



Physical abilities and academic performance

Cross-sectional and longitudinal studies of Icelandic children

Elvar Smári Sævarsson

Dissertation submitted in partial fulfilment of a Ph.D. degree



UNIVERSITY OF ICELAND
SCHOOL OF EDUCATION

**Physical abilities and academic
performance**
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Icelandic children*

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Abstract

Background: The academic performance of children has been correlated with their future educational attainment and health and has therefore been viewed as a public health concern. Physical activity and cardiorespiratory fitness are known to exert many beneficial effects on the physical and mental health of children, but the relationship with academic performance remains unclear. The relationship between adiposity and academic performance also remains inconclusive.

Aim: The main aim of this dissertation was to examine the associations between cardiorespiratory fitness, physical activity, adiposity and academic performance using cross-sectional and longitudinal data.

Methods: This dissertation builds on data from three different studies. The first was a cross-sectional study conducted in 2003 titled Lifestyles of 9- and 15-year-old Icelanders, n = 448 subjects. The second study was a two-year cluster randomized intervention trial conducted between 2006 and 2008 on 7-year-old school children titled Lifestyles of 7 – 9-year-old children: intervention towards better health, n = 267 subjects. The third study was a follow up of the second study titled Longitudinal study of physical health status in a young Icelandic cohort (born in 1999): Interrelations with sleep and educational attainment, n = 321 subjects. Physical activity was measured by accelerometers and by a self-report instrument. Cardiorespiratory fitness was assessed by a cycle ergometer, and adiposity was determined by calculating the body mass index (BMI) and body fat percentage via a Dual Energy X-ray Absorptiometry (DXA) scan. The results from standardized testing retrieved from the Directorate of Education were used to assess academic performance.

Results: No cross-sectional or longitudinal associations were identified between physical activity, cardiorespiratory fitness, and academic performance. Self-reported physical activity (frequency of sport participation) was associated with higher math performance in 9-year-olds. A long-term increase in adiposity level was associated with deteriorating academic performance in math, independent of changes in physical activity.

Conclusions: An increase in adiposity from the fourth to 10th grades was accompanied by worsening academic performance. Further studies are required to identify factors that may negatively affect both changes in academics and body composition in school-aged children.

Abstract in Icelandic

Líkamlegt atgervi og námsárangur

Þverskurðar- og langtímasniðsrannsókn á íslenskum börnum og unglingum

Bakgrunnur: Sýnt hefur verið fram á að regluleg hreyfing, og í framhaldi þrek, hefur góð áhrif á heilsufar ungs fólks. Tengsl milli hreyfingar og námsgetu hafa verið rannsökuð en niðurstaðan er óljós. Það sama gildir um tengsl milli líkamsfitu og námsárangurs.

Markmið: Að skoða tengsl hreyfingar, þreks og líkamsfitu við námsárangur hjá íslenskum börnum og unglingum.

Aðferð: Stuðst var við gagnasöfn frá þremur íslenskum rannsóknum á lífsstíl og heilsufari þátttakenda. Þverskurðartengsl sem og langtímatengsl voru rannsökuð. Hreyfing var mæld með hreyfímælum en einnig sögðu þátttakendur sjálfir frá hve mikið þeir hreyfðu sig. Þrek var mælt með stigvaxandi hámarksprófi á þrek hjóli og líkamsfita var metin með líkamsþyngdarstuðli og hlutfalli líkamsfitu af heildar þyngd (DXA mæling). Niðurstöður úr samræmdum prófum voru notaðar til að meta námsárangur.

Niðurstöður: Hvorki hreyfing né þrek reyndust hafa tengsl við námsárangur, hvorki í þverskurðarsniðið né langtímasniði. Þeir nemendur sem voru í offituflokki reyndust hafa lægri einkunnir en aðrir nemendur og aukning á líkamsfitu umfram meðaltal frá 9 -15 ára aldri tengdist lakari námsgetu.

Ályktun: Aukning á líkamsfitu er áhættuþáttur gagnvart námsgetu barna og unglunga. Erfitt er að segja til um orsakasamhengi en frekari rannsókn er þörf á þáttum sem geta tengst báðum þáttum. Heildarhreyfing, mæld með hreyfímælum virðist ekki vera tengd námsgetu en við frekari flokkun á hreyfingu geta komið fram tengsli s.b.r. fjöldi íþróttæfinga í viku.

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List of abbreviations

| ABBREVIATION | EXPLANATION |
|--------------|------------------------------------------|
| PA | Physical activity |
| MVPA | Moderate to vigorous physical activity |
| CRF | Cardiorespiratory fitness |
| OLSP | Organized leisure time physical activity |
| BMI | Body mass index |

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List of original papers

Paper 1:

Elvar Smari Sævarsson, Erla Svansson, Thorarinn Sveinsson, Tinna Laufey Asgeirsdottir, Sigurbjorn Arni Arngrimsson, Erlingur Johannsson (2017). **Organized leisure-time sport participation and academic achievement in preadolescents.** *Scandinavian Journal of Public Health*, 45(8), 861-868.

Paper 2:

Elvar Saevarsson, Erla Svansdottir, Sigurbjorn Arngrimsson, Thorarinn Sveinsson, Erlingur Johannsson (2018). **Different cardiorespiratory fitness expressions based on the maximal cycle ergometer test show no effect on the relation of cardiorespiratory fitness to the academic achievement of nine-year-olds.** *Plos One*, 13(7), e0200643.

Paper 3:

Elvar Smari Sævarsson, Sigridur Lara Gudmundsdottir, Marko Kantomaa, Sigurbjorn A. Arngrimsson, Thorarinn Sveinsson, Sigurgrimur Skulason, Erlingur Johannsson (2018). **Above average increases in body fat from 9 to 15 years of age had a negative impact on academic performance, independent of physical activity.** *Acta Paedrica [Epub ahead of print]*

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1 Introduction

“Mens sana in corpore sano” (i.e., “A sound mind in a healthy body”) was written in *SatireX* by the Roman poet Juvenal in ~60–127 AD (Taubert & Pleger, 2014). Concerns regarding the overall health, well-being and academic performance of children are at an all-time high. Childhood obesity has increased in the last few decades, with approximately one of every six children considered overweight or obese in the OECD countries in 2017 (OECD, 2017). An increase in this rate have been observed after a short period of stabilization (U.S. Department of Health and Human Services-Centers for Diseases Control and Prevention-National Center for Chronic Disease Prevention and Health promotion, 2015).

Physical activity (PA) exerts positive effects on both physical health and emotional well-being, and children can gain a sense of mastery and competence from participating in both organized and unorganized sports (Kozyrskyj et al., 2002). Strong evidence-based data for the beneficial effects of physical activity on musculoskeletal health, several components of cardiovascular health, adiposity in overweight youth, and blood pressure in bomildly hypertensive adolescents exist (Janssen & LeBlanc, 2010; Strong et al., 2005). Most youth, however, do not engage in the recommended level of physical activity of 60 min per day, and only one-third of 2-18-year-olds were reported to be sufficiently active (Ekelund, Tomkinson, & Armstrong, 2011).

Physical fitness refers to the full range of physical qualities, including cardiorespiratory fitness, muscular strength, agility, coordination and flexibility (Castro-Pinero et al., 2010). Physical fitness is associated with a variety of health benefits in young people and adults, i.e., a negative correlation with cluster of cardiovascular diseases, increased bone mineral density and vascular health (Anderssen et al., 2007; Janssen & LeBlanc, 2010; Ried-Larsen, Grontved, Froberg, Ekelund, & Andersen, 2013). At the same time, physical fitness scores have decreased and academic performance scores and scores for health and well-being are decreasing (A. M. Halldórsson, Ólafsson, & Björnsson, 2013; G. Tomkinson & Olds, 2007) However, these parameters are often treated as unrelated.

Childhood obesity is a global phenomenon affecting all SES groups, regardless of age, sex or ethnicity (Raj & Kumar, 2010). Childhood obesity

has increased in the last few decades, with approximately one in every six children considered overweight or obese (OECD, 2017). Many comorbid conditions, such as metabolic, cardiovascular, psychological, orthopaedic, neurological, hepatic, pulmonary and renal disorders, are associated with childhood obesity (Raj & Kumar, 2010).

A growing body of research is focused on determining the associations between PA, physical fitness, adiposity, and academic performance among school-aged youth. This developing literature indicates that these lifestyle-related factors may impact academic performance through a variety of direct and indirect physiological, cognitive, emotional, and learning mechanisms, but the results are inconclusive (Donnelly et al., 2016; LeBlanc et al., 2012; Pindus et al., 2014).

The purpose of this study was to explore the associations between PA, physical fitness, adiposity, and academic performance in Icelandic schoolchildren. Four sources of data were used in the analysis: a) data from a study conducted in 2003 titled *Lifestyles of 9- and 15-year-olds*, b) a study conducted in 2006 – 2008 titled *Lifestyles of 7-9-year-old; intervention towards better health*, c) data from a longitudinal study conducted between 2006 to 2015 titled *Longitudinal study of physical activity status in a young Icelandic cohort (born in 1999): Interrelations with sleep and educational attainment*, and d) results from national standardized testing retrieved from the Icelandic Directorate of Education.

2 Background

2.1 Physical activity

The definition for PA is “any bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above a basal level” (Caspersen, Powell, & Christenson, 1985). PA is associated with a better quality of health and improved health outcomes, such as a reduced risk for developing chronic disease risk factors and improved mental health (Penedo & Dahn, 2005). PA is also associated with improved cognitive function and a delay in the onset and a decreased incidence of age-related neurodegenerative diseases (Gallaway et al., 2017; Hillman, Erickson, & Kramer, 2008; Karp et al., 2006). Low levels of PA are common in adults and children, with the global status referred to as “a pandemic of physical inactivity”, which is the fourth leading cause of death worldwide (Kohl et al., 2012). The recommended PA level is at least 60 minutes of moderate to vigorous physical activity (MVPA) five days a week for children and adolescents, and 150 min of moderate intensity aerobic activity per week (World Health Organization, 2010). Most youth, however, do not engage in the recommended level of PA, with only one-third of 2-18-year-olds described as sufficiently active (Ekelund et al., 2011).

Secular changes in PA are difficult to establish due to methodological limitations, and a conclusive description of PA trends may be impossible because of the absence of suitable baseline data (Dollman, Norton, Norton, & Cleland, 2005). Reviews on the subject have reported different results. Decreasing trends in some forms of PA, such as active transport, physical education classes in school and sport participation have been reported in recent decades (Dollman et al., 2005). In contrast, other researchers have stated that the literature does not firmly support the notion that PA has decreased in youth (Ekelund et al., 2011). According to Icelandic data, participation in vigorous intensity PA and sports has increased steadily in 14 – 15-year-olds, with 40% participating in sports in 1992 but 60% participating in 2014 (Eithsdottir, Kristjansson, Sigfusdottir, & Allegrante, 2008; V. Halldórsson, 2014).

2.1.1 Physical activity assessment

Methods for assessing PA are divided into subjective and objective methods. Subjective methods include self-reported questionnaires, proxy-reported questionnaires, activity diaries and interviews. PA questionnaires

are the simplest and most commonly used subjective method for assessing PA, but they have some unavoidable limitations. The accuracy of self-reports is influenced by the ability of the respondent to accurately recall all relevant activities retrospectively. Self-reports are therefore subject to recall bias and may be influenced by the opinions and perceptions of the participant (Ekelund et al., 2011). The accuracy of self-reported data collected from young children is particularly problematic since the child may be less able to recall their PA than an adolescent or adult because their activity pattern is more variable and more difficult to remember (Sallis, 1991). Furthermore, age-related differences in cognitive and linguistic abilities also play a role (Sallis, 1991). Therefore, parental and teacher-reported (proxy-reported) questionnaires are often used, but the recall of youths' PA may also be difficult for adults (Sirard & Pate, 2001).

A systematic review of childhood sedentary behaviour questionnaires was conducted in 2017 (Hidding, Altenburg, Mokkink, Terwee, & Chinapaw, 2017). The aim was to summarize studies examining the measurement properties of self-report or proxy-report questionnaires for children and adolescents under the age of 18 years. The authors concluded that none of the questionnaires included in the review were considered both valid and reliable. Therefore, in addition to errors associated with the study participants, questionnaire-related issues also exist.

Among adults, the activity diary is considered one of the most accurate subjective techniques, but its usefulness is limited in youth due to the burden required to maintain an accurate diary and a possible behaviour-modifying affect (Sirard & Pate, 2001). Interviewer-administered surveys comprise many of the same strengths and limitations as self-reported measures, and this technique may produce better results, but the interviewer may introduce additional sources of bias (Sirard & Pate, 2001)

Human energy metabolism involves the production of energy from nutrients by consuming oxygen and producing carbon dioxide. The measurement of energy expenditure involving the direct measurement of heat production or heat loss is referred to as direct calorimetry. Indirect calorimetry involves the measurement of a proxy of heat production or heat loss by measuring oxygen consumption and/or carbon dioxide production (Leonard, 2012). The doubly labelled water technique is currently regarded as the gold standard for measuring total energy expenditure under real world conditions (Schoeller, 2008). In this technique, participants ingest a known amount of water enriched with stable isotopes of both hydrogen and oxygen. Changes in the isotope level in urine samples are then monitored for the next eight to 17 days (Schoeller

& van Santen, 1982). Despite the accuracy of the techniques, they are not feasible to use in large studies due to the high cost and sophisticated technology required. They serve as a criterion for the validation of other methods suitable for large-scale use (Ainslie, Reilly, & Westerterp, 2003). Other objective methods that are more suitable for large-scale studies designed to assess movement and energy expenditure include heart rate monitoring, pedometry, and accelerometry (Hills, Mokhtar, & Byrne, 2014). Accelerometry has gained considerable popularity in recent years and is probably the most widely used objective method to assess PA. Accelerometry enables researchers to estimate the volume, intensity, and duration of movement and is considered a practical, non-invasive, and reliable tool with minimal discomfort (Hills et al., 2014).

Accelerometers provide information about movement in counts per unit of time. The intensity of movement is captured using piezoelectric sensors to detect acceleration in one plane (uni-axial), two planes (bi-axial), or three (tri-axial) orthogonal planes representing up/down, back/forth, and side to side directions (K. Y. Chen & Bassett, 2005). Tri-axial accelerometers provide a more comprehensive assessment of movement than uni-axial accelerometers, particularly in children, as they may be more sensitive to activities such as climbing and jumping (Eston, Rowlands, & Ingledew, 1998). The activity counts provided by the device have no biological meaning and must be converted to more relevant constructs that are typically based on intensity (Reilly et al., 2008). An estimation of the amount of time spent in different intensity categories, sedentary, moderate to vigorous physical activity (MVPA) or vigorous physical activity (VPA), requires an interpretation of activity counts using intensity cut-off points from calibration studies. Intensity thresholds for the Actigraph accelerometer range between 100 and 1100 counts per minute for time spent sedentary and between 615 and 3600 counts per minute for time spent in MVPA (Ekelund et al., 2011). However, a consensus on the best cut-off points for the classification of MVPA in children and youth is unavailable (Kim, Beets, & Welk, 2012); nevertheless, the intensity of the PA is significant, as it is associated with improvements in cardiometabolic risk factors in youth (Ekelund et al., 2012) and mental health (Janssen & LeBlanc, 2010). The cut-off point of 3200 counts has been reported to be the most useful for defining the optimal level of PA for preventing paediatric obesity (Gaba, Dygryn, Mitas, Jakubec, & Fromel, 2016).

