004–2005, US.	Physical fitness with five tests adapted from the Amateur Athletic Union (AAU) and FITNESSGRAM® (composite score of an endurance cardiovascular test, an abdominal strength test, a flexibility test, an upper-body strength test, and an agility test), the Massachusetts Comprehensive Assessment System (MCAS) for math and English.	Overall physical fitness was positively associated with passing the MCAS English test and the MCAS Mathematics test.
Crova et al. 2014.	9–10 y, n=70, a RCT: 6-month enhanced PE programme including cognitively demanding (open skill) activities or curricular physical education only, Italy.	The random number generation (RNG) task measuring inhibitory control and working memory.	Overweight children participating in cognitively demanding activities improved their inhibitory control but not working memory ability, compared to lean children and children who participated in curricular PE. More fit children had better inhibitory control but not working memory performance, compared to less fit children.
Davis & Cooper 2011.	7–11 y, n=170, cross-sectional, 2003–2006, US.	CRF fitness with a graded treadmill test (Modified Balke, Protocol for Poorly Fit Children), academic achievement with the Woodcock-Johnson Tests of Achievement III: The Broad Reading and Broad Mathematics clusters, cognitive functions with the Cognitive Assessment System (CAS) consisting of 4 sub-categories: Planning, Attention, Simultaneous, and Successive.	Peak VO_2 and treadmill time were positively associated with math and reading test. Peak VO_2 and treadmill time were positively associated with performance in Planning and Attention categories. Peak VO_2 and treadmill time were not associated with performance in Simultaneous or Successive categories.
Davis et al. 2011.	7–11 y, n=171, a RCT: exercise programme adding 20 or 40 minutes of aerobic exercise per day for 13 weeks, 2003–2006, US.	Academic achievement with the Woodcock-Johnson Tests of Achievement III: The Broad Reading and Broad Mathematics clusters, cognitive functions with the Cognitive Assessment System (CAS) consisting of 4 sub-categories: Planning, Attention, Simultaneous, and Successive and Antisaccade task.	There was a dose-response benefit of PA on mathematics achievement, planning ability and inhibition. PA was not associated with reading achievement or attention, simultaneous, and successive performance.

APPENDIX 1. Continued.

Donelly. et al. 2009.	7–9 y (at baseline), n=1527, a three-year, cluster-RCT: 90 minutes of MVPA was combined with learning objectives in academic lessons during school week, 2003→2006, US.	Academic achievement with the Wechsler Individual Achievement Test (2nd Edition) for reading, writing, mathematics and oral language skills.	Academic achievement scores for composite, reading, spelling and math significantly improved from baseline to three years in children participating in intervention, compared to control group.
Drollette et al. 2012.	9–11 y, n=36, a within-subjects counterbalanced design: children's cognitive performance were measured before, during or after walking or seated rest, US.	Inhibitory control and working memory with a modified flanker task and a modified spatial n-back task.	After moderately intense aerobic walking, children's performance in inhibitory control improved but working memory, compared to seated rest. There were no changes in task performance during actively walking or at seated rest in both tasks.
Drollette et al. 2014.	8–10 y, n=40, children categorized by higher- and lower-task performance completed inhibitory control task before and after 20 min. of treadmill walking and seated rest, US.	Inhibitory control with a modified flanker task.	Following exercise, higher-performers maintained accuracy compared to seated rest, whereas lower-performers demonstrated improvements in inhibitory control accuracy following exercise.
Duncan & Johnson 2014.	8–11 y, n=18, a repeated measures design: children completed academic achievement test following rest and two different intensity exercises, UK.	20 minutes of rest, 20 minutes on a cycling ergometer at 50% HRR, and 20 minutes on a cycling ergometer at 75% HRR, academic achievement with the Wide Range Achievement Test (WRAT 4).	High and moderate intensity exercise improved spelling. Moderate intensity exercise improved reading. Exercise had no effect on sentence comprehension, but attenuated arithmetic.
Edwards, Mauch & Winkelman 2011.	11–13 y, n=800, cross-sectional, 2005, US.	PA with Youth Risk Behavior Surveillance Survey, physical fitness with FITNESSGRAM® (aerobic capacity with the mile run, muscle strength with push-ups and curl-ups), academic achievement with measures of Academic Progress (MAP) standardized tests for math and reading.	Vigorous PA, but not moderated PA, CRF and participation in sports teams were positively associated with MAP math scores. Vigorous PA and moderate PA was positively associated with MAP reading scores. Increased CRF or participation in sports teams were not associated with MAP reading scores. Curl-ups and push-ups were not associated with MAP math or reading scores.

APPENDIX 1. Continued.