Accelerometers are highly reliable (interrater correlation coefficient = 0.7 – 0.9) in measuring activity in natural settings, but the data are sensitive to the algorithms used for processing, potentially affecting the results

(Sirard, Forsyth, Oakes, & Schmitz, 2011). The possible behaviour-modifying effect observed during this process on the phenomena being studied is known as the “Hawthorne effect” (Corder, Ekelund, Steele, Wareham, & Brage, 2008). In the field of PA, this effect may be a greater problem when using objective methods rather than subjective methods, except for diaries. An accelerometer may encourage the person wearing it to be more physically active (Dössegger et al., 2014). Therefore, the authors suggested that researchers should plan for at least one familiarization day and randomly assign start days.

2.1.2 Self-reported versus objectively measured physical activity

Self-reported measures of PA are generally considered of lower validity than objective measures such as accelerometers (Adamo, Prince, Tricco, Connor-Gorber, & Tremblay, 2009). The strength of the association between self-reported and objectively measured PA has been reported to be low to moderate in adults, and very low to large in youth, where the self-report instruments overestimate the intensity and duration (Corder et al., 2008; Prince et al., 2008; Zelener & Schneider, 2016). The strength of the association between PA questionnaires and the two criterion methods, doubly labelled water and accelerometers, has been reported to vary ($r = 0.09$ to $r = 0.46$), with some questionnaires able to access group-level but not individual-level PA in some age groups (Corder et al., 2009). PA measured using accelerometers and a questionnaire has been compared with the doubly labelled water technique (Hallal et al., 2013). Total energy expenditure was positively correlated with PA estimated from accelerometer counts ($r = 0.57$; $p = 0.003$) and with minutes per week of PA recorded in the questionnaire ($r = 0.41$; $p = 0.04$). PA energy expenditure positively correlates with accelerometry ($r = 0.64$; $p = 0.007$), but not with minutes per week of PA estimated using the questionnaire ($r = 0.30$; $p = 0.15$).

The explanation for the discrepancy between self-reported and objectively measured PA can only be speculated. PA questionnaires ask about time spent in MVPA, which is subjective and depends on the participant’s physical fitness, on which objective measuring methods do not depend (Aadahl & Jorgensen, 2003; Dyrstad, Hansen, Holme, & Anderssen, 2014). Social desirability bias may explain the overestimation observed in self-reported instruments compared to objective instruments. The inability of accelerometers to measure activities that do not involve vertical acceleration, such as cycling and upper body movement, may serve as an explanation and the fact that high-intensity activities are easier to

remember because of their association with the feeling of exhaustion and could therefore easily be overestimated (Dyrstad et al., 2014). However, self-reported instruments may be the only feasible way to estimate different modes of PA and have been used to rank, group or categorize PA levels (Corder et al., 2008; Slinde, Arvidsson, Sjoberg, & Rossander-Hulthen, 2003).

The perfect tool for the examination of PA may not exist, and thus researchers aim to incorporate appropriate objective measures that are specific to the behaviours of interest when examining PA in real world environments (Dowd et al., 2018).

2.2 Physical fitness

Physical fitness is a set of attributes that people have or achieve and has been defined as “the ability to carry out daily tasks with vigour and alertness, without undue fatigue and with ample energy to enjoy leisure-time pursuits and respond to emergencies” (Caspersen et al., 1985). Physical fitness refers to the full range of physical qualities, i.e., cardiorespiratory function, muscular strength, agility, coordination and flexibility (Castro-Pinero et al., 2010). Components of physical fitness are divided in two groups, with one related to health, i.e., CRF, muscular strength and endurance, body composition, and flexibility, and the other related to skills, i.e., agility, balance, coordination, speed, power, and reaction time (Caspersen et al., 1985).

Physical fitness is associated with a variety of health benefits, with most studies showing an inverse dose-response gradient across fitness categories for morbidity from coronary heart disease, stroke, cardiovascular disease, cancer, and all-cause mortality (Blair, Cheng, & Holder, 2001). Favourable effects of CRF on health have also been established in youth, such as negative correlations with a cluster of cardiovascular disease risk factors (Anderssen et al., 2007), increased bone mineral density (Janssen & LeBlanc, 2010) and more favourable vascular health (Ried-Larsen et al., 2013).

Results on the temporal changes in CRF are somewhat inconsistent. In a review of secular changes in aerobic performance, a global annual decrease of 0.36% between 1958 and 2003 was reported (G. Tomkinson & Olds, 2007). The pattern of change, however, was not consistent over time, with improvements in performance observed from the late 1950s until approximately 1970 and decreases of increasing magnitude observed every

decade thereafter. According to another review, aerobic performance (operationalized as maximal field-based endurance running), but not aerobic fitness (operationalized as mass-related peak VO_2), has decreased in recent decades (Armstrong, Tomkinson, & Ekelund, 2011). The reported temporal decrease in CRF levels might be explained by the increased adiposity rate rather than a deterioration in cardiovascular function (Rowland, 2007).

2.2.1 Cardiorespiratory fitness testing

Physical fitness testing evolved from a focus on athletic performance to a focus on health in the early 1900s (Committee on Fitness Measures and Health Outcomes in Youth Food and nutrition board institute of Medicine, 2012). CRF, the ability to perform large-muscle whole-body exercise at moderate to high intensities for extended periods, has been considered a key component of physical fitness throughout the history of the field (Committee on Fitness Measures and Health Outcomes in Youth Food and nutrition board institute of Medicine, 2012). The gold standard measure of CRF is estimating maximal oxygen uptake ($\text{VO}_{2\text{max}}$), which refers to the highest oxygen level that is deemed attainable by an individual. CRF testing is divided into two categories: laboratory-based tests and field-based tests. The most commonly used laboratory-based approaches for CRF testing are the cycle ergometer and the motor-driven treadmill. $\text{VO}_{2\text{max}}$ values are approximately 10% higher when measured during treadmill running compared with cycle ergometry (J. A. Davis, 1995; Maffei et al., 1994).

$\text{VO}_{2\text{max}}$ is assessed with direct or indirect procedures, with the direct measures providing the most precise assessment of CRF, which are obtained by performing a ventilator gas analysis at maximal exertion during a graded exercise ergometer test (J. A. Davis, 1995). Indirect methods estimate $\text{VO}_{2\text{max}}$ from maximal exercise duration, the peak workload and heart rate responses achieved during submaximal or maximal exercise ergometer tests (J. A. Davis, 1995). A well-known indirect method to estimate $\text{VO}_{2\text{max}}$ in children is the maximal multi-stage cycle ergometer test. This test does not measure oxygen uptake but has been validated against the same test in which oxygen uptake was measured (Hansen, Froberg, Nielsen, & Hyldebrandt, 1989).

$\text{VO}_{2\text{max}}$ depends partially on body size and body composition; therefore, $\text{VO}_{2\text{max}}$ data have been normalized using ratio scaling, with body weight most commonly used as the divisor, which is known as the ratio method, to compare CRF in subjects with different body sizes (Toth, Goran, Ades, Howard, & Poehlman, 1993). $\text{VO}_{2\text{max}}$ is typically expressed as millilitres of

oxygen uptake per kilogram of body mass per minute or metabolic equivalents (METs), where 1 MET = 3.5 ml of oxygen per kilogram of body mass per minute (Jurca et al., 2005). Other known divisors in the ratio methods are height, body mass scaled to the 2/3 power, and square metre of body surface area (McMurray, Hosick, & Bugge, 2011). However, the ratio method has been criticized because it assumes a linear relationship between VO_{2max} and the body size measured, with the y-intercept equal to zero, which is rarely satisfied in biological research and can lead to spurious results (Toth et al., 1993).

Because of the high cost of laboratory-based fitness testing, requirements for sophisticated equipment and qualified technicians, and time constraints, their use is limited in school settings and in population-based studies. Field-based tests are a reasonable alternative since they can be simultaneously administered to large number of people, have low cost and equipment requirements and are time efficient (Castro-Pinero et al., 2010). An example of a popular field-based physical fitness test battery is the Fitnessgram, which was originally developed in 1977 as a fitness report card and consists of 6 parts (Plowman & Meredith, 2013). The test battery estimates CRF (PACER – a 20 m shuttle run test), body composition, muscular strength, and endurance and flexibility.

The ICC of the test-retest reliability of the field-based 20-meter shuttle run test (including PACER) was found to ranges from 0.78 to 0.93 in children and adolescents aged 8-18 years (Artero et al., 2011). The reliability of the percentage of body fat estimated from skinfold thickness has proven to be sufficient, with an ICC of up to 0.99. In a systematic review of the criterion-related validity of field-based fitness tests in youth, the 20-meter shuttle run test was reported to be a suitable test to estimate CRF at the group level but not at the individual level (Castro-Pinero et al., 2010). The most valid equations (Ruiz et al., 2008) required further information to increase precision, i.e., sex, age, weight and height (Castro-Pinero et al., 2010).

2.3 Adiposity

Obesity trends are causing serious public health concerns worldwide, threatening the viability of basic health care delivery in many countries (Raj & Kumar, 2010). Obesity is an independent risk factor for cardiovascular diseases and significantly increases the risk of morbidity and mortality. Childhood obesity is a global phenomenon affecting all SES groups, regardless of age, sex or ethnicity (Raj & Kumar, 2010). Childhood obesity has increased in the last decades, with approximately one in every six children considered overweight or obese (OECD, 2017). Many comorbid conditions, such as metabolic, cardiovascular, psychological, orthopaedic,

neurological, hepatic, pulmonary and renal disorders, are correlated with childhood obesity (Raj & Kumar, 2010).

Different methods for estimating adiposity exist, with imaging methods (i.e., axial CT and MRI), DXA, ultrasonography, isotope dilution, and air displacement plethysmography considered the gold standards for body composition assessments in youth (Castro-Pinero et al., 2010; Silva et al., 2013). Bioelectrical impedance analysis (BIA) has also been used as a reference method for body fat determination, whereas hydrodensimetry, which is considered the gold standard in adults, is not typically performed in children because they have difficulties with the breathing manoeuvre involved in determining underwater weight (Castro-Pinero et al., 2010). An estimate of skinfold thickness is an example of a field-based adiposity assessment, as is BMI, which has been the most commonly used method to assess adiposity (Bass, Brown, Laurson, & Coleman, 2013). Body composition, which is based on skin fold thickness, is a valid method to estimate body fat in youth, but not in obese children, where BMI seems to be the best indicator. The accuracy of BMI varies by the percentage of body fat, and significantly improves at higher levels of body fat. Waist circumference is a valid measure to estimate central adiposity (Castro-Pinero et al., 2010). Field-based methods have been shown to underestimate body fat in youth, with DXA as the reference method (Eisenmann, Heelan, & Welk, 2004).

2.4 Academic performance

The purpose of a curriculum evaluation is to confirm the policies that led to the creation of the curriculum (C. J. Marsh & Willis, 2007). Teachers undertake evaluations for a variety of reasons, including to improve teaching and to better meet the needs of students, to justify school practice to the public and to examine the effects of introducing a new curriculum (C. J. Marsh & Willis, 2007). Assessing students' academic process is a part of the curriculum evaluation and is considered as the main goal of the curriculum evaluation (Black, 2001). Many techniques exist for obtaining information useful for assessing student performance, including objective tests and essay tests. Objective tests are deemed objective because answers are definitely classified as correct or incorrect. These tests have the advantages of being able to measure a wide range of specific topics and are quick, efficient, and reliable, but do not measure aspects such as creativity and divergent thinking. Responses to essay tests are recorded in the form of short paragraphs to full-fledged essays and have the advantages of providing students with the opportunity to demonstrate understanding and

express ideas. Disadvantages include a lack of assessment of systematically measured factual knowledge (C. J. Marsh & Willis, 2007).

Standardized testing has been defined as “any form of test that requires all test takers to answer the same questions, or a selection of questions from common bank of questions, in the same way that is scored in a ‘standard’ or consistent manner” (C. J. Marsh & Willis, 2007). Standardized testing is widely used to estimate academic performance in children and adolescents (“The glossary of education reform,” 2014). The responsibility placed on teachers and schools to prepare students for standardized tests has been noted as the greatest benefit of standardized testing (*Pros and Cons of Standardized Testing*, 2013). Standardized testing provides teachers guidance to determine what material to teach students and when to teach it, making better use of time. Standardized testing is objective in nature and allows a comparison of academic performance with other students’ academic performance locally and in different countries. Standardized testing has been criticized and argued to only evaluate a student’s performance on one particular day without considering external factors. Additionally, while the use of standardized is generally acknowledged to lead to a higher quality of learning, the pressure in schools to improve results may cause teachers to only teach what is relevant to the test, which may hinder a student’s overall learning potential (*Pros and Cons of Standardized Testing*, 2013; Wiliam, Lee, Harrison, & Black, 2004). Standardized testing in Iceland dates to 1929 and was made mandatory by law in 1946 (Proppé, 1999). The tests were criticized for requiring students to learn things by memorization, but not emphasizing understanding.

Self-assessed academic performance in children and adolescents deviates from actual results. The agreement generally ranges from weak to moderate between student self-assessment and the ratings of their teachers or performance on tests (Brown, Andrade, & Chen, 2015). Younger students have been found to be less accurate in the their self-assessment than older students (Blatchford, 1997). The commonly used teacher evaluations might be problematic because of a lack of accuracy and reliability in grading practices (Heldsinger & Humphry, 2013; Kirby & Downs, 2007).

Children’s academic performance has been shown to impact their future educational attainments and health, and a number of factors are associated with academic performance, including gender, ethnicity, quality of school and school experience, absenteeism, nutrition, health, PA, body composition, gestational age, and birth weight (Florence, Asbridge, & Veugeliers, 2008; Kirkegaard, Obel, Hedegaard, & Henriksen, 2006; Kramer,

Allen, & Gergen, 1995; Rasberry et al., 2011; Sardinha, Marques, Martins, Palmeira, & Minderico, 2014; Sigfusdottir, Kristjansson, & Allegrante, 2007). Student background (family characteristics, student interest and attitude, and prior knowledge) accounts for approximately 80% of the variance in academic performance, school-related factors account for 7%, and teacher-related factors account for 13% (Marzano, 2001). Girls tend to perform better in school on average, as reported in a study involving 1.5 million 15-year-olds, where girls outperformed boys in 70% of the participating countries but boys outperformed girls in only 4% of the participating countries (Stoet & Geary, 2015). The difference might be explained by different maturity levels or the higher rate of neurological disorders among boys, such as ADHD and autism, which affect academic performance (Levy, Hay, Bennett, & McStephen, 2005; Salazar et al., 2015).

2.4.1 Physical activity and academic performance

Research on the association between PA and cognition started in the fourth decade of the last century, when the response times of athletes was studied (Burpee & Stroll, 1936). In the following decades, additional research revealed age-related variations in response times, with the fastest response observed in early adulthood in both sexes (Hodgkins, 1963). Athletes seemed to exhibit a faster response than non-athletes (Youngen, 1959), and physically active elderly people responded faster than individuals who were more sedentary (Spiriduso, 1975). Human and animal studies indicate that PA targets many aspects of brain structure and function, has broad effects on overall brain health resilience, learning and memory, depression, and the risk of neurodegeneration, and may delay age-related cognitive decline (Carvalho, Rea, Parimon, & Cusack, 2014; Cotman, Berchtold, & Christie, 2007; Hayes, Hayes, Cadden, & Verfaellie, 2013). The effects are exerted at the systemic, molecular and cellular levels and are associated with changes in brain volume, central blood volume flow, signalling cascades and growth factor availability (neurotrophins) (Bailey et al., 2013; Lovden et al., 2013; Ratey & Loehr, 2011). The neurotrophins include brain-derived neurotrophic factor, which is involved in cell survival and synaptic plasticity, insulin-like growth factors that are crucial for exercise-induced angiogenesis and vascular endothelial-derived growth factor (Chaddock-Heyman, Hillman, Cohen, & Kramer, 2014; Trejo, Llorens-Martin, & Torres-Aleman, 2008). The most consistently observed effect of an exercise treatment on animals is an increase in cell proliferation and cell survival in the dentate gyrus of the hippocampus, but dementias such as Alzheimer's disease are characterized by a marked

reduction in the number of neurons in the hippocampus(Hillman et al., 2008).

Physical activity interacts with neurotrophic factors to predict the cognitive function of adolescents (Lee et al., 2014). According to a review on the topic, PA generally exerted a positive effect on children's cognition and PA was not documented to have any negative impact on children's cognition (Lees & Hopkins, 2013). Even an acute bout of submaximal exercise may facilitate memory storage among preadolescents (Pesce, Crova, Cereatti, Casella, & Bellucci, 2009).

Several cognitive processes are related to academic performance, including general cognitive ability, intelligence, processing speed, and aspects of goal-directed executive control function(Hillman et al., 2012). Event-related brain potentials have provided an online measurement of cognitive processing and potentially provide insights into specific aspects of cognition that constitute variability in academic performance. P3 is large positive-going peak of an event-related brain (ERP) potential that reflects attentional processes involved in stimulus evaluation and inhibitory control and has been associated with academic performance in reading and arithmetic beyond the variance accounted for by IQ and school grade .

The association between PA and academic performance has been studied to some extent. The results are promising, but the proposed effect of PA on academic performance are likely similar to the effect of PA on cognitive function. A review of 50 cross-sectional and intervention studies examining the association between PA and academic performance reported 251 associations between physical activity and academic performance, representing measures of academic performance, academic behaviour, and cognitive skills and attitude (Rasberry et al., 2011). Of all the associations examined, slightly more than half (50.5%) were positive, 48% were not significant, and only 1.5% were negative. Significant and positive effects of physical activity on academic performance and cognitive outcomes have been reported, with aerobic exercise exerting the greatest effect. The effect on math performance was the strongest, followed by IQ and reading achievements (Fedewa & Ahn, 2011)In a more recent systemic review, the evidence suggested positive correlations among physical activity and academic performance. However, the findings were inconsistent and the effects of numerous elements of PA on cognition remain to be explored, such as the type, amount, frequency, and timing (Donnelly et al., 2016).

Physical education exerted a positive effect on school achievement, whereas screen time exerted the opposite effect (Poulain, Peschel, Vogel, Jurkatat, & Kiess, 2018). Another recent systemic review including 26

studies (10 205 children, aged from 4 to 13 years) reported that PA, particularly physical education, improved classroom behaviours and several aspects of academic performance, particularly mathematics-related skills, reading, and composite scores (Alvarez-Bueno et al., 2017). PA might differentially impact academic performance based on the children's initial learning capability. Only children who initially presented the poorest performance improved their academic performance following a PA intervention (Resaland et al., 2016).

The acute effects of physically active learning and classroom movement breaks on children's physical activity, cognition, academic performance and classroom behaviour were the topic of a recent systematic review (Daly-Smith et al., 2018). Classroom behaviour was reported to improve after longer moderate-to-vigorous (>10 min) or shorter more intense (5 min) classroom movement breaks or physically active learning bouts in nine of 11 interventions. Support for enhanced academic performance was not obtained. The authors concluded that since low-to-medium quality study designs predominated in investigations of the acute impacts of classroom movement breaks and physically active learning on PA, academic performance, and classroom behaviour, the formulation of conclusions is problematic. Classroom movement breaks and physically active learning did however increase PA and time on task (Daly-Smith et al., 2018).

2.4.1.1 Self-reported physical activity

Many cross-sectional studies using self-reported PA have reported positive correlations with academic performance in various age groups. Correlations have been established among 14- to 15-year-olds (Kristjansson, Sigfusdottir, & Allegrante, 2010; Sigfusdottir et al., 2007), 15- to 16-year-olds (Kantomaa, Tammelin, Demakakos, Ebeling, & Taanila, 2010; Morales, Pellicer-Chenoll, Garcia-Masso, Gomis, & Gonzalez, 2011), 12- to 17-year-olds (Martinez-Gomez et al., 2012; So, 2012; Stea & Torstveit, 2014), and between vigorous PA and academic performance in 12-year-olds (Coe, Pivarnik, Womack, Reeves, & Malina, 2006) and 12 – 17-year-old boys (So, 2012). Correlations were also reported in a recent study among 8th graders (Asigbee, Whitney, & Peterson, 2018).

Not all studies using self-reported PA have reported positive correlations between PA and academic performance. In a study of 11 – 14-year-olds, PA was associated with lower academic performance after controlling for adiposity (Huang, Goran, & Spruijt-Metz, 2006). Another study reported no or weak negative correlations between PA and academic performance among 13 – 16-year-olds (Daley & Ryan, 2000). The positive causal

correlation between sport participation and academic performance in adolescents has been questioned (Rees & Sabia, 2010), and an active commute to school was not positively correlated with academic performance in all studies (Van Dijk, De Groot, Van Acker, Savelberg, & Kirschner, 2014).

A study conducted over 5 years of 6 – 11-year-olds reported a correlation between higher amounts of physical education, 70-300 min per week, with an academic benefit among girls, but not boys (Carlson et al., 2008). A two year study involving adolescents (mean age 14.4 years) reported higher grades among female athletes than non-athletes (Miller, Melnick, Barnes, Farrell, & Sabo, 2005). A two-year study in Finland of 6-8-year-olds observed positive correlations between higher levels of PA during recess and physically active school transportation with better reading fluency, (Haapala, Poikkeus, Kukkonen-Harjula, et al., 2014). A positive correlation between PA and academic performance was established in 12,000 adolescents, aged 12 - 18 years, in a two year study (Nelson & Gordon-Larsen, 2006). Strengthening exercises did not correlate with academic performance in Korean adolescent students; however, a correlation with PA was observed (So, 2012).

2.4.1.2 Objectively measured physical activity

A systematic review of studies exploring how academic performance related to objectively measured PA reported inconsistent finding (Marques, Santos, Hillman, & Sardinha, 2017). In a cross-sectional study of 270 children, the associations of self-reported PA and objectively measured PA (MVPA) with academic performance were compared (Syvaaja et al., 2013). The results showed positive correlations between the self-reported PA and academic performance, but no correlations were identified when objectively measured PA data were applied (Syvaaja et al., 2013). The authors speculated that the discrepancy was caused by differences in the reflections of subjective and objective measures of constructs and contexts of PA associated with academic performance, and the accelerometer may not accurately measure PA during swimming, cycling or similar activities. Furthermore, estimating PA in a period of one week or less may not be sufficient to depict children's usual physical activity (Syvaaja et al., 2013). These findings are supported by a study of 4th – 6th graders, where no associations between objectively measured PA (MVPA) and academic performance were observed (LeBlanc et al., 2012). Other studies have also failed to establish correlations between objectively measured PA and academic performance. a) A cross-sectional study involving 6-9-year-olds

showed that PA mediated the effect of CRF on math, with no associations with reading or spelling after controlling for grade, sex, BMI, mother's education level, and household income (Lambourne et al., 2013). b) A Spanish longitudinal study conducted over 3 years of 1778 6- to 18-year-olds and reported a negative correlation between objectively measured PA and academic performance in some cases after controlling for age, sex, city, maternal education, neonatal information, CRF (ALPHA fitness test battery (Ruiz et al., 2011)) and obesity (Esteban-Cornejo et al., 2014). A positive correlation between objectively measured vigorous PA and academic performance in girls was reported in a study involving adolescents (Kwak et al., 2009), and time spent in MVPA was reported to predict increased academic performance in some subjects after controlling for total PA (Booth et al., 2014).

2.4.1.3 Sport participation

One aspect of physical activity is sport participation which is offered to children and adolescents in school environments or as an organized leisure-time sport participation (OLSP) by sport clubs in most western countries. OLSP was reported to relate to higher levels of objectively measured total PA in children (Hebert, Moller, Andersen, & Wedderkopp, 2015; Leek et al., 2011). Self-reported OLSP was found to account for about 20% of total daily energy expenditure in children, and OLSP accounted for more than half of the daily amount of moderate to vigorous PA (Katzmarzyk & Malina, 1998). Furthermore, self-reported OLSP correlated with higher levels of objectively measured MVPA and achieving the recommended levels of MVPA in youth. (Marques, Ekelund, & Sardinha, 2016). Therefore, OLSP may serve as a viable proxy for PA.

Positive correlation between sport participation and academic achievement has been established, primarily among adolescents participating in school sports (Fox, Barr-Anderson, Neumark-Sztainer, & Wall, 2010; Trudeau & Shephard, 2010). However, school sports have been argued to enhance school identification which may promote academic performance (H. Marsh, 1993), and requirements that athletes maintain minimum grades to be eligible to participate may cause grade inflation (Snyder & Spreitzer, 1990). Furthermore, adolescent OLSP has been shown to correlate with future educational attainment and cognitive performance (Pfeifer & Cornelißen, 2010; Ruiz et al., 2010). Fewer studies have investigated the relationship between OLSP, which is independent of the school environment, and academic performance. The only known study involving OLSP among pre-adolescents, reported positive relations between

engagement in any kind of OLSP and performance in math among six-year-olds (Haapala, Poikkeus, Kukkonen-Harjula, et al., 2014) .

2.4.2 Cardiorespiratory fitness and academic performance

Studies of preadolescent children have observed a correlation between CRF and structural changes in the brain, including larger volumes of the basal ganglia and hippocampus, which relate to superior performance on tasks of cognitive control and memory, and the microstructure of white matter fibres (Chaddock-Heyman, Erickson, et al., 2014; Chaddock-Heyman, Hillman, et al., 2014; Chaddock et al., 2010). CRF has also been linked to differences in brain function measured using ERP, a neuro electric index of attention and working memory (Hillman, Buck, Themanson, Pontifex, & Castelli, 2009; Hillman, Castelli, & Buck, 2005), and functional magnetic resonance imaging (Chaddock et al., 2012). ERPs (P3), which reflect attentional processes involved in stimulus evaluation and inhibitory control, are also related to academic performance and may therefore serve as a biomarker of academic performance during childhood(Hillman et al., 2012) .

2.4.2.1 Cross-sectional field-based studies

The association between CRF and academic performance has been studied to some extent in the literature. Similar to the association between PA and academic performance, the association between CRF and academic performance appears to vary according the measurement methods. The field-based fitness tests have, in most cases, reported positive correlations with academic performance, while the laboratory-based fitness tests have not. A commonly used field-based fitness test is the Fitnessgram test battery (Plowman & Meredith, 2013) in which the participants are categorized as FIT or UNFIT according to their performance on the tests. A Portuguese study involving 1,531 12- to 14-year-old children observed a correlation between CRF (measured using the Fitnessgram CRF test PACER) and academic performance after controlling for BMI and sex (Sardinha et al., 2014). An American study of 38,992 third to 12th graders assessed CRF with PACER or the 1-mile-run [1.6 km] test and observed a modest correlation between CRF and academic performance (Welk et al., 2010). According to a study of 838 sixth to eight graders (mean age 13 yrs), boys in the healthy fit zone, according to Fitnessgram standards for CRF and muscular endurance tests, were 2.5 to 3 times more likely to pass their math or reading exam and girls were 2 to 4 times more likely to meet or exceed reading and math test standards compared to children who were not in the healthy fit zone (Bass et al., 2013). All Fitnessgram variables,

except for BMI, were positively correlated with academic performance in a study of 25,4743 third to 11th graders (Van Dusen, Kelder, Kohl, Ranjit, & Perry, 2011). Furthermore, CRF showed a dose-dependent correlation with academic performance that was independent of other socio-demographic and fitness variables, and the association appeared to peak in late middle to early high school. Another kwon field-based fitness test battery is the ALPHA battery (Ruiz et al., 2011). Results from studies using the ALPHA test battery have also reported positive findings among nine to 11-year-old children, where all fitness variables, except for muscular strength, were associated with academic performance in boys (Torrijos-Nino et al., 2014) and 10 – 12-year-olds (Muntaner-Mas, Pere, Vidal-Conti, & Esteban-Cornejo, 2018).

Although most field-based fitness tests have reported positive correlations with academic performance, some have not completely supported those findings. In a study of third, sixth and ninth grade students, the number of fitness tests completed in the healthy fitness zone (Fitnessgram) was associated with academic performance, but CRF was not independently associated with academic performance in sixth and ninth grade students (not administered in 3rd grade) (Coe, Peterson, Blair, Schutten, & Peddie, 2013). In another study, a positive correlation between CRF (ALPHA battery) and academic performance was observed in 395 seventh graders, but the association was rendered insignificant after controlling for screen time and other confounding variables (Aguilar, Vergara, Velasquez, Marina, & Garcia-Hermoso, 2015)

2.4.2.2 Longitudinal field-based studies

In a longitudinal study, participants received baseline CRF testing and academic assessments as fifth graders and at a 2-year follow up. Students who remained in the healthy fitness zone (Fitnessgram) exhibited significantly better academic performance than students who remained in the “needs improvement” zone (Wittberg, Northrup, & Cottrell, 2012). Students who moved into or out of the healthy fitness zone occasionally exhibited significantly better academic performance than students who remained in the needs improvement zone.

The association between physical fitness changes and subsequent academic performance was explored in children from seventh to ninth grade (L. J. Chen, Fox, Ku, & Taun, 2013). Improvements in CRF (1600- and 800-m runs in boys and girls, respectively), but not in muscular endurance or flexibility were significantly correlated with better academic performance. Students who were initially fit received better academic

scores at baseline and the rate of change in CRF was related to the rate of change in academic performance. No correlations between CRF and math and language performance were observed when school subjects were separated in univariate or multivariate regression models (L. J. Chen et al., 2013).