Ericsson 2008.	Grades 1-3, n=251, controlled intervention: intervention groups with 5 PE lessons and 1 motor-training lesson per week, control group with 2 PE lessons per week, 1999–2002, Sweden.	Academic achievement with the national tests for mother language and mathematics, and reading development test, attention with Conners' abbreviated questionnaire filled in by teacher.	Children participating in intervention outperformed control children in reading development, mother language and mathematic tests. Intervention children had better teacher-reported attention (attention/ hyperactivity and impulse control, attention in total) in school year 2, but the difference were small and did not remain in school year 3.
Eveland-Sayers et al. 2009.	Grades 3–5 (mean age 9.7 y), 134, cross-sectional, 2005, US.	CRF with one-mile run time, muscular fitness with combination of curl-ups and sit-and-reach test, academic achievement with the TerraNova achievement test for math and reading/language arts.	A negative association between one-mile run times and math scores in girls (also for total group). Negative association between one-mile run times and reading scores in girls. A positive relationship between muscular fitness and math scores only in total. No relationship between muscular fitness and reading/language arts.
Fisher et al. 2011.	6.2 y, n=64, a RCT: an experiment group with 2 hours of aerobic exercise lessons per week for 10 weeks and a control group with 2 hours of standard physical education lessons, UK.	Cognitive function with the Cognitive Assessment System (CAS) consisting of four subcategories: Planning, Attention, Simultaneous, and Successive, the Cambridge Neuropsychological Test Battery (CANTAB) with tests SSP and SWM, measuring working memory, the Attention Network Test (ANT) measuring inhibition.	Children participating in intervention outperformed control children in working memory and inhibition measures (SSP, SWM, ANT accuracy) at posttest, but did not have better performance in other cognitive tests measuring planning, attention, simultaneous and successive.
Fox et al. 2010.	14.9 y, n=4746, cross-sectional, 1998–1999, US.	PA with self-reported PA and sport team participation, academic achievement with self-reported GPA.	For high-school girls, PA and sports team participation were each independently associated with higher GPA. For high-school boys, only sports team participation was independently associated with higher GPA. For middle-school girls, PA (not sports team participation) were associated with higher GPA. For middle-school boys, PA and sports team participation were associated with higher GPA.

APPENDIX 1. Continued.

Gallotta et al. 2012.	8–11 y, n=138, children's attention abilities were tested before and immediately after school curricular lesson, traditional PE lesson, and coordinative PE lesson.	Attention performance with the d2 Test.	Each exertion type led to enhanced attention performance. Coordinative PE lessons led to a lower improvement in attentional performances, compared with both traditional physical education lessons and school curricular lessons.
Haapala et al. 2014a.	6–8 y, n=186, prospective longitudinal: The Physical Activity and Nutrition in Children (PANIC) study and The First Steps Study, 2007–2009 and 2006–2011, Finland.	PA with the PANIC Physical Activity Questionnaire, academic achievement with the nationally normed reading achievement battery (ALLU) for reading comprehension and fluency, and with a basic arithmetic test.	Children who had more PA during recess and children who most often commuted actively to school had better reading fluency across grades 1–3. Children who engaged in organized sports had better arithmetic skills. Among boys, higher levels total PA and physically active school transportation were associated with reading fluency and reading comprehension. Among girls, total PA was positively associated with reading fluency and arithmetic skills only girls, whose parents had university level education, while the association was inverse in girls whose parents were less educated.
Haapala et al. 2014b.	6–8 y, n=167, longitudinal: The Physical Activity and Nutrition in Children (PANIC) study and The First Steps Study, 2007–2009 and 2006–2011, Finland.	CRF with a maximal cycle ergometer test, academic achievement with the nationally normed reading achievement battery (ALLU) for reading comprehension and fluency, and with a basic arithmetic test.	CRF was not related to reading fluency, reading comprehension or arithmetic skills.
Hill et al. 2010.	8–11 y, n=1224, a randomized crossover design: children in two groups received 30 minutes of classroom-based physical exercise for one week and no exercise during the other.	Cognitive performance with paced serial addition, size ordering, listening span, digit-span backwards, digit-symbol encoding.	Exercise benefit cognition: Group B receiving exercise during the second week gained benefits. However, group A receiving exercise during the firsts week did not gained benefits from exercise.

APPENDIX 1. Continued.