Among sixth to eighth grade students, an increase in performance on physical fitness (Fitnessgram) tests from the previous year resulted in a greater improvement in academic performance, and substantial decreases in physical fitness were associated with a significant decrease in academic ranking (Bezold et al., 2014). In a recent study, changes in CRF between sixth and eighth grade were positively correlated with changes in academic performance in both reading and math (Raine et al., 2018).

2.4.2.3 *Cross-sectional laboratory-based studies*

Laboratory-based tests have been considered a more accurate estimate of CRF than field-based tests (G. O. Tomkinson, Timothy S., 2008). No association between CRF and academic performance were observed in a Finnish study of 16-year-old adolescents in which CRF was predicted using a submaximal cycle ergometer test and expressed in W/kg/min (Kantomaa et al., 2013). The authors speculated that the cycle ergometer's independence from motor control might explain the lack of a correlation between CRF and academic performance (Haapala, Poikkeus, Tompuri, et al., 2014). These speculations are supported by the findings from another Finnish study where motor control was associated with academic performance (Haapala, Poikkeus, Tompuri, et al., 2014; Kantomaa et al., 2013).

An Australian study of 7- to 15-year-old children consistently observed correlations between academic performance and questionnaire measures of PA, performance in the 1-mile run, sit-up and push-up tests, 50 m sprint, and standing long jump across age and sex groups (Dwyer, Blizzard, & Dean, 1996). In contrast, academic performance was not correlated with a submaximal prediction of CRF, estimated as physical work (expressed in W/kg FFM) capacity on a cycle ergometer at a heart rate of 170 bpm. The authors speculated that this discrepancy may prompt questions as to whether the associations between academic performance and the field tests were due to measurement bias or confounding variables, e.g., body fat percentage, genetic factors or foetal nutrition (Dwyer et al., 1996).

In a study using a motor-driven treadmill, a higher CRF level was associated with increased performance on a test of algebraic functions (but not math) among seventy-nine 9- to 11-year-old children (Kao, Westfall, Parks, Pontifex, & Hillman, 2017)

2.4.2.4 Longitudinal laboratory-based studies

Very few longitudinal studies using laboratory-based CRF tests have been conducted. A two year prospective study of six-year-old children conducted in Finland using the maximal cycle ergometer to measure CRF did not observe cross-sectional association at baseline between CRF and academic performance nor between baseline CRF and academic performance two years later (Haapala, Poikkeus, Tompuri, et al., 2014). A cohort study of all Swedish men born between 1950 and 1976 who were enlisted for military service at age 18 reported that changes in CRF between the ages of 15 and 18 years predicted cognitive performance at 18 years of age. Furthermore, CRF at the age 18 years predicted educational attainments later in life (10 – 36 years of follow up) (Aberg et al., 2009).

2.4.2.5 Sex-based differences

Few studies have report any significant sex-related difference in the association between CRF and academic performance. Eveland-Sayers et al. reported significant sex-specific differences in the association between CRF and academic performance in a study of 134 third to fifth graders, where significant correlations were only observed in girls (Eveland-Sayers, Farley, Fuller, Morgan, & Caputo, 2009). A Swedish study of 232 ninth grade students observed a correlation between CRF and academic performance in boys, but not in girls (Kwak et al., 2009). The authors speculated that the sex-specific difference might be explained by factors related to physiological growth that might differentially modify or mediate the relationship between PA and academic performance in boys and girls. A greater spatial learning ability was observed in females with higher levels of physical fitness than in males, which is a possible explanation for the reported sex-related difference (Guyot, Fairchild, & Hill, 1980).

2.4.3 Adiposity and academic performance

The evidence for the mechanism by which weight status might affect a student's academic performance is inconclusive. Some studies have not established clear relationships between weight status and academic performance, cognitive function and school performance (Dwyer et al., 1996; Lambourne et al., 2013; LeBlanc et al., 2012; Rauner, Walters, Avery, & Wanser, 2013), while others have shown that overweight and obesity are inversely correlated with academic performance and cognition (C. L. Davis & Cooper, 2011; Kantomaa et al., 2013; Kristjansson et al., 2010; Pindus et al., 2014; Sardinha et al., 2014; Torrijos-Nino et al., 2014). The method used to estimate adiposity may impact the association with academic

performance, as shown in a study where negative associations with BMI, but not with body fat percentage obtained from by a DXA scan, were observed (Bass et al., 2013). Furthermore, adiposity correlates with self-reported school grades but not with actual academic performance, indicating that the method used to assess school grades may also impact the association (Huang et al., 2006)

A plausible biological mechanism underlying the reported inverse correlation between a high-fat diet and academic performance include the reduced hippocampal level of brain-derived neurotrophic in animals consuming a high-fat diet (Molteni, Barnard, Ying, Roberts, & Gomez-Pinilla, 2002). Brain-derived neurotropic factor is a crucial modulator of synaptic plasticity and a predictor of learning efficacy. Other possible explanations include unobserved confounding variables, such as depression, which has been associated with obesity in adolescence and may impact academic performance (McLeod, Uemura, & Rohrman, 2012; Sjoberg, Nilsson, & Leppert, 2005). Associations with decreased health-related quality of life, which may affect school performance, may also serve as an explanation for both positive and negative correlations (Williams, Wake, Hesketh, Maher, & Waters, 2005).

2.5 Socioeconomic status

Socioeconomic status (SES) has been defined as “a person’s overall social position to which attainments in both the social and economic domain contribute” (Ainley, Graetz, Long, & Batten, 1995). SES encompasses income, educational attainment, financial security, and subjective perceptions of social status and social class (American Psychological Association, 2018). Socioeconomic status can encompass quality of life attributes and the opportunities and privileges afforded to people within society. SES is a consistent and reliable predictor of a vast array of outcomes across the life span, including physical and psychological health. SES affects health by influencing access to health care, nutrition and recreation, and social psychological factors, such as self-esteem and health awareness (Kozyrskyj et al., 2002). SES is considered relevant to all realms of behavioural and social science, including research, practice and education (American Psychological Association, 2018).

SES is related to the academic performance of children. Learning disabilities and other negative psychological outcomes that affect academic performance are correlated with a low SES (McLaughlin & Sheridan, 2016; Morgan, Farkas, Hillemeier, & Maczuga, 2009). Initial reading competency correlates with the home literacy environment, number of books owned,

and parent distress (Morgan et al., 2009; van Bergen, van Zuijen, Bishop, & F. de Jong, 2016). A mother's SES is related to her child's inattention, disinterest, and lack of cooperation in school (Mistry, Benner, Tan, & Kim, 2009; Morgan et al., 2009). Children from families with a low SES are less likely to attend a university (Considine & Zappalà, 2002).

The association between SES and PA is unclear. Higher PA scores were reported among adolescents with a low SES than among the high SES group (McMurray et al., 2000). In contrast, the low SES group less frequently participated in vigorous PA than the high SES group (Giles-Corti & Donovan, 2002). In Iceland, a low SES (low income and parental education) was linked to less frequent participation in sports and leisure-time activities in 6th and 9th grade but not in 1st or 3rd grade (Björnsdóttir, Kristjánsson, & Hansen, 2009; Karlsdóttir & Sigurðardóttir, 2015). This discrepancy might be explained by the different domains of PA measured or definitions of PA. The financial costs of participating in organized leisure time sports may explain the less frequent engagement among lower SES groups. Although the association between SES and PA remains unclear, SES should be considered when engagement in PA is explored in youth.

The association between SES and adiposity appears to be somewhat clearer than with PA levels. Earlier studies reported some inconsistencies, but more recent studies have predominately identified an inverse correlation, with parental education being more consistently associated than other indicators, and positive correlations have all but disappeared (Shrewsbury & Wardle, 2008). These inverse correlations might be explained by differences in PA levels or other lifestyle related factors, such as nutrition (Sallis, Zakarian, Hovell, & Hofstetter, 1996).

Family structure may be linked to SES since single parents have lower average income levels, lower educational attainment and are less likely to be in the labour force. Children from these families are likely to exhibit lower academic performance (Considine & Zappalà, 2002). In addition, the nature of the parent-child relationship in single-parent families may be the cause of emotional and behavioural problems in the child, which may impact academic performance. These findings may be explained by the observations that children from two-parent families receive sufficient care, attention, warmth, father- and mother-figure attachment and emotional stability that may be characteristic of two-parent families. The association between family structure and PA is somewhat inconclusive. Adolescents living in single-parent households and step families have been reported to more physically active than adolescents living in two-parent homes with their biological parents (Wang & Qi, 2016). In contrast, children from two-

parent families have been reported to be more active than children from single-parent families (Quarmby & Dagkas, 2010). Similar to SES, the discrepancy may be explained by the different domains of PA measured and/or the method used to assess PA.

Family structure correlates with children's adiposity. Children living with a single parent were reported to be heavier and or gain more weight than children living within other family structures (Formisano et al., 2014). Single parents may be less likely to be able to spend quality time with their children and might give less importance to their food choices, allowing them to eat high-energy foods (A. Y. Chen & Escarce, 2014; Sandberg & Hofferth, 2001). In addition, single parents may have less time to play with their children or to encourage them to participate in PA (A. Y. Chen & Escarce, 2014).

3 Aims of the study

Even though the relationship between PA, CRF, adiposity and academic performance has been studied to quite some extent the relationships remain unclear. Studies exploring the relationship between OLSP and academic performance are very rare and long-term studies involving follow up objective measures of PA, adiposity, and academic performance are needed to further our understanding of the relationships between these variables. The relationship between CRF and academic performance needs also further examination, specifically the way CRF is expressed. The aim of this study was threefold:

1. To explore the relationship between PA and academic performance. Results from previous studies vary with some reporting positive relationships but others have reported no or even negative. The method used to measure PA may provide an explanation for this discrepancy. Positive relations are generally reported when self-reported PA is applied but when objectively measured PA is applied the results are inconclusive. The reason for this discrepancy is unclear but it has been suggested that it may be caused by different domains of PA measured or by confounding effects of unobserved variables, i.e. social desirability. Attempting to further elucidate the relationship between PA and academic performance, both self-reported PA and objective PA data will be used, and results compared. This will add to the existing literature since studies using both methods within the same cohort are scarce. This will eliminate any potential cohort-related biases that might impact results.

Weekly OLSP will represent the self-reported PA but the relationship between OLSP and academic performance needs to be studied further. Previous studies reported positive relations between engagement in OLSP academic performance, but a possible dose-response relationship has not been explored. OLSP has become a significant part of the daily life of Icelandic youth with rates of weekly participation rising from 40% in 1992 to 60% in 2014 (V. Halldórsson, 2014). This might impact the much important academic performance and needs therefore to be examined.

Attempting to clarify the relationship between PA and academic performance, long term changes in these variables will be explored. This approach eliminates the influence of unobserved confounders that vary across children but that remain constant over time within the same child

i.e. SES. Studies using long term designs and objective data are rare, especially ones which span more than one or two years.

2. To study the relationship between CRF and academic performance. CRF is generally considered to be positively related to academic performance but there are still some issues that remain to be resolved. When the literature is explored in detail, discrepancy in the relation between CRF and academic performance based on the method used to assess CRF is noted. Studies using running based activities, predominantly field-based tests, report positive findings while studies using the cycle ergometer do not. This may indicate the presence of confounding variables when running based activities are applied. Since results from the cycle ergometer are usually scaled to the individuals body size (W/kg), it can be speculated if factors related to body size may be the confounding factors. This speculation is supported by the results from the only study using the cycle ergometer to assess CRF and did not scale the absolute power output (W), (Kwak et al., 2009). The importance of proper scaling of CRF when relating to cardiometabolic risk factors has described previously but the impact different CRF expressions may have on the relation to academic performance needs to be studied (McMurray et al., 2011)

In this study, laboratory-based cycle ergometer test will be used to assess CRF level. In addition to expressing CRF test results as absolute power output, results will also be scaled to different body size related variables. This approach could shed light on the possible presence of body size related confounding variables. The long-term relationship between CRF and academic performance will also be studied. No long-term studies have used follow-up measures of CRF measured by the cycle ergometer.

3. To explore the relationship between adiposity and academic performance. Results from previous studies are mixed with some reporting negative relation but others have failed establish relationships. Different methods used to assess adiposity, or the lack of adjustment for relevant confounders, might provide an explanation for this discrepancy. Most studies have studied the cross-sectional relationships but long-term studies including follow up measures of adiposity are scarce. This approach eliminates the influence of unobserved confounders and might therefore clarify the relationship. Adiposity will be measured by BMI, which is the most commonly method, and by DXA scan which is considered one of the gold standards in estimating body composition in youth.

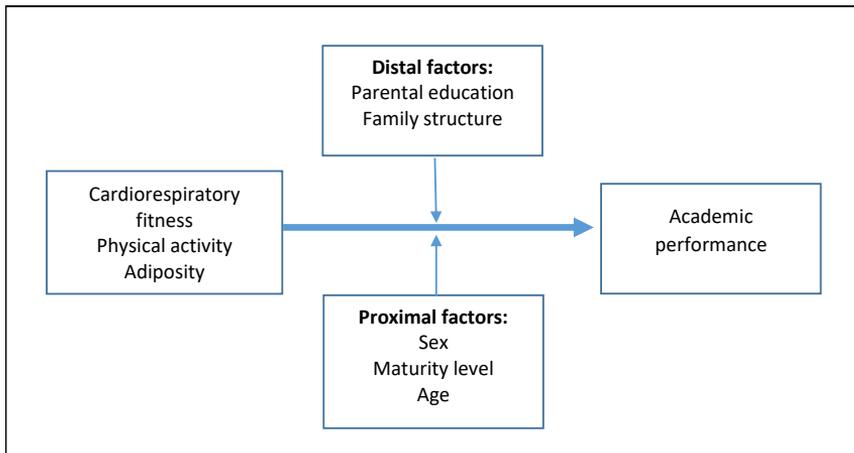


Figure 1. Working model for the dissertation

The specific aims of the study are listed below.

1. Does the method with which CRF is assessed affect the association with academic performance? (Paper 1)
2. Is self-reported PA (sport participation) associated with the academic performance of preadolescents after controlling for adiposity, family structure, parental education, CRF, sex and age? (Paper 2)
3. Are changes in PA and adiposity associated with changes in academic performance over a six-year period? (children aged 9 to 15 years)? (Paper 3)
4. Is healthy living, i.e., physical activity and healthy eating habits, associated with academic performance in school-aged youth?

4 Methods

4.1 Study design and participants

This dissertation builds on data from three different studies. The first, Cohort A – born in 1994, is a cross-sectional study conducted in 2003 and titled “Lifestyles of 9- and 15-year-old Icelanders” (Arngrimsson et al., 2008; Johannsson, Arngrimsson, Thorsdottir, & Sveinsson, 2006; Sveinsson, Arngrimsson, & Johannsson, 2009). Eighteen schools in the nation’s capital, Reykjavik, surrounding areas and towns and rural areas in the Northeast were recruited to participate. Six hundred sixty-two students were recruited to participate, with 488 accepting. Half of the cohort was randomly selected and asked to participate in the CRF test. Participants were approached again in 2014, when they were 20 years of age, by mail and phone and asked for their consent to add their academic performance in the fourth grade to the study’s database (Figure 2 (A)). The study was part of the European Youth Heart Study (EYHS) and follows the EYHS study protocol (Riddoch et al., 2005). The primary objective of the EYHS was to study the nature, strength, and interactions between personal, environmental, and lifestyle influences on CVD risk factors in a large population of children of differing ages, sexes, cultures, and ethnicities. The secondary objective was to assess the age-, sex-, and time-specific prevalences of personal, environmental, lifestyle, and physiological risk factors (Riddoch et al., 2005) (Figure 2).

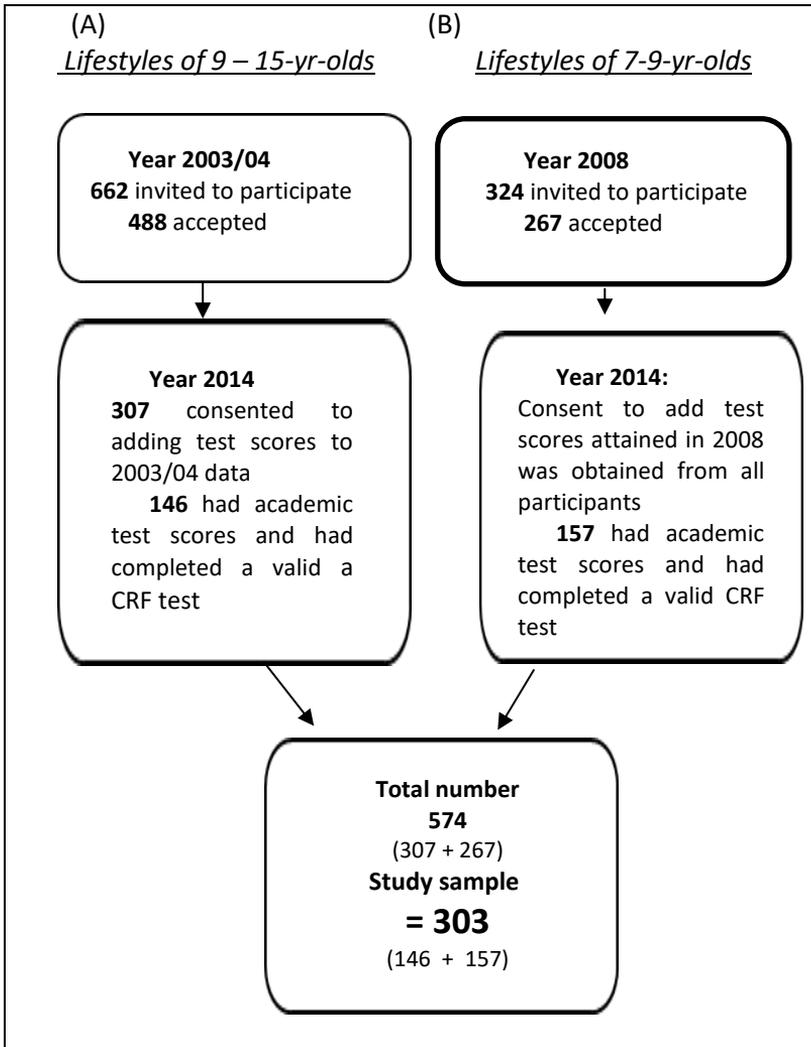


Figure 2. Origins and total number of participants in Paper 1

Participants originated from two different study cohorts, Lifestyles of 9 – 15-year-olds and Lifestyles of 7 – 9-year-olds. Participation rates, inclusion criteria and total number of participants are displayed.

The second study, Cohort B – born in 1999, was a two-year clustered randomized intervention trial conducted between 2006 and 2008 on 7- to 9-year-old school children titled “Lifestyles of 7 – 9-year-old children: intervention towards better health” (Magnusson, Hrafnkelsson, Sigurgeirsson, Johannsson, & Sveinsson, 2012). Three hundred twenty-one students in six schools in Reykjavík were recruited to participate, with 267 accepting. Two hundred fifty-eight completed the study at age 9. As in Cohort A, this study also followed the EYHS measurement protocol (Figure 2 (B)).

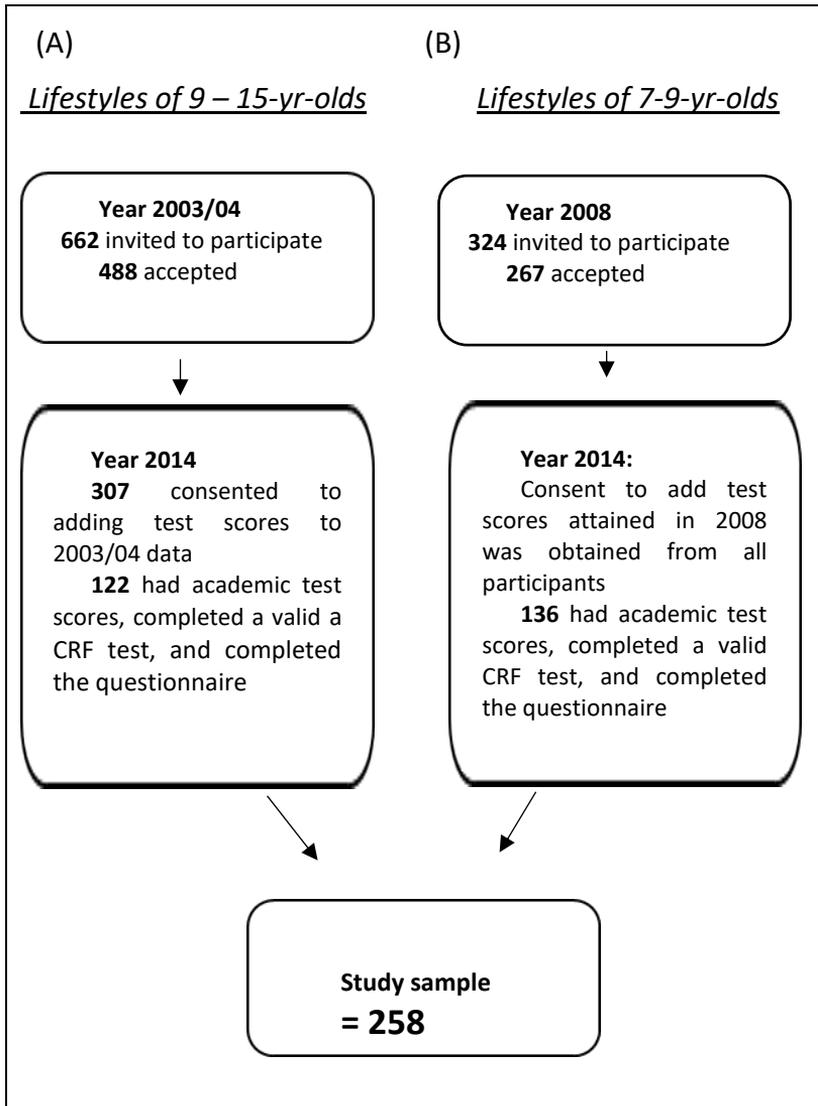


Figure 3. Origins and number of participants in Paper 2

The third study, Cohort C, was a follow up of Cohort B and titled Longitudinal study of physical health status in a young Icelandic cohort: Interrelations with sleep and educational attainment, which was conducted in 2015, and all participants who were recruited to participate in Cohort B were offered the opportunity to participate. An additional 156 participants were recruited from three other schools to increase the statistical power for cross-sectional analyses (Figure 3).

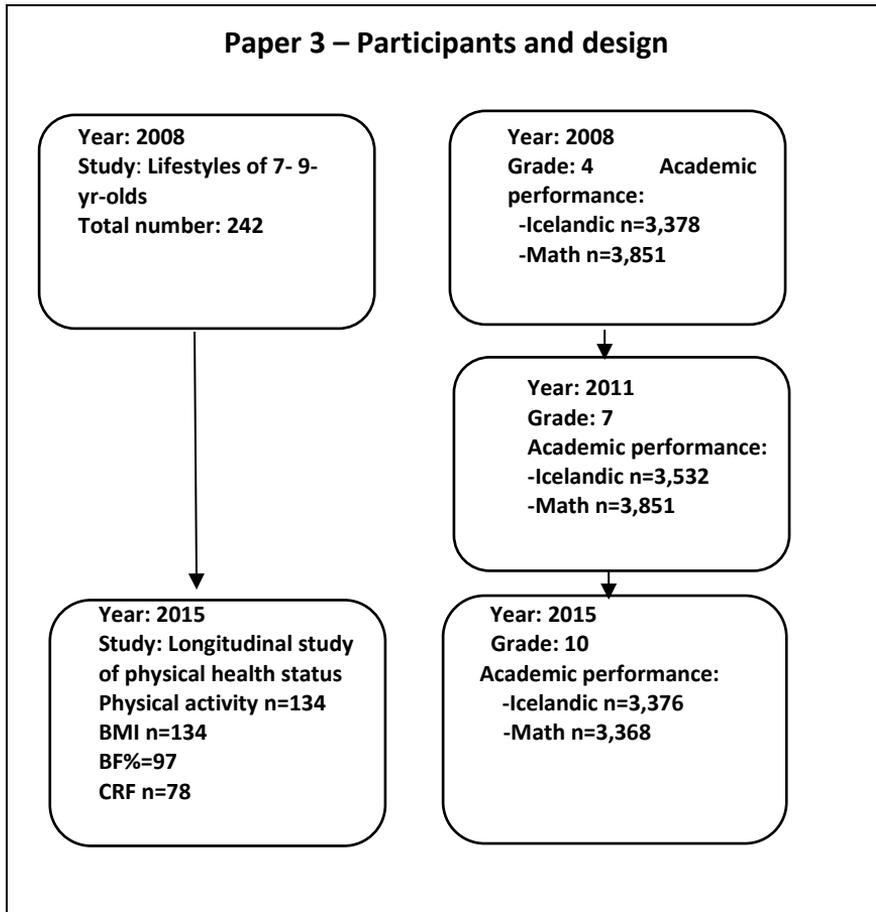


Figure 4. Study design and number of participants in Paper 3.

BMI: body mass index; BF%: body fat percentage; CRF: cardiorespiratory fitness. Only the participants for whom measurements were recorded at both time points were included (n=134). Academic performance was assessed in the fourth, seventh and 10th grades. The results from standardized testing in Icelandic and math in the fourth, seventh, and 10th grades were retrieved from the Icelandic Directorate of Education.

4.2 Physical activity

Accelerometers were used to objectively assess children’s physical activity over five to seven days, or for a minimum of two weekdays and one weekend day for a minimum of 14 hours a day in Cohorts A and B. Actigraph accelerometers (ActiGraph Inc., Pensacola, Florida, USA) were used (MTI 716 and GT1M for Cohorts A and B, respectively) and are among the most widely used devices of their kind in the field, have been

extensively validated and are reliable and easy to use (Ekelund et al., 2001; Freedson, Pober, & Janz, 2005; Trost, McIver, & Pate, 2005; Trost et al., 1998). Participants in Cohort A and Cohort B wore the accelerometer on their waist from the time they woke up until they went to sleep. PA parameters were analysed using MATLAB software (MathWorks Inc., Massachusetts, USA). In Cohort C, the participants wore the metres (GT3X+) on their wrist 24 hours a day for seven consecutive days. The metres have been validated and are considered reliable for estimating PA in youth (Johansson, Larisch, Marcus, & Hagstromer, 2016). PA parameters were derived from ActiLive software, version 6.13.0, from Actigraph Inc.

Physical activity was also estimated using a self-report instrument. Participants, with the assistance of their legal guardians, completed a questionnaire assessing various health behaviours, which was based on the EYHS questionnaire. The legal guardians also completed a separate questionnaire on themselves, including their educational level and income. The question about respondent's physical activity assessed their participation in organized leisure time physical activity (OLSP) and was phrased as follows: "How often do you participate (practice or compete) in sports with a club?" Response options were: 'Never', 'Less than once a week', 'Once a week', '2-3 times a week', '4-5 times a week', or 'Almost every day' (Magnusson et al., 2012; Riddoch et al., 2005).

4.3 Anthropometry

Height was measured to the nearest mm with a transportable stadiometer, and a calibrated scale was used to measure body weight to the nearest 0.1 kg (Seca 708, Seca Ltd., Birmingham UK). Body mass index (BMI) was calculated as body weight (kg) divided by height squared (m^2). Skinfold thickness (SKF) was measured three times at four sites (triceps, biceps, subscapular and suprailiac) on the left side of the body using a Harpenden skinfold calibre (Baty International Burgess Hill, UK). The mean value of the two closest measurements was calculated and the sum of the four skinfolds (mm) was used for analysis. The same trained personnel performed all measurements at all schools in each of the three studies. Participants in Cohorts B and C underwent a DXA using the paediatric program of Hologic QDR 4500 (Hologic Inc., Bedford, MA, USA) in Cohort B and a Lunar bone densitometer (GE Healthcare, Madison, Wisconsin USA) in Cohort C. These measurements yielded estimates of the children's total lean mass and fat mass (g).

4.4 Cardiorespiratory fitness

CRF was assessed with a graded maximal cycle ergometer test using a Monark 829E bike (Monark Exercise AB, Vansbro Sweden). The European Youth Heart Study (EYHS) CRF test protocol was followed (Arngrimsson et al., 2008; Riddoch et al., 2005; Wedderkopp, Froberg, Hansen, & Andersen, 2004). Participants cycled for three minutes at each predetermined workload (watts or W) until exhaustion. Electrocardiography was used to record participants' heart rate during the test. The initial workload was 20 W for the 9-year-olds who weighed less than 30 kg and 25 W for those who weighed more than 30 kg. The criterion for a valid maximal test was a) a heart rate ≥ 185 , and b) subjective observation from the researcher that the child could not continue (after vocal encouragement, if necessary). In Cohort C, the initial workload was 40 W for girls and 50 W for boys. The workload was increased every third minute until voluntary exhaustion or until a minimal pedalling rate of 40 rpm was not able to be maintained. The recommended pedalling rate was 70 rpm and the tests were terminated if the rate fell below 40 rpm. Heart rate (Polar Vantage, Polar Electro, Kempele, Finland) was recorded, as well as ratings of perceived exertion on the Borg test (Borg, 1982). The test was considered maximal if at least two of the following three criteria were attained: 1) heart rate of no more than 5% less than the age-predicted maximum ($207 - (0.7 * \text{age}) \pm 10$ beats), 2) perceived exertion of 19 – 20 on the Borg scale, and 3) researchers' subjective estimate of maximal effort. The power output (W_{\max}) was calculated by multiplying the person's workload (W_d) by the time at the final incomplete stage and then adding the maximum workload at the last fully completed stage (W_h). Thus: $W_{\max} = W_h + W_d * t/180$ (Hansen et al., 1989).