Hillman et al. 2009.	9.4 y, n=38, cross-sectional, US.	CRF with FITNESSGRAM® (PACER), inhibitory control with the Eriksen flanker task.	CRF has positive association with flanker task accuracy across conditions. Fitness has no association with reaction time.
Hillman et al. 2009.	9.5 y, n=20, a within-subjects design: children completed cognitive testing after rest and exercise, US.	Inhibitory control with a modified Flanker task, academic achievement with the Wide Range Achievement Test - 3rd edition (WRAT3) for reading, spelling and arithmetic.	After acute exercise, reading comprehension test performance increased. Acute exercise did not affect spelling or arithmetic. Acute treadmill walking did not affect response speed in flanker task. Response accuracy in incongruent flanker task trials increased after walking. Response accuracy in congruent condition was not affected.
Hogan et al. 2013.	13–14 y, n=30, children classified as fit or unfit performed cognitive tasks after a 20 minutes of moderate intensity biking exercise and a period of relaxation, Germany.	Physical fitness with a continuous-graded maximal exercise test, inhibitory control with Go/NoGo version of the Erikson flanker task.	Acute PA or fitness level had no effect on reaction time in inhibitory control task. However, fit participants had significantly faster reaction times in the exercise condition in comparison with the rest condition and unfit participants showed significantly higher error rates for NoGo relative to Go trials in the rest condition, compared to exercise condition.
Kamijo et al. 2011.	7–9 y, n=43, a RCT: 9-month afterschool physical activity programme including two hours per school day of aerobically demanding physical activities, US.	Working memory with a modified Sternberg task.	Response accuracy at post-test was greater than pre-test for the intervention group, but no such difference existed the for control group. There were no differences between groups in reaction times.
Kantomaa et al. 2010.	15–16 y, n=7344, cross-sectional: The Northern Finland Birth Cohort, 2001–2002, Finland.	PA with self-reported MVPA, academic achievement with self-reported GPA.	MVPA was positively associated with GPA.
Kantomaa et al. 2013.	7–8 y → 15–16 y, n=8061, longitudinal: The Northern Finland Birth Cohort, 1992–1004 → 2001–2002, Finland.	Parent-reported motor function, self-reported PA, predicted cardiorespiratory fitness with a submaximal cycle ergometer test, teacher-rated GPA.	PA was associated with a higher GPA. Compromised motor function in childhood had a negative indirect effect on adolescents' academic achievement via physical inactivity and obesity, not via CRF.

APPENDIX 1. Continued.

Kristjánsson et al. 2009.	14–15 y, n=5810, cross-sectional: Youth in Iceland, 2000, Iceland.	PA with self-reported PA, academic achievement with self-reported grades.	PA was positively and moderately related to academic achievement.
Kristjánsson, Sigfúsdóttir & Allegrante 2010.	14–15 y, n=6346, cross-sectional: Youth in Iceland, 2000, Iceland.	PA with self-reported PA, academic achievement with self-reported grades.	PA had direct positive association with academic achievement. Self-esteem was a weak mediator of the association of PA and academic achievement.
Kwak et al. 2009.	16 y, n=232, cross-sectional, Sweden.	Objectively measured PA with an accelerometer (model WAM 7164) (4 days, at least 3 days of 10 h valid data), CRF with a maximal cycle ergometer test, academic achievement with scores from schools.	Vigorous PA was positively associated with GPA only in girls. CRF was positively associated with GPA only in boys.
LeBlanc et al. 2012.	Grades 4–6 (mean age 10.4 y), n=261, cross-sectional, US.	Objectively measured PA with an ActiGraph GT1M accelerometer (3 days, at least 2 days of 10h valid data), academic achievement with criterion-referenced tests for English/language arts, math, science and social studies.	Objectively measured MVPA was not associated with English, math, science, or social studies.
London & Castrechini 2011.	Grades 4–6 at baseline, n=2735, longitudinal: the Youth Data Archive (YDA), 2002–2003 → 2007–2008, US.	Physical fitness with FITNESSGRAM® (composite score of aerobic capacity, body composition, abdominal strength and endurance, trunk extensor strength and endurance, upper body strength and endurance, and flexibility), academic achievement with the California standardized test (CST) in math and English/language arts.	Overall physical fitness was positively associated with English and math in total. From 5^{th}- to 7^{th}-grade, overall physical fitness was positively associated with math, but not associated with English. For 7^{th}-to 9^{th}-grade, overall physical fitness was positively associated with math. For 7^{th}-to 9^{th}-grade, overall physical fitness was positively associated with English only in girls.
Martínez-Gómez et al. 2012.	13–17 y, n=1825, cross-sectional, 2007–2008, Spain.	PA with the Physician-based Assessment and Counselling for Exercise (PACE+) questionnaire, academic achievement with self-reported grades.	In boys, there was no association between PA and academic performance. In girls, PA was associated with good math and language + math performance, but not language only.
Monti, Hillman & Cohen 2012.	9.5 y, n=44, a RCT: a 9-month after-school aerobic exercise intervention including at least 70 min of MVPA every schoolday, US.	Memory performance with a memory task inspired by Hannula et al. 2007 containing relational and item memory conditions.	There were no differences in memory performance between children participating in the aerobic exercise programme and the control group.

APPENDIX 1. Continued.

Moore et al. 2014.	9–10 y, n=40, cross-sectional, US.	CRF with maximal treadmill test using a modified Balke protocol, mathematics achievement with the Kaufman Test of Academic and Educational Achievement 2 (KTEA-2) and with an experimental arithmetic verification task, including small and large addition problems).	There were no differences in mathematics achievement. More fit children had better performance in arithmetic verification tasks, including large addition problems, compared to less fit children.
O'Dea & Mugridge 2012.	Grades 3-7, n=824, cross-sectional, 2008, Australia.	Self-reported PA, the standardized National Assessment Program for Literacy and Numeracy (NAPLAN).	PA was not associated with literacy scores. PA was positively associated with math scores in boys, but not in girls.
Padilla-Moledo et al. 2012.	6–17.9 y, n=690, cross-sectional, Spain.	Muscular fitness with standing long jump test and basketball throwing test, self-reported academic performance compared with those of their classmates.	Low muscular fitness was associated with low academic performance.
Perce et al. 2009.	11–12 y, n=52, children's cognitive functions were measured right after two physical education lessons (aerobic circuit training or team games) and baseline session, Italy.	Free-recall memory performance with a test involving free-recall of items from a 20-item word list.	The team games (not the circuit training) improved immediate recall scores in both primacy and recency portions, compared to the baseline session. Both team game and circuit training improved delayed recall scores in the recency portion (not in primacy), compared to the baseline session.
Pontifex et al. 2011.	Mean age 10.1 y, n=48, cross-sectional, US.	CRF with maximal treadmill test using a modified Balke protocol, inhibition with a modified version of the Eriksen flanker task.	More fit children maintained accuracy across compatible and incompatible task conditions, whereas less fit children showed lower accuracy in the incompatible condition relative to the compatible condition. There were no group differences in reaction times.
Pontifex et al. 2012.	9–11 y, n=62, cross-sectional, US.	CRF with maximal treadmill test using a modified Balke protocol, inhibition with a modified version of the Eriksen flanker task.	Less fit children had poorer overall accuracy compared to more fit children, with a greater number of errors of omission, as well as longer and more frequent sequential errors of omission.

APPENDIX 1. Continued.

Puder et al. 2011.	Mean age 5.1, n=652, cluster-randomized controlled single-blinded trial: multidimensional lifestyle intervention including four 45 minute sessions of physical activity a week, 2008–2009, Switzerland.	Cognitive functions with tests of attention and spatial working memory.	The intervention had no effect on cognitive abilities.
Raine et al. 2013.	9–10 y, n=48, cross-sectional, US.	CRF with maximal treadmill test using a modified Balke protocol, memory and learning ability with a map task in which children had to learn the names of specific regions on a map, under 2 learning conditions in which they only studied versus a condition in which they were tested during study.	In terms of initial learning, there were no differences in task performance between more fit and less fit children. During the retention session, more fit children outperformed less fit children when the study-only learning strategy was used.
Reed et al. 2010.	9.5 y, n=155, a RCT: 90 minutes of physical activity was integrated into the core curricula over four months, children were measured only after the intervention, 2008, US.	Academic achievement with the Palmetto Achievement Challenge Tests (PACT) measuring English/language arts, mathematics, science, and social studies, cognitive functions with the Standard Progressive Matrices (SPM) Test of Fluid intelligence (total score).	Experimental group children outperformed control children in social studies mandated academic achievement test. There were no significant differences in English/language arts, math and science achievement tests between the experimental and control groups. PA participation was positively associated with fluid intelligence.
Reed et al. 2013.	Grades 2–8 (mean age 10.2/11.2 y), n=470, controlled intervention: seven-month intervention providing 45 minutes of daily physical education, 2009–2010, US.	Cognitive functions with the Standard Progressive Matrices (SPM) fluid intelligence test (5 sets: A-E) and the Perceptual Speed Test (sections 1–3).	In elementary school, boys (not girls) in experimental group improved fluid intelligence performance on section D more than controls. In middle school, girls in experimental group improved fluid intelligence performance on sections B, C, D and E more than controls, whereas boys in experimental group improved their fluid intelligence performance on section E more than boys in control group. In elementary school, girls (not) in experimental group improved perceptual speed on sections 2 and 3 more than controls.

APPENDIX 1. Continued.

Roberts, Freed & McCarthy 2010.	Grades 5, 7 and 9, n=1989, cross-sectional, 2002–2003, US.	CRF with a one-mile run/walk test, Academic achievement with California Achievement Tests version 6 (CAT6) and California Standards Tests (CST) for math and reading (CAT) or math and language (CST).	Low CRF was associated with lower scores in math, reading and language.
Ruiz et al. 2010.	13–18.5 y, n=1820, cross-sectional, 2002–2002, Spain.	Self-reported participation in sports, CRF with 20-minute shuttle run test, upper-body muscular strength with handgrip strength test, lower-body muscular strength with standing long jump test, cognitive functions with SRA Test of Educational Ability (TEA).	Participation in sports was positively associated with cognitive performance (verbal, numeric, and reasoning abilities and an overall score). CRF and muscular fitness were not associated with cognitive performance.
Scudder et al. 2014.	9–10 y, n=46, cross-sectional, US.	CRF with maximal treadmill test according to a modified Balke protocol, academic achievement with the Standard Progressive Matrices (WRAT3) for reading, spelling, and arithmetic, sentence processing with Neuroscan STIM2 software.	More fit children had greater reading and spelling scores compared to less fit children. There were no differences in arithmetic scores. In sentence processing tasks, more fit children exhibited overall shorter response times and performed more accurately across all sentence types.
Shi et al. 2013.	7–14 y, n=3708, cross-sectional, 2008–2009, US.	PA with self-reported PA, academic achievement with self-reported academic problems.	PA was associated with less academic problems.
So 2012.	Grades 7–12, n=75066, cross-sectional: Korea Youth Risk Behavior Web-based Survey (KYRBWS-V), 2009, Korea.	PA with self-reported frequency of VPA, frequency of MPA and frequency of strengthening exercises, self-reported academic performance.	VPA was positively associated with academic performance in boys, but not in girls. MPA was positively associated with academic performance in both boys and girls. Strengthening exercises were not associated with academic performance.