4.5 Academic performance

Children's performance on national standardized tests in math and Icelandic, including all students attending fourth, seventh and 10th grade, was used to measure academic performance. The number of participants each year ranged from three to four thousand (Skúlason, Gunnarsson, & Einarsdóttir, 2004; Skúlason & Gunnarsson, 2008). These tests are administered and reviewed annually in October by the Icelandic Directorate of Education. The purpose of the standardized tests is to gather information regarding students' basic knowledge and capability in academic subjects, upon which further education is based. The test in Icelandic estimates skills in reading, writing, and grammar and is comprised of multiple choice questions, reading comprehension assessments, writing short stories, and

the correct use of words. The test in math is comprised of multiple choice questions, word problems, sentence completion, operations, geometry, and numerical understanding.

4.6 Questionnaires

Similar background data were collected from all participants and their guardians/parents in all cohorts. Information on parental education and income, as well as indicators of the overall health of parents was collected. Information regarding the frequency and enjoyment of physical activity among parents and their children was collected as along with nutritional information (Riddoch et al., 2005). The participants in Cohort A received a paper copy of the questionnaire, but an electronic version was administered to Cohort B and participants responded online.

4.7 Statistical analyses

The data was analysed using SPSS 22.0 software (IBM Corp., Armonk, NY, USA) latent growth models was conducted with Mplus statistical software version 8.0 (Muthen & Muthen, Los Angeles, CA, USA). All variables were inspected for normality. One-way ANOVA (continuous variables) and chi-square (categorical variables) tests were used to explore the mean differences on key variables. ANCOVA, univariate and multivariate linear regressions were used to explore the relation between variables. Latent growth model was estimated in the long-term analyses for achievement in both Icelandic and maths. The model included test scores for all students in Icelandic schools, born in 1999, who completed the Icelandic Annual Assessment in Icelandic and maths in when they were nine, 12 and 15. This was done to allow our study to compare each participant's academic progress to the progress of the overall Icelandic cohort. The latent growth model summarises the information from the three-time points into two statistics, with an intercept representing initial status and slope representing change over time. The Z-scores in 2008 were subtracted from the 2015 Z-scores to establish an individual participant's change within the cohort over the six years for each parameter. Bivariate correlation was explored, using Pearson's *r*. No mediating effects were analysed since the conditions required for such analyses were not met such as significant relations between independent variables (Baron & Kenny, 1986). Statistical significance was accepted at an α level < 0.05 .

The strenght of the signficiant relations reported in the literature between PA, CRF, adiposity and academic performances is weak to medium. In this

study we need 131 participants to have 75% power to detect weak correlations ($r = 0.02$) which will suffice for all main analyses.

4.8 Ethics statement

Written informed consent was obtained from the participants and their parents in all studies before measurements were collected. Strict procedures were followed to ensure confidentiality; the participants were paired to their code number that they received during the baseline measurements. The research projects were approved by the Icelandic Data Protection Authority, according to the Icelandic Act on Processing of Personal Data and the Icelandic Bioethics Committee, VSNa2003060014/03-12/BH/, for Lifestyles of 9- and 15-year-olds; VSN b200605002&03 for Lifestyles of 7- to 9-year-olds: Intervention towards better health; and VSNb2015020013/13.07 for Longitudinal study of physical health status in a young Icelandic cohort (born in 1999): Interrelations with sleep and educational attainment.

5 Results and Discussion

The main finding of this dissertation was that above average increases in body fat from 9-15 years of age had a negative impact on academic performance in math that was independent of physical activity. Additionally, self-reported physical activity correlated with academic performance in math, but six-year longitudinal changes in objectively measured physical activity did not correlate with changes in academic performance. Furthermore, CRF was not associated with academic performance, regardless of the method used to assess CRF.

5.1 Physical activity and academic performance.

Significant cross-sectional associations were observed between self-reported PA, which was reported as frequency of organized leisure time sport participation (OLSP) per week, and math performance in the combined group of nine-year-olds in Cohorts A and B (Table 1). Participation in OLSP at least four times per week resulted in significantly higher test scores than less frequent participation. No significant difference was detected in Icelandic performance (Table 2). No interaction was detected between the sexes and the association with academic performance.

Table 1. ANCOVA results with math performance as the dependent variable

| | B | Std. err | Sig. | 95% CI |
|-----------------------|--------------|-------------|--------------|-----------------------|
| Intercept | 47.79 | 35.69 | 0.182 | [-22.53, 118.10] |
| Parents' education | 4.30 | 1.53 | 0.001 | [1.69, 6.95] |
| Sport participation | | | 0.024 | |
| ≤1x per week (n 51) | -3.84 | 1.91 | 0.045 | [-7.59, -0.08] |
| 2-3x per week (n 125) | -4.08 | 1.53 | 0.008 | [-7.09, -1.07] |
| ≥ 4x week (n 71) | 0 | 0 | 0 | 0 |
| Maturity offset | 2.16 | 3.39 | 0.525 | [-4.51, 8.83] |

Adjusted for family structure, sex, age, sum of skinfold thickness measurements and CRF. Parents' education, 0 = parental education, neither parent with a university degree, 1= one or both parents with a university degree. Maturity offset = years from peak height velocity. Adj R² = 0.06.

Table 2. ANCOVA results with Icelandic performance as the dependent variable

| | B | Std. err | Sig. | 95% CI |
|--------------------------------|-------------|-------------|------------------|---------------------|
| Intercept | 12.89 | 33.89 | 0.704 | [-53.89, 79.65] |
| Parents' education | 5.50 | 1.27 | <0.001 | [2.99, 8.01] |
| Sport participation | | | 0.750 | |
| ≤1x per week (<i>n</i> 52) | -1.33 | 1.81 | 0.462 | [-4.89, 2,23] |
| -2-3x per week (<i>n</i> 124) | -0.80 | 1.46 | 0.582 | [-3.68, 2.07] |
| > 4x week (<i>n</i> 72) | 0 | 0 | 0 | 0 |
| Maturity offset | 2.33 | 3.19 | 0.466 | [-3.95, 8.6] |

Adjusted for family structure, sex, age, sum of skinfold thickness measurements and fitness. Parents' education 0 = parental education, neither parent with a university degree. Maturity offset = years from peak height velocity. Adj R² = 0.12.

These findings are consistent with previous studies reporting associations between self-reported PA and academic performance (Asigbee et al., 2018; Fox et al., 2010; Sigfusdottir et al., 2007). The current results support the hypothesis that PA may improve factors associated with better academic performance, e.g., classroom behaviour and multiple aspects of brain function and cognition (Hillman et al., 2008; Trudeau & Shephard, 2010). Furthermore, the benefits of PA may be mediated by motor learning and psychosocial mechanisms (Trudeau & Shephard, 2010). Other factors associated with sport participation may also mediate the association with academic performance, e.g., cooperation, sharing, discipline, and obedience (Rees & Sabia, 2010).

These findings add to the findings of Haapala et al. (2014) by establishing a threshold in the association between OLSP and performance in math among preadolescents. Significant dose–response relationship was not found. In line with the findings of Haapala et al. (2014), OLSP was significantly associated with performance in math but not in language. These findings indicate that relationship might be explained by the PA component of OLSP since PA has been reported to be more strongly related to math performance than other school subjects (Fedewa & Ahn, 2011)

Current findings indicated that spending considerable amount of time on OLSP, or four times a week or more is not harmful to school performance even though there is less time available for activities that can more directly promote school performance, like reading or doing homework. Another possible explanation for the reported findings is that only the most dedicated OLSP participants possess or acquire the skills, for example self-discipline, necessary to favourably effect academic performance.

In contrast to the significant association observed between self-reported PA (sport participation) and academic performance, no cross-sectional association was identified between objectively measured PA and academic performance in Cohorts B and C or at the ages of 9 and 15 years. Furthermore, long-term changes in these variables from the age of 9 to 15 years were unrelated (Table 3). Stratification by sex did not alter the results.

The reported lack of consistency between self-reported and objectively measured PA in relation to academic performance has been recognized in the literature. This discrepancy has even been reported within the same cohort (Syvaoja et al., 2013). Furthermore, the authors of a systematic review concluded that self-reported PA was consistently and positively correlated with academic performance, but objectively measured PA was inconsistently correlated with academic performance (Marques et al., 2017).

The explanation for the inconsistencies in relation to academic performance between self-reported and objectively measured PA can only be speculated. These two methods for estimating PA may not target the same aspects of physical activity. Objective measures of PA mainly illustrate PA that accelerates heart rate and respiratory frequency, whereas self-reported PA may illustrate broader constructs and contexts of PA, including skill-specific physical activity requiring balance and agility, which rarely accumulate activity counts (Syvaoja et al., 2013). Some accelerometers are unable to measure activities involving vertical acceleration, such as cycling and upper body movement, and researchers have questioned whether objectively measured PA, which contains data gathered in one week or less, accurately represents the total daily physical activity performed throughout the year (Syvaoja et al., 2013).

PA questionnaires may ask about time spent in MVPA, which is subjective and depends on the participant's physical fitness (Aadahl & Jorgensen, 2003; Dyrstad et al., 2014). Self-reported instruments may be the only feasible method to estimate different modes of PA and have been used to rank, group or categorize PA levels (Corder et al., 2008; Slinde et al., 2003). When reporting PA, high-intensity activities are easier to remember because of their association with the feeling of exhaustion, which may lead to an overestimation of total PA. Self-report instruments have indeed been shown to overestimate the PA intensity and duration, with social desirability also serving as an explanation (Corder et al., 2010; Dyrstad et al., 2014; Strath et al., 2013).

Table 3. Multivariate regression estimates of the associations of body composition and physical activity with academic performance

| Variables | Fat % to estimate body composition | | | | BMI to estimate body composition | | | | | | | |
|-----------|------------------------------------|--------------------|-------|-------|----------------------------------|-------|-----|--------------------|-------|-------|-------|--------|
| | n | adj R ² | B | β | t | p | n | adj R ² | B | β | t | p |
| MATH | 96 | 0.09 | | | | 0.004 | 133 | 0.05 | | | | 0.02 |
| Δ Fat% | | | -0.55 | -0.34 | -3.44 | 0.001 | | | -0.44 | -0.23 | -2.71 | < 0.01 |
| Δ PA | | | -0.03 | -0.03 | -0.33 | 0.742 | | | 0.08 | 0.07 | 0.82 | 0.41 |
| ICELANDIC | 97 | < 0.01 | | | | 0.724 | 134 | 0.03 | | | | 0.18 |
| Δ Fat% | | | -0.15 | -0.05 | -0.49 | 0.625 | | | -0.51 | -0.16 | -1.79 | 0.08 |
| Δ PA | | | -0.13 | -0.07 | -0.69 | 0.492 | | | 0.05 | -0.03 | -0.31 | 0.76 |

PA: Physical activity; BMI: Body mass index (kg/m³); Fat%: bodyfat percentage

Psychological factors have been found to impact academic performance and PA. Self-efficacy is an individual's belief in his or her innate ability to achieve goals and has been defined as a personal judgement of "how well one can execute courses of action required to deal with prospective situations"(Bandura, 1982). Self-efficacy is known to be associated with both academic performance and physical activity and may therefore impact the association (Dishman et al., 2005; Doménech-Betoret, Abellán-Roselló, & Gómez-Artiga, 2017). Researchers have speculated that self-reported PA is only mediating the effect of self-efficacy on academic performance. This hypothesis may explain the findings that children who overestimated physical activity also exhibit higher academic performance (Syvaioja et al., 2013).

The reliability of objectively measured and self-reported PA has been studied. The strength of the association between self-reported and objectively (directly) measured PA has been reported to be low to moderate in adults and very low to large in youth (Corder et al., 2008; Corder et al., 2009; Prince et al., 2008; Zelener & Schneider, 2016). Compared with the doubly labelled water technique, both methods showed significant correlations. Total energy expenditure measured using the doubly labelled water technique was positively correlated with PA estimated from accelerometer total counts ($r = 0.57$; $p = 0.003$) and with minutes per week of PA recorded in the questionnaire ($r = 0.41$; $p = 0.04$). PA energy expenditure was positively correlated with accelerometry data ($r = 0.64$; $p = 0.007$), but not with minutes per week of PA estimated from the questionnaire ($r = 0.30$; $p = 0.15$) (Hallal et al., 2013). These findings validate the use of both methods to estimate PA, although the objective method may be deemed a more valid method. Based on this evidence, the perfect tool for assessing PA may not exist; therefore, researchers should aim to incorporate appropriate objective measures that are specific to the behaviours of interest when examining PA in real world environments (Dowd et al., 2018).

The inconsistent results observed for objective and self-reported PA show that the relationship between physical activity and academic performance is not yet conclusive. Self-reported PA methods may possess several limitations in terms of reliability and validity and are often problematic in children and adolescents because they are less time conscious than adults (Shephard & Vuillemin, 2003). Furthermore, children and adolescents tend to engage in physical activity in sporadic periods with different intensities rather than consistent patterns.

5.2 Adiposity and academic performance

The linear correlation between adiposity, as estimated using BMI and body fat percentage, and academic performance was explored cross-sectionally in the 4th and 10th grades. The only significant association was the negative correlation between BMI and Icelandic performance in 10th grade (Table 4). No interactions were observed between the sexes.

Table 4. Cross-sectional associations in 4th and 10th grades

| | Icelandic 4th grade | | Math 4th grade | | Icelandic 10th grade | | Math 10th grade | |
|-------|---------------------|-----|----------------|-----|----------------------|-----|-----------------|-----|
| | | n | | n | | n | | n |
| BMI | -0.03 | 532 | -0.03 | 538 | -0.20* | 276 | -0.08 | 273 |
| Fat % | 0.04 | 171 | -0.03 | 174 | -0.03 | 274 | -0.09 | 271 |

Fat%: body fat percentage estimated using DXA. * $p < 0.05$.

In addition to exploring the association between adiposity and academic performance, participants were also divided into two groups: those who were considered normal weight and those who were considered obese (Cole, Bellizzi, Flegal, & Dietz, 2000b). The obese group received lower scores for both academic subjects in both 4th and 10th grades, with a statistically significant difference detected in Icelandic performance in the 4th grade (Table 5). Participants were also divided into a normal weight group and an overweight group. Although the normal weight group received higher test scores on average, the difference was not statistically significant (data not shown).

Table 5. Weight categories and academic performance

| | n | mean | SD | p value |
|-------------------|-----|-------|-------|---------|
| 4th grade | | | | |
| <i>Icelandic</i> | | | | |
| Normal weight | 507 | 31.83 | 9.83 | 0.016 |
| Obese* | 25 | 26.96 | 10.51 | |
| <i>Math</i> | | | | |
| Normal weight | 514 | 30.60 | 9.99 | 0.853 |
| Obese* | 24 | 30.21 | 10.46 | |
| 10th grade | | | | |
| <i>Icelandic</i> | | | | |
| Normal weight | 265 | 34.00 | 9.51 | 0.08 |
| Obese* | 11 | 24.45 | 9.53 | |
| <i>Math</i> | | | | |
| Normal weight | 262 | 32.71 | 9.65 | 0.326 |
| Obese* | 11 | 29.64 | 9.73 | |

*Cut-off points were defined by Cole and colleagues (Cole, Bellizzi, Flegal, & Dietz, 2000a).