APPENDIX 1. Continued.

Spitzer & Hollmann 2013.	12–13 y, experiment #1 n=44, experiment #2 n=88, 2 experimental observations: 3 extra exercise lessons were added to school week for 4 months, Germany.	Academic achievement with academic grades in mathematics, German (mother tongue), and English (foreign language), the d2 test of attention.	In experiment #1, children participating in extra exercise slightly improved German grades, while the control group children worsened their grades. There were no changes in math or English scores. In experiment #2, children participating in extra exercise improved math grades, while the control group children had worse math grades. There were no changes in German or English scores. In experiment #2, children who participated in extra exercise had higher performance in attention tests compared to control children, but not in experiment #1.
Stevens et al. 2008.	From kindergarten to 5th grade, n~3200, the Early Childhood Longitudinal Study, 1998–1999→2002, US.	PA with parent-reported physical activity of their children, academic achievement with standardized test scores in math and reading.	PA was positively associated with mathematics and reading achievements in boys and girls.
Stroth et al. 2009.	13–14 y, n=35, a controlled cross-over study design: children classified as fit and unfit performed cognitive task after 20 minutes of cycling exercise and 20 minutes of a rest period, Germany.	CRF with a continuous graded maximal exercise test, inhibitory control with a Go/NoGo version of the Eriksen flanker task.	Neither CRF nor exercise had any association with inhibitory control performance.
Telford et al. 2012.	Grades 2 and 4, n=757, cross-sectional, Australia.	Objectively measured PA with pedometers, CRF with 20 minutes multistage run, academic achievement with government literacy and math test scores.	PA and CRF were not associated with reading scores. CRF, but not PA, was positively associated with numeracy scores. PA and CRF were positively associated with writing scores.
Van Dusen et al. 2011.	Grades 3–11, 254743, cross-sectional, 2008–2009, US.	Physical fitness with FITNESSGRAM® (CRF with the mile run or PACER test, muscular fitness with curl-ups, trunk lift and push-ups, and flexibility with shoulder stretch or the sit-and-reach test.), academic achievement with Texas Assessment of Knowledge and Skills (TAKS™) for reading and math.	All physical fitness variables were positively associated with math and reading.

APPENDIX 1. Continued.

Vindfeld, Schnohr & Niclasen 2009.	11–17 y, n=1366, cross-sectional: the Health Behaviour in School-Aged Children (HBSC) study in Greenland, 2006, Greenland.	PA with self-reported PA, academic achievement with self-reported academic achievement.	PA was positively associated with overall self-reported academic achievement.
Voss et al. 2011.	9–10 y, n=36, cross-sectional, US.	CRF with maximal treadmill test using a modified Balke protocol, inhibitory control with a modified version of the Eriksen flanker task.	More fit children were more accurate for the incongruent condition but not the congruent condition, compared to less fit children. There were no differences in reaction times.
Welk et al.2010.	Grades 3–12, 1770–6864, cross-sectional, 2007, USA.	CRF with FITNESSGRAM® (the mile run or the Pacer), academic achievement with Texas Assessment of Knowledge and Skills (TAKS™).	CRF fitness was positively associated with academic performance (overall knowledge and skills assessment).
Wingfield et al. 2011.	Grades 4–5, 132, cross-sectional, 2008–2009, US.	Physical fitness with the President's Challenge Physical Activity and Fitness Awards Program (composite score of curl-ups, shuttle run, one mile run/walk, pull-ups, flexed-arm hanging), academic achievement with the Florida Comprehensive Assessment Test (FCAT) for reading and math.	Overall physical fitness was not associated with reading and math.
Wittberg et al. 2010.	Grade 5, n=1740, cross-sectional, 2006–2008, US.	CRF with FITNESSGRAM® (the mile run or the Pacer), academic achievement with West Virginia standardized academic test scores (WESTEST) for reading/ language arts, math, science and social studies.	CRF was positively associated with academic performance.
Wittberg, Northrup & Cottrell 2012.	Grade 5 at baseline, n=1725, longitudinal study, 2005–2006 → 2007–2008, 2006–2007 → 2008–2009, 2007–2008 → 2009–2010, US.	CRF with FITNESSGRAM® (the one-mile run or the PACER), academic achievement with West Virginia standardized academic test scores (WESTEST) for reading/ language arts, math, science and social studies.	Students whose CRF stayed in the "healthy" fitness zone had significantly higher academic scores than did students whose CRF stayed in the "needs improvement" zone.
Wu et al. 2011.	8–11 y, n=48, cross-sectional, US.	CRF with maximal treadmill test using a modified Balke protocol, inhibitory control with a modified version of the Eriksen flanker task.	More fit children had better response accuracy across task conditions than lower fit children. There were no differences in reaction times.

APPENDIX 1. Continued.

Wu & Hillman 2013.	9–10 y, n=39, cross-sectional, US.	CRF with maximal treadmill test using a modified Balke protocol, attention performance with a modified attentional blink paradigm with the same experimental settings and methodology as those used by Slagter et al. (2007).	Higher-fit children had better attentional task performance than lower fit children.
Åberg et al. 2009.	15→18, 1221727, longitudinal: Swedish men born 1950 through 1976 and who were enlisted for military service between 1968 and 1994, Sweden.	CRF with a cycle ergometer test. Isometric muscle strength with knee extension, elbow flexion, and hand grip, intelligence with 4 cognitive tests (logical performance test, verbal test of synonyms and opposites, test of visuospatial/geometric perception, and technical/mechanical skills including mathematical/physics problems).	CRF (not muscular strength) was positively associated with intelligence. Changes in CRF between age 15 and 18 years predicted cognitive performance at the age of 18.

Abbreviations: CRF, cardiorespiratory fitness; GPA, grade point average; HRR, heart rate reserve; MPA, moderate physical activity; MVPA, moderate to vigorous physical activity; PA, physical activity; PACER, Progressive Aerobic Cardiovascular Endurance Run; PE, physical education; RCT, randomized controlled trial; VPA, vigorous physical activity.

APPENDIX 2. Summary of the studies examining the association of screen time with academic performance and cognitive functions.

Authors and publication year	Age and number of subjects, design, year, country (if mentioned)	Measurements of screen time, academic achievement and cognitive functions	Main results
Bittman et al. 2011.	Younger cohort: 0–1 y and older cohort 4–5 y at the baseline, n=5107 and n=4983, longitudinal: the Longitudinal Study of Australian Children (LSAC): children were assessed at four time points during two years, 2004–2007, Australia.	TV viewing, computer use and game console ownership with parent-reported 24 h diary kept during one weekday and one weekend day, language ability with the Peabody Picture Vocabulary Test (3rd edition) (PPVT-III) and with the Language and Literacy Academic Rating Scale (ARS).	TV viewing was not associated with language skills. Computer use was positively associated with development of language skills. The ownership of game consoles was negatively associated with literature achievements in the older cohort.
Borzekowski & Robinson 2005.	Grade 3, n=348, cross-sectional, 1999–2000, US.	Media environment with self-reported questionnaire, academic achievement with the Stanford Achievement Test for math, reading, and language arts.	Having TV in the children's bedroom was negatively associated with academic achievement. Computer access and use were positively associated with academic achievement.
Drowak et al. 2007.	13.5 y, n=11, children were exposed to computer game or video film between 6 pm – 7 pm, German.	Visual and verbal memory with Swets Test Services 4 to 5 hours before bedtime on each experimental day.	Excessive video game playing (but not television viewing) resulted decreased verbal memory performance (but not visuospatial memory performance), compared to basal condition.
Dye & Bavelier 2009.	7–22 y, n=131, cross-sectional, US.	Video game play with self-reported questionnaire, attention abilities (including inhibitory control) with the Attentional Network Test (ANT).	Action-game playing was associated with enhanced attention skills.

APPENDIX 2. Continued.

Ennemoser & Schneider 2008.	6.4 y and 8.6 y, n_1=165 and n_2=167, longitudinal: children's TV viewing and reading performance were assessed at five time points during four years, 1998→2001, German.	Screen time with parent-reported diaries over 7 days, reading comprehension with a reading comprehension test developed by Näslund (1990) (grades 1−2), a subtest of the Knuspel Reading Test (grades 3−4), a subtest of the General School Achievement Test (grades 2−3), and subtests of the General German Language Test and the Zurich Reading Comprehension Test (grade 5), decoding speed with the Würzburg Silent Reading Test.	TV viewing had a negative association with tests of reading speed and comprehension. Children classified as heavy TV viewers, especially having high amounts of entertainment programme viewing, showed lower progress in reading performance compared to medium and light viewers in both age-groups.
Espinoza 2009.	High school juniors, cross-sectional, US.	TV viewing with determining the number of appliances in the house and the time of operation of each appliance, academic achievement with physics performance.	The number of television sets at home and the number of hours that the televisions are on were negatively associated with student performance in physics.
Ferguson et al. 2013.	10−17, n=333/n=143, cross-sectional/prospective 1-year longitudinal, US.	Videogame playing with self-reported questionnaire, academic achievement with Wide Range Achievement Test-IV (WRAT) for math, visuospatial cognition with the Kaufman Brief Intelligence Test-II.	Violent video game exposure was not associated with math achievement or visuospatial cognition in short-term or in long-term.
Gentile & Walsh 2002.	2−17 y, n=527, cross-sectional, 1998, US.	Family media habits and academic achievement with parent-reported questionnaire.	Amount of TV viewing and TV in children's bedroom were negatively associated with school performance.