The association between long-term changes in adiposity and academic performance was explored. Bivariate correlation analyses revealed correlations between changes in BMI and changes in performance in both academic subjects (Table 6). Changes in body fat percentage were only significantly correlated with changes math performance. No interactions were detected between the sexes, but when participants were stratified by sex, the associations were rendered insignificant due to a loss of power (Table 6). The bivariate correlations observed between changes in BMI and changes in performance in Icelandic were rendered insignificant when the analysis was adjusted for PA (Table 3).

Table 6. Bivariate correlations between changes in variables

| | Δ Fat%-Z | n | Δ PA-Z | n | Δ BMI-Z | n | Δ CRF | n | Math | n |
|----------------|-----------------|-----|---------------|-----|----------------|-----|--------------|----|-------|------|
| ALL | | | | | | | | | | |
| Δ PA-Z | -0.11 | 97 | | | | | | | | |
| Δ BMI-Z | 0.77* | 105 | -0.09 | 134 | | | | | | |
| Δ CRF-Z | -0.39* | 75 | 0.18 | 78 | -0.40* | 84 | | | | |
| Math | -0.33* | 104 | 0.09 | 133 | -0.23* | 145 | 0.18 | 83 | | |
| Icelandic | -0.04 | 105 | 0.04 | 134 | -0.17* | 146 | -0.08 | 84 | 0.38* | 3425 |
| GIRLS | | | | | | | | | | |
| Δ PA-Z | -0.35* | 58 | | | | | | | | |
| Δ BMI-Z | 0.77* | 63 | -0.21 | 61 | | | | | | |
| Δ CRF-Z | -0.19 | 42 | 0.07 | 46 | -0.14 | 46 | | | | |
| Math | -0.33 | 63 | 0.16 | 78 | -0.32 | 84 | -0.06 | 46 | | |
| Icelandic | -0.01 | 63 | 0.04 | 78 | -0.21 | 84 | -0.25 | 46 | 0.38* | 1775 |
| BOYS | | | | | | | | | | |
| Δ PA-Z | -0.25 | 39 | | | | | | | | |
| Δ BMI-Z | 0.74* | 42 | -0.08 | 56 | | | | | | |
| Δ CRF-Z | -0.47* | 33 | 0.35* | 37 | -0.47* | 38 | | | | |
| Math | -0.28 | 41 | 0.15 | 55 | -0.12 | 61 | 0.10 | 37 | | |
| Icelandic | -0.04 | 42 | 0.05 | 56 | -0.13 | 62 | 0.01 | 33 | 0.38* | 1650 |

Δ PA-Z: Changes in physical activity Z-scores; Δ BMI-Z: changes in body mass index Z-scores; Δ CRF-Z: changes in cardiorespiratory fitness Z-scores; Δ Fat%-Z: changes in body fat percentage Z-scores; * p < 0.05.

Since the growth curve model included students throughout the nation, an additional analysis was performed for comparison purposes, with the change in the Z score for academic performance as the dependent variable (Table 7). The association between changes in math performance and changes in BMI was weaker and non-significant, but the association with changes in fat percentage (DXA) remained significant.

Table 7. Bivariate correlation analysis using the only the change in Z-scores from fourth to 10th grades as the dependent variable

| | Δ BMI | n | Δ DXA | n | Δ PA | n | Δ CRF | n |
|-----------|--------------|-----|--------------|-----|-------------|-----|--------------|----|
| Icelandic | -0.15 | 142 | -0.02 | 103 | 0.03 | 130 | -0.07 | 84 |
| Math | -0.10 | 145 | -0.22* | 104 | 0.06 | 133 | 0.14 | 83 |

Δ : changes in; BMI: body mass index; PA: physical activity; CRF: cardiorespiratory fitness. *p < 0.05

The lack of significant linear cross-sectional associations between adiposity and academic performance in 9-year-old children are consistent with the findings from a study of nine-year-olds (95% seven- and eight-year-olds) (Lambourne et al., 2013). In contrast, when the participants were 15 years old, positive correlations were detected between BMI and performance in Icelandic, but not math. This result is partially consistent with the findings from a study of university students (Anderson & Good, 2017). The differences in results for the academic subject used to represent academic performance may partially explain the discrepancy in the literature regarding the association between adiposity and academic performance. Furthermore, as shown in the current results, the age of the participants may also explain the inconsistency, as well as method used to estimate adiposity, as no significant associations were identified when body fat percentage was used. Other possible explanation include the use of different covariates (Torrijos-Nino et al., 2014) and the use of self-reported grades (Huang et al., 2006).

Investigations of the linear association between adiposity and academic performance may not be the method of choice since a normal weight status is considered to range from a BMI of 18.5 to 25 and values below the cut-off are considered detrimental to health (Cole et al., 2000a). Participants are therefore quite often divided into groups based on their BMI. In the current study, the obese group had lower test scores in all cases, but the only significant difference was Icelandic performance in the 4th grade. The results from previous studies on this topic are inconsistent. No difference in academic performance between BMI groups was observed in 4th to 6th graders (LeBlanc et al., 2012), but obese 7th grade students received lower

test scores than normal weight students (Sardinha et al., 2014). This discrepancy might be explained by the different methods used to classify students as either obese or normal weight, as well as the age of the participants or which academic subject is used to assess academic performance, as reported in the current study.

Since cross-sectional studies may be confounded by unobserved differences, they are considered less valid for examining cause-and-effect relationships than longitudinal studies (Caruana, Roman, Hernández-Sánchez, & Solli, 2015). In the longitudinal analyses presented in the current study, associations were detected between increased adiposity levels and deteriorating math performance after adjusting for PA. This result contradicts the findings of a longitudinal study in which the association between changes in BMI and changes in academic performance in adolescents were non-significant (L. J. Chen et al., 2013). The discrepancy between the current study and the results reported by Chen et al. (2013) might be explained by the method used to assess academic performance or the longer time interval employed in the current study. Chen et al. (2013) used teacher-graded mean scores from four academic subjects, but this method has been criticized (Tomprowski, Davis, Miller, & Naglieri, 2008). Furthermore, changes in adiposity levels occur slowly and gradually, and the process should be more prominent after six years, the time period assessed in our study, than after two years, which was used in the study by Chen et al. (2013). No sex-specific difference was detected in the association between increased adiposity levels and deterioration in math performance (interaction). This result contradicts the findings from a four year longitudinal study, where increased body fat levels only correlated with decreasing academic performances in girls (Datar & Sturm, 2006). This discrepancy might be explained by the younger age of the participants in the study by Datar and Sturm (2006) or an age of 4.5 years at baseline.

Based on the current findings, high adiposity levels exert detrimental effects on academic performance, which is further supported by the association between long-term changes in adiposity levels and academic performance. A possible biological explanation for the negative correlation is the observation that a high-fat diet reduces hippocampal levels of brain-derived neurotrophic factor in animals. This neurotrophin is a crucial modulator of synaptic plasticity and a predictor of learning efficacy (Molteni et al., 2004). Other possible explanations include unobserved confounding variables, such as depression, which has been associated with obesity in adolescents and may impact academic performance (McLeod et al., 2012; Sjöberg et al., 2005).

In this dissertation, some discrepancies in the correlations between PA and adiposity with academic performance were noted and depended on the academic subject used as the dependent variable. Self-reported PA was only associated with math performance and long-term changes in adiposity after controlling for changes in PA. In contrast, obesity was only negatively correlated with performance in Icelandic in 4th grade. The explanation for this discrepancy can only be speculated. Stronger correlations between PA and math performance have been described in previous publications without a profound explanation (Fedewa & Ahn, 2011), but differences in adiposity have not been described. Biological explanations may include dissimilar effects of PA and adiposity on different parts of the brain and therefore different aspects of cognitive performance. Language skills develop as a result of extramural learning rather than formal instruction, as is the case for math (*Language development across the lifespan*, 2018). This difference may very well affect the association between PA and adiposity with academic performance. These hypotheses are supported by the moderately strong correlation between the two academic subjects assessed in this study (Table 6).

Although our approach eliminated the influence of unobserved confounders that vary across children but remain constant over time for the same child, we were unable to control for the influence of other unobserved variables that may have changed contemporaneously with the body fat level and academic performance, such as maturity level.

5.3 Cardiorespiratory fitness measures and academic performance

When the cross-sectional correlations between CRF and academic performance in fourth grade were explored in Cohorts A and B, no significant correlations were identified, regardless of the method used to assess CRF (Table 8). Adjustments for parental education, adiposity, maturity, and sport participation did not impact the association between CRF, expressed as W/kg, and academic performance. No cross-sectional correlations were observed between CRF (W/kg) and academic performance in 10th grade in Cohort C ($r = 0.07$, $p = 0.48$; $r = 0.15$, $p = 0.11$ for Icelandic and math, respectively).

Table 8. Regression coefficients between academic performance and different CRF measures in the 4th grade

| CRF measure | Boys (n=140) | | | Girls (n=163) | | |
|--------------------|--------------|---------|-----------------|---------------|---------|-----------------|
| | B | β | B 95% CI | B | β | B 95% CI |
| Max W | -0.03 | -0.06 | [-0.11, 0.05] | 0.07 | 0.15 | [-0.003, 0.15] |
| Regression scaling | | | | | | |
| Max W | -0.03 | -0.07 | [-0.12, 0.06] | 0.05 | 0.09 | [-0.04, 0.13] |
| log(kg) | 1.06 | 0.02 | [-8.18, 10.29] | 7.20 | 0.19 | [-1.71, 16.10] |
| Ratio scaling | | | | | | |
| log(W/kg) | -1.76 | -0.04 | [-9.21, 5.68] | 0.08 | 0.02 | [-6.08, 7.85] |
| W/cm | -4.80 | -0.07 | [-17.14, 7.53] | 8.13 | 0.11 | [-3.36, 19.62] |
| W/BSA | -0.03 | -0.06 | [-0.13, 0.06] | 0.03 | 0.05 | [-0.06, 0.13] |
| Allometry/ratio | | | | | | |
| W*kg-0.66 | -0.28 | -0.06 | [-1.11, 0.54] | 0.23 | 0.05 | [-0.56, 1.11] |
| W*kg-0.51 | | | | 0.25 | 0.08 | [-0.25, 0.75] |
| W*kg-0.35 | -0.09 | -0.06 | [-0.35, 0.17] | | | |

* p < 0.05. W = watts. BSA = body surface area. CRF = cardiorespiratory fitness. In linear regression scaling, max watts and body weight (log(kg)) were the independent variables included in the model.

Table 9. Regression estimates of the longitudinal associations of body composition and CRF with academic performance

| | Fat % used to estimate body composition | | | | BMI used to estimate body composition | | | | |
|--------------------|-----------------------------------------|---------|-------|-------|---------------------------------------|--------------------|---------|-------|-------|
| | adj R ² | β | t | p | n | adj R ² | β | t | p |
| All | | | | | | | | | |
| MATH | 74 | 0.05 | | 0.073 | 83 | 0.06 | | | 0.088 |
| Δ body comp | | -0.22 | -1.77 | 0.081 | | | -0.18 | -1.50 | 0.138 |
| Δ CRF | | 0.09 | 0.68 | 0.489 | | | 0.11 | 0.95 | 0.345 |
| ICELANDIC | 75 | 0.01 | | 0.597 | 84 | 0.00 | | | 0.680 |
| Δ body comp | | -0.01 | -0.10 | 0.919 | | | -0.07 | -0.60 | 0.551 |
| Δ CRF | | -0.12 | -0.96 | 0.338 | | | -0.10 | -0.83 | 0.409 |

CRF: cardiorespiratory fitness; BMI: body mass index (kg/m²); Fat%: body fat percentage.

When both sexes were analysed together, the bivariate correlation analysis did not reveal a significant correlation between changes in CRF from the ages of nine to 15 years and changes in academic performance ($r = 0.18$, $r = 0.10$; $r = -0.07$, $r = 0.52$, for math $n = 83$, and Icelandic $n = 84$, respectively). Further adjustments for adiposity did not substantially impact the association (Table 9). When the sexes were analysed separately, no significant correlations with math or Icelandic performance were identified, but the correlation coefficients for math performance in boys were stronger than in the combined analysis, 0.28 ($p = 0.097$, $n = 37$), or in girls, -0.06 ($p = 0.69$, $n = 46$).

Bivariate correlation analyses using the Z scores of the sample instead the slope produced by the latent growth curve to represent the change in CRF (W/kg) from fourth to 10th grade as the dependent variable did not reveal a significant association with academic performance (Table 7). Based on these results, CRF may not be associated with academic performance. An assessment of the association between changes in CRF and academic performance is the most valuable analysis since it is more indicative of a causal relationship than a cross-sectional analysis. Causal relationships were not able to be concluded since changes in other unobserved variables may impact the relationships between the study variables.

The association between CRF and academic performance has been studied to some extent. In previous publications, the association between CRF and academic achievement has been equivocal. Some studies have reported relationships between increased CRF levels and improved academic performance (Welk et al., 2010), but others have not (Kantomaa et al., 2013). Positive correlations have been established in cross-sectional studies, but results from longitudinal studies are inconclusive (Santana et al., 2017). In this dissertation, long-term changes in CRF were not associated with academic performance, consistent with other findings (Suchert, Hanewinkel, & Isensee, 2016). In contrast, positive correlations between increased CRF and improved academic performance have been reported (L. J. Chen et al., 2013). The discrepancy between the current study and the results reported by Chen et al. might be explained by the method used to assess academic performance. Chen et al. (2013) used teacher-graded scores, which have been criticized (Tomprowski et al., 2008).

The proposed explanation for the positive correlation between CRF and academic performance is the potential effects of CRF on cognitive function and performance on attention tasks, as well as increased levels of brain-derived neurotrophic factor (Hillman et al., 2008; Latorre-Roman, Mora-

Lopez, & Garcia-Pinillos, 2016). Motor skills and cognition have several common underlying processes, such as monitoring, sequencing, and planning, which may positively influence academic performance (van der Fels et al., 2015). Another possible explanation is that students with better academic performance may be better oriented for success, and therefore might attempt to achieve success in both academics and physical fitness (Thogersen-Ntoumani & Ntoumanis, 2006). The latter explanation is supported by the results from a study showing cross-sectional associations between CRF and academic performance, but the authors failed to establish association between changes in CRF and academic performance (Suchert et al., 2016)

The relationship between CRF and academic performance has mainly been explored using CRF field-based tests (Lambourne et al., 2013; Welk et al., 2010). The association between CRF and academic performance might depend on the test (Dwyer, Sallis, Blizzard, Lazarus, & Dean, 2001). However, this correlation may be influenced by motor skills and running efficiency rather than CRF itself (Haapala, Poikkeus, Tompuri, et al., 2014; Kantomaa et al., 2013).