APPENDIX 2. Continued.

Haapala et al. 2014a.	6–8 y, n=186, prospective longitudinal: The Physical Activity and Nutrition in Children (PANIC) study and The First Steps Study, 2007—2009 and 2006—2011, Finland.	Sedentary behaviour with the PANIC Physical Activity Questionnaire, academic achievement with the nationally normed reading achievement battery (ALLU) for reading comprehension and fluency, and with a basic arithmetic test.	Sedentary behaviour related to academic skills in 1st grade were positively associated with reading fluency in grades 1–3. Among boys (not among girls), higher levels of sedentary behaviour related to academic skills and higher computer use and video game play were associated with better reading fluency and arithmetic skills, respectively. TV viewing had no association with academic skills. Among girls, high levels of total sedentary behaviour (including sedentary behaviours related to screen time, music, academic skills, arts, crafts, games, and sitting and lying for a rest) and sedentary behaviour related to music and arts, crafts and games was negatively associated with arithmetic skills.
Hancox, Milne & Poulton 2005.	5→26 y, n=1037, longitudinal: children were followed from the birth to age of 26, children were born 1972 and 1973, New Zealand.	TV viewing with parent- or self-reported questionnaires at the age of 5, 7, 9, 11, 13 and 15, the highest level of educational attainment with four-point scale.	Television viewing in childhood (ages 5–11 years) and adolescence (ages 13 and 15 years) had negative associations with later educational achievement (at the age of 26).
Jackson et al. 2006.	10−18 y, n=140, longitudinal: children's Internet use was continuously recorded and academic performance many time measured during 16 months, 2000−2002, US.	Internet use with automatic recordings, academic achievement with GPAs and the Michigan Educational Assessment Program (MEAP) tests for reading and mathematics.	Frequent Internet use was associated with higher reading (but not math) test scores and higher GPAs 6, 12 and 16 months later.
Jackson et al. 2011.	12 y, n=482, longitudinal: children's Internet use and video game playing were assessed at baseline and one year later, US.	Internet use and video game play with self-reported questionnaire, academic achievement with self-reported GPAs and the Wide Range Achievement Test (WRAT-3) for reading and math, visuospatial skills with the Wide Range Assessment of Visual Motor Abilities Section 2, Matching.	Video game playing was associated with lower GPAs. Internet use was associated with better reading skills (for children with initially low or average reading skills) and GPAs, but not math skills. Video game playing was positively associated with visuospatial skills.

APPENDIX 2. Continued.

Johnson et al. 2007.	14→16→22 y, n=678, longitudinal: participants' TV viewing and attention and learning difficulties were assessed at four time points, 1983→1985–1986 →1991–1993 →2001–2004, US.	TV viewing with the Disorganizing Poverty Interview, attention and learning difficulties with the Diagnostic Interview Schedule for Children at the age of 14 and 16, and age-appropriate version of the same test for 22 years-olds.	Frequent TV viewing at the age of 14 predicted poor academic grades, failure to complete high school, negative attitudes towards school and poor homework completion, as well as long-term academic failure. Children who watched television 3 or more hours per day at the age of 14, had higher prevalence of frequent attention difficulties at the age of 16, compared to children who watched less television.
Kim & So 2012.	13–18 y, n=75066, cross-sectional, 2009, Korea.	Academic achievement and Internet use with self-reported questionnaire.	Children who used Internet three hours a day or less had higher school performance than children who never used the Internet, while children who used the Internet over three hours a day had weaker performance.
Landhuis et al. 2007.	3 y at baseline, 1037, longitudinal: children's TV viewing was assessed at the age of 5, 7, 9, 11 and attention problems at the age of 13 and 15, children were born 1972 and 1973, New Zealand.	TV viewing with parent- and self-reported questionnaire, attention problems with self-, parent- and teacher-rated questionnaires (the age-appropriate Diagnostic Interview Schedule for Children, the Quay and Peterson Revised Problem Behavior Checklist and the Rutter Child Scale (Scale B for teachers)).	Both childhood and adolescent television viewing were independently associated with attention problems in adolescence.
Mizuno et al. 2013.	Grades 7–9, n=158, cross-sectional, Japan.	TV viewing with self-reported questionnaire, cognitive function with the kana pick-out test.	The high amounts of television viewing were associated with a weaker ability to divide attention.
Munasib & Bhattacharya 2010.	5–10 y, cross-sectional: data from the National Longitudinal Survey of Youth (NLSY), 1990, 2002, US.	TV viewing with mother-reported questionnaire, academic achievement with the Peabody Individual Achievement Test (PIAT) for math and reading.	There were no association between television viewing and academic achievement after adjusting for socioeconomic determinants, parents' TV viewing behaviours and parents' role in monitoring children's viewing.