CRF is recognized as a key component of physical fitness and has been used as a proxy for physical activity in previous studies. Differences in CRF levels are attributed to both genetic and environmental factors, with physical activity being the main influential factor in adults (Blair et al., 2001). In children, the relation between CRF and physical activity is less clear. Both trained and untrained youth can increase their CRF through endurance training, but the relative intensity of the exercise required to obtain a benefit must be higher than that recommended for adults (Armstrong & Barker, 2011). The relation between habitual physical activity and CRF has been reported to be weak or insignificant (Armstrong et al., 2011; Dencker et al., 2012; Sveinsson et al., 2009). In our data, the associations between changes in CRF and PA were weak and nonsignificant ($r = 0.15$, $p = 0.201$). Cross-sectional association between CRF and PA in 4th grade was moderate ($r = 0.37$, $p < 0.001$) but weaker in the 10th grade ($r = 0.19$, $p = 0.042$). This low level of strength between CRF and PA raises questions regarding the use of CRF as a proxy for PA. Genetics are therefore most likely the major contributor to CRF in children, making the results from cross-sectional studies applying CRF as a proxy for PA questionable. A remaining question is whether CRF may be used as a proxy for high intensity physical activity as it may not accurately reflect habitual physical activity, which may not be of a sufficient intensity to improve CRF in youths. However, the strength of the association between time spent in moderate

to vigorous PA has only been shown to be moderate ($r = 0.365$, $p < 0.01$) (Oliveira et al., 2017).

5.4 Academic performance

A growth model with three-time points was established the using Institute of National Examination data for fourth, seventh, and 10th grades for the cohort born in 1999. The model for Icelandic consisted of 3,736 students and the model for math consisted of 3851 students. The model includes test scores for all students in Icelandic schools who were born in 1999 who completed the Icelandic Annual Assessment in Icelandic ($n = 3,736$) and math (3,851) in the fourth, seventh and 10th grades. This approach facilitated comparisons of the academic progress of each participant in our study to the progress of the overall Icelandic cohort. The latent growth model summarizes the information from the three-time points into two statistics, an intercept representing the initial status and a slope representing changes over time. Values are displayed as standard deviations from the average change within the cohort, and thus a value of 0 represents an unchanged status within the cohort. A negative slope indicates decreasing academic performance of the individual study participants over the three-time points compared with the overall Icelandic 1999 cohort, and, similarly, a positive slope indicates improved performance relative to the overall cohort.

The growth model for Icelandic had an intercept with a mean value of 29.46 (average score in 4th grade) and a variance of 87.80, and a slope of 0.02 with a variance of 9.40 (Figure 5). The correlation between the intercept and the slope was $r = -0.21$, $p < 0.001$, showing that students who received low scores in 4th grade fell behind their peers to a greater extent in the 7th and 10th grades on average.

The growth model for math had an intercept of 29.89 (average score in 4th grade) with a variance of 71.30 and a slope of -0.15 with a variance of 6.30 (Figure 6). The correlation between the intercept and the slope was $r = 0.033$, $p > 0.05$.

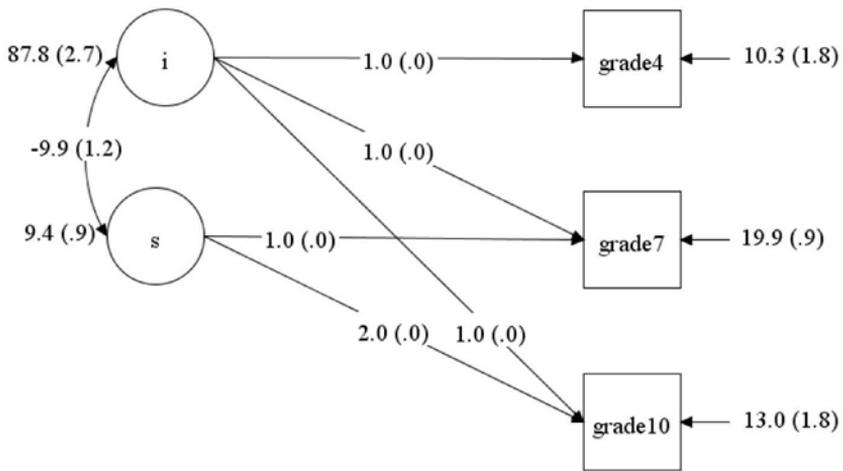


Figure 5. The latent growth curve model for Icelandic

"i" (intercept) represents students' original status (in 4th grade); s represents the slope, which is defined as the change in students' academic performance in relation to the average change of the cohort. Lines extending from "i" to the boxes show the weight of each grade in the model; all grades had equal weight and are marked as 1.0. Lines from "s" to the grade 7 box and grade 10 box indicate the time units, i.e., a line from grade 4 to grade 7 is one time unit (three years - marked 1.0) and lines from grade 4 to grade 10 are two time-units (six years - 2.0). Numbers adjacent to grade boxes represent residuals, the part of the variance not explained by the model. Numbers adjacent to "i" represent the variance explained by the model. Numbers adjacent to "s" indicate the variance of the slope within the cohort. Numbers between "i" and "s" indicate the covariance (correlation). Standard errors are displayed in brackets. The result of the chi-square test for the model was 8.68, $df = 1$, $p = 0.003$. Model fit indices indicated a good fit, standardized root mean square residual = 0.008 and root mean square error of approximation = 0.045 (90% C.I. of 0.021 to 0.075 and 54% probability of being less than 0,05), Confirmatory Fit Index = 0.999 and Tucker-Lewis index = 0.997.

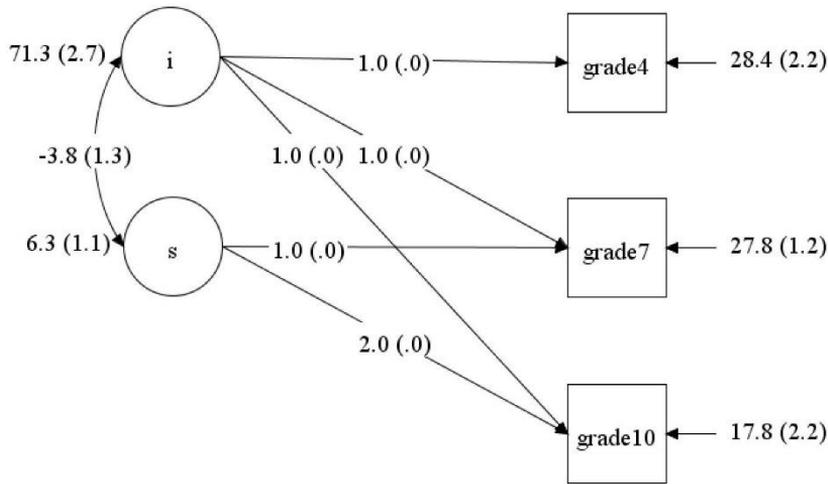


Figure 6. The latent growth curve model for math

“i” (intercept) represents the students’ original status (in 4th grade); s represents the slope, which is defined as the change in students’ academic performance in relation to the average change in the cohort. Lines extending from “i” to the boxes show the weight of each grade in the model; all grades had equal weight and are marked as 1.0. Lines from “s” to the grade 7 box and grade 10 box indicate the time units, i.e., a line from grade 4 to grade 7 is one time-unit (three years - marked 1.0) and lines from grade 4 to grade 10 are two time-units (six years - 2.0). Numbers adjacent to grade boxes represent residuals, the part of the variance not explained by the model. Numbers adjacent to “i” represent the variance explained by the model. Numbers adjacent to “s” indicate the variance of the slope within the cohort. Numbers between “i” and “s” indicate the covariance (correlation). Standard errors are displayed in brackets. The model had a chi-square value of 1.28 with 1 df and $p = 0.258$. The model exhibited an excellent fit, standardized root means square residual = 0.004 and root mean square error of approximation = 0.008 (90% C.I. of 0.000 to 0.045 and 98% probability of being less than 0.05), and both the confirmatory fit index and Tucker-Lewis index had a value of 1.00.

Test scores of the study sample used in the long-term analyses were compared to the national cohort that lived in the nation’s capital area to assess the representativeness of the study sample and significant differences were observed in all cases (Table 8). This finding indicates some selection bias that was most likely caused by the more school-oriented background of individuals who decided to participate in the study.

Table 10. Comparison of test results between the study sample and the cohort from the nation's capital area

| | | N | Mean | SD | p value |
|----------------------|--------|------|-------|-------|---------|
| Math 4th grade | Cohort | 2000 | 30.53 | 9.78 | < 0.001 |
| | Sample | 159 | 32.60 | 9.16 | |
| Icelandic 4th grade | Cohort | 1979 | 30.46 | 10.01 | < 0.001 |
| | Sample | 156 | 33.40 | 9.00 | |
| Math 7th grade | Cohort | 1988 | 30.84 | 9.77 | < 0.001 |
| | Sample | 157 | 34.23 | 8.84 | |
| Icelandic 7th grade | Cohort | 1991 | 30.96 | 9.82 | < 0.001 |
| | Sample | 158 | 34.31 | 9.02 | |
| Math 10th grade | Cohort | 1988 | 30.84 | 9.77 | < 0.001 |
| | Sample | 157 | 34.23 | 8.84 | |
| Icelandic 10th grade | Cohort | 1991 | 30.96 | 9.82 | < 0.001 |
| | Sample | 158 | 34.31 | 9.02 | |

Results from standardized tests administered by a third party were used to assess academic performance. The responsibility placed on teachers and schools to prepare students for standardized tests has been noted as the greatest benefit of standardized testing (*Pros and Cons of Standardized Testing*, 2013). Standardized testing provides teachers guidance in determining what material to teach students and when to teach it, making better use of time. Standardized tests are objective in nature and allow parents to compare their child's academic performance with other students locally and across the country (*Pros and Cons of Standardized Testing*, 2013). Standardized testing has been criticized and argued to only evaluate a student's performance on one particular day without considering external factors (*Pros and Cons of Standardized Testing*, 2013). Additionally, standardized testing may cause teachers to only teach material relevant to the test, which may hinder a student's overall learning potential.

Self-reported academic performance data in children and adolescents have been found to deviate from teacher-rated or test performance, with the agreement generally ranging from weak to moderate (Brown et al., 2015). Younger students have been found to be less accurate in their self-assessments than older students (Blatchford, 1997). However, a comparison between a student's self-assessment and the teacher's evaluation may be problematic because of a lack of accuracy and reliability in teacher grading practices (Heldsinger & Humphry, 2013; Kirby & Downs, 2007).

5.5 Socioeconomic status

SES was significantly related to performance in math and Icelandic in 4th grade (Table 1 and 2). These findings are in line with previous findings showing that SES consistently relates to academic performance (Sirin, 2005). Most likely this relationship can be explained with the resources provided directly by the family and by the indirect family-provided social capital necessary to succeed in school (Coleman, 1988). Family structure (living with both parent v/s single parent, one parent and stepmom/dad, or other arrangements) was not related to academic performance (data not shown). Therefore, it may be speculated that single parents are able to provide their children with the same support as both-parent families.

SES did not statistically significantly relate to OLSP frequency (Chi-square $p > 0.05$, data not shown). However, there was a tendency towards higher OLSP participation rates among the higher SES group. Over 34% of children in the higher SES group reported to participate four times a week or more compared to over 26% in the lower SES group. These findings are in line with Björnsdóttir et al. (2009) findings who reported no relations between SES and after school activities (including sports) among 1st and 3rd graders. These findings indicate that children seem to have an equal access to OLSP, independently of the family SES. This could partly be explained with the financial support most communities offer to all families to reduce the costs that follow participation in organized after-school activities.

5.6 Strengths and limitations

This study possesses several strengths, including the use of results from standardized tests to assess academic performance. These tests were administered and reviewed by a third party, which eliminates biases known to affect both self-reported and teacher-graded tests. This approach enabled the use of sophisticated statistical analyses. In addition, our database included test results from students throughout the nation, which were used in the analyses. The long-term repeated measure design of this study is also viewed as a strength, as it provides greater insights into cause and effect than studies with cross-sectional research design. Furthermore, the six-year time span is worth mentioning since studies investigating a long period are very rare in this field. Other strengths include the use of DXA to estimate body composition, both objective and self-reported methods to estimate PA and a laboratory-based CRF test. Limitations include the low number of participants in the long-term analyses, which were partly due to the inclusion criteria for the PA measurements and the low number of total

participants. Moreover, only half of the study sample in Cohort A was offered the opportunity to participate in the CRF, impacting the number of participants in the cross-sectional analyses among the 9-year-olds. Since cut-off points for moderate to vigorous PA in the recently available wrist worn accelerometers used in Cohort C had not yet been developed, participants were not able to be divided into groups according number of minutes spent participating in PA with different intensity levels.

6 Conclusions

Our findings are consistent with previous findings showing positive correlations between self-reported PA and academic performance. Children who participate four times a week or more in self-reported organized leisure time sports do not experience negative effects on academic performance, and this level of physical activity may benefit learning. In contrast, objectively measured PA was not related to academic performance, which is also consistent with previous findings. This discrepancy might be explained by the differences in the reflective capabilities of subjective and objective measures of constructs and contexts of PA associated with academic performance, and the accelerometer may not accurately measure PA during swimming, cycling, or similar activities.

Adiposity did not cross-sectionally correlate with academic performance, but long-term changes in adiposity levels correlated with decreasing academic performance. This finding might be explained by the age of the participants, e.g., the relation might be more difficult to establish in younger children. We did not observe changes in physical activity that mediated the observed negative correlation between changes in academic performance and body composition. The longitudinal design used to explore the association between changes in adiposity and changes in academic performance does not allow us to ascertain causality. The current results merely indicate that an increase in adiposity from fourth to 10th grades was accompanied by worsening academic performance. Further studies are required to identify factors that may negatively affect both changes in academics and body composition in school-aged children.

The use of different methods to assess CRF, as estimated on a cycle ergometer, do not affect the correlation with academic performance. Body weight or body size must be considered when the associations between CRF and academic performance are explored. Body weight expressed allometrically to the sample's exponent when ratio scaling is applied, or linear regression scaling may be the methods of choice to adjust for different body sizes when exploring the correlations between CRF and academic performance.

Communities may seek to increase organized leisure time sport offerings independently and in cooperation with non-profit sport clubs. Organized leisure time sports are often costly for families; therefore, communities

may consider assisting low-income families with providing OLSP opportunities for their children. The educational system should implement factors related to healthy living, such as PA, to promote a normal weight status in attempt to prevent deteriorating academic performance as children progress from late childhood to adolescence.

7 Future perspectives

The present study aimed to examine the associations between PA, CRF, adiposity and academic performance in children and adolescents. Based on the findings of a negative correlation between increased adiposity and academic performance, future studies should focus on exploring which, if any, factors might explain the negative correlation. These factors may include factors related to a person's psyche, e.g., self-efficacy, or environmental factors, such as social networks and well-being. The reported discrepancy between self-reported and objective PA requires further exploration. Studies including both methods to assess PA are needed and should also collect information about an individual's psychological and social status in attempt to explain the potential mediating/moderating effects of these variables on academic performance using structural equation modelling. Future studies of the association between CRF and academic performance should include both laboratory-based and field-based CRF tests to explore the reported difference in the correlations with academic performance. The mediating/moderating effects of factors that have been reported to impact academic performance and CRF, such as motor control and biological maturity, should be included. In studies examining the association between sport participation and academic performance, the type of sport in which participants engage should be considered since PA levels may vary considerably.

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Paper I

Paper II

Paper III