APPENDIX 2. Continued.

Mößle et al. 2010.	Study 1. Grade 4, n=5529, cross-sectional, 2005, German. Study 2. Grade 3, n=1157, longitudinal: children's media use and academic achievement were assessed in four times, 2005→2006→2007→2008, German. Study 3. Grade 3 at baseline, N=1020, a RCT: school-based media intervention to affect children's media habits, 2006–2008, Germany.	Media use and academic achievement with self-reported questionnaires.	Study 1: The time spent playing computer or video games and watching TV, DVDs or videos was negatively associated with school achievement, including grades in mother tongue, science and math. Study 2: In terms of cross-sectional associations, media use – especially playing computer games – was negatively associated with marks in mother tongue, foreign language and science, but not math scores at all measurement occasions in 3rd, 4th and 5th grades. In longitudinal analysis, daily computer game playing was negatively associated with academic achievement, but TV usage had only few negative associations with academic achievements. Study 3: The decline in school grades was smaller in intervention groups, compared to control group.
Ruiz et al. 2010.	13–18.5 y, n=1820, cross-sectional, 2002–2002, Spain.	Self-reported time spent in TV viewing and playing video games, cognitive functions with SRA Test of Educational Ability (TEA) (verbal, numeric, and reasoning abilities and an overall score).	TV viewing or playing video games were not associated with cognitive functions.
Sharif & Sargent 2006.	Grades 5−8, n=4508, cross-sectional, US.	TV viewing and video game playing and academic achievement with self-reported questionnaires.	Weekday television viewing was negatively associated with school performance. Videogame play was not associated with school performance.
Sharif, Wills & Sargent 2010.	10−14 y, n=6486, longitudinal: children's media exposure and academic achievement were assessed at baseline, 8,16 and 24 months later, 2003→2005, US.	Screen time and academic achievement with telephone interview.	Screen exposure was negatively associated with change in school achievement.

APPENDIX 2. Continued.

Shin 2004.	6−13 y, n=1203, cross-sectional, 1997, US.	TV viewing with parent-reported 24 h diary kept during one weekday and one weekend day, academic achievement with the Woodcock–Johnson Revised Tests of Achievement for reading and math.	Children who watched more television had weaker math and reading achievements.
Swing et al. 2010.	Younger: 6−12 y, n=1323, older: 18−32, n=210, cross-sectional, US.	TV and video game exposure with self- and parent reported questionnaires, attention problems with teacher-reported questionnaire in childhood and with a composite of three self-report measures: the Adult ADHD Self-Report Scale (ASRS), the Brief Self-Control Scale (BSCS), and the Barratt Impulsiveness Scale (BIS-11) in the late adolescence/early adulthood.	High amounts of TV viewing and video game playing was associated with attention problems.
Weis & Cerankosky 2010.	6−9 y, n=64, a RCT: experimental group receiving a video game system at baseline and the control group receiving a video-game system after four months intervention.	Academic achievement with The Woodcock–Johnson—III: Tests of Achievement (WJ–III) for reading, mathematics and written language, school and home behaviour (including attention and learning difficulties) with The Parent Rating Scale (PRS) and Teacher Rating Scale (TRS).	At the post-test, children in the experimental group, who had higher amounts of video game play, got lower reading and writing scores, but not math scores, compared to control children. The ownership of a video game system or video game playing did not affect attention problems.
Willoughby 2008.	Grades 9−10 at baseline, n=1591, longitudinal: children's Internet use, computer use and academic performance were assessed at baseline and 21 months later, Canada.	Internet and computer use with self-reported questionnaire, academic performance with standardized scores for ratings of typical school grades.	There were no association between computer game play and academic performance. The moderate use of Internet was associated with more positive academic performance, compared to non-use or high use.

Abbreviations: ADHD, attention deficit hyperactivity disorder; GPA, grade point average; RCT, randomized controlled trial.

ORIGINAL PUBLICATIONS

I 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 (11), 2098–2104.

II Syväoja, H.J., Tammelin, T.H., Ahonen, T., Räsänen, P., Tolvanen, A., Kankaanpää, A. & Kantomaa, M.T. 2014. Internal consistency and stability of the CANTAB neuropsychological test battery in children. Psychological Assessment (Accepted for publication).

III 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 (7): e103559.

The original publications are not included in the electronic version of the dissertation.