DISSERTATION FROM THE
NORWEGIAN SCHOOL OF
SPORT SCIENCES
2018

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Indices of physical activity, executive function, and academic performance among 10-year-old schoolchildren

Cross-sectional, prospective, and intervention findings from The Active Smarter Kids (ASK) school-based cluster-randomized controlled trial

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ISBN 978-82-502-0548-2

SUMMARY

Background: A growing number of studies shows that children derive cognitive benefits from physical activity. However, few studies of high quality have investigated the effects of physical activity interventions, incorporated into the public schools' curricula, on executive functions and academic performance.

Main aims: To investigate the relationships for indices of physical activity (physical activity, aerobic fitness, and motor skills) to executive functions and academic performance, and furthermore examine if the potential effects of physical activity on academic performance are mediated by improvements in executive functions.

Materials and methods: This thesis is part of the Active Smarter Kids (ASK) study; a multicomponent cluster randomized controlled trial, including 1129 fifth grade children (10-year-olds) from 57 elementary schools in the county of Sogn og Fjordane in Norway. The intervention lasted seven months, and consisted of three components, generating an additional of 165 minutes/week of physical activity: (1) physical active educational lessons, (2) physical activity breaks during the classroom lessons, and (3) physical activity homework. Baseline and post-intervention data collections included accelerometer assessed physical activity, measures of aerobic fitness, and motor skills, as well as measures of executive functions, behavioral self-regulation, school related well-being, and academic performance.

Main results: Objectively measured physical activity levels were not, whereas motor skills were, associated with executive functions and academic performance cross-sectionally and prospectively. Aerobic fitness was only associated with executive functions and academic performance cross-sectionally, and in boys only. Intention-to-treat analyses revealed no significant effects of the ASK intervention on executive function or academic performance. No significant effect was observed for physical activity. In sub-group analyses, a significant effect of the intervention was found on numeracy for children in the lowest tertile in numeracy at baseline. Per protocol analyses showed significant intervention effects on executive functions and motor skills. Executive function did generally not mediate the relationships between indices of physical activity and academic performance.

Conclusions: Aerobic fitness and motor skills were related to executive functions and academic performance, showing that varied physical activity may have the potential to positively affect executive function and academic performance. Still, inclusion of more physical activity in the school curriculum did generally not improve executive functions or academic performance, but neither did it have an adverse consequence. The alternative didactic approach the ASK intervention represents, can potentially raise the academic performance of the children most in need.

Key words: physical activity, aerobic fitness, motor skills, cognition, executive function, self-regulation, academic performance, elementary school children, intervention, structural equation modeling

SAMANDRAG

Bakgrunn: Eit aukande tal studiar viser at born oppnår kognitive fordelar av deltaking i fysisk aktivitet. Få studiar av høg kvalitet har derimot undersøkt effekten av skuleintervensjonar med fysisk aktivitet som er integrert i opplæringa på eksekutive funksjonar og skuleprestasjon.

Hovudføremål: Å undersøkje samanhengar mellom ulike mål på fysisk aktivitet (objektivt målt fysisk aktivitet, aerob fysisk form og motorikk) og eksekutive funksjonar og skuleprestasjon, samt om dei potensielle effektane av fysisk aktivitet på skuleprestasjon er mediert av betra eksekutiv funksjon.

Materiale og metode: Denne avhandlinga er ein del av studien Active Smarter Kids (ASK); ein multikomponent klynge-randomisert kontrollert studie, som inkluderte 1129 femteklassingar (10 år gamle) frå 57 grunnskular i Sogn og Fjordane, Noreg. Intervensjonen gjekk over sju månader og bestod av tre komponentar som til saman utgjorde 165 minutt per veke ekstra fysisk aktivitet: (1) fysisk aktivitet integrert i skulefag, (2) pausar med fysisk aktivitet i skulefag, og (3) heimelekse med fysisk aktivitet. Datainnsamling vart gjennomført før og etter intervensjonen, og inneheldt målingar av fysisk aktivitetsnivå (med akselerometer), aerob fysisk form og motorikk, samt målingar av eksekutiv funksjon, åtferd i klasserommet, skulerelatert livskvalitet og skuleprestasjon.

Hovudresultat: Det var ingen samanheng mellom objektivt målt fysisk aktivitetsnivå og eksekutive funksjonar og skuleprestasjon verken i tverrsnitts- eller prospektive analysar. Fysisk form var berre assosiert med eksekutiv funksjonar og skuleprestasjon i tverrsnittsanalysar, og berre for gutar. Motorikk var assosiert med både eksekutive funksjonar og skuleprestasjon i tverrsnitts- og prospektive analysar. Intention-to-treat analysar viste ingen effekt av ASK intervensjonen på eksekutive funksjonar eller skuleprestasjon. Det var ingen signifikant effekt på fysisk aktivitetsnivå. Subgruppeanalysane viste ein effekt av intervensjonen i matematikk for den svakaste tredjedelen i matematikk før intervensjonen. Per protokollanalysane viste ein signifikant intervensjonseffekt på eksekutive funksjonar og motorikk. Eksekutiv funksjon medierte generelt ikkje samanhengen mellom ulike mål på fysisk aktivitet og skuleprestasjon.

Konklusjonar: Aerob fysisk form og motorikk var assosiert med eksekutive funksjonar og skuleprestasjon, noko som indikerer at variert og allsidig fysisk aktivitet kan ha ein positiv effekt på eksekutive funksjonar og skuleprestasjon. Meir fysisk aktivitet i skulekvardagen førte generelt ikkje til betre skuleprestasjon, men hadde heller ikkje uheldige konsekvensar. Det er mogleg den alternative didaktikken som ASK intervensjonen representerte kan betre skuleprestasjonen hjå dei borna som treng det mest.

Nøkkelord: fysisk aktivitet, aerob fysisk form, motorikk, kognisjon, eksekutiv funksjon, sjølvregulering, skuleprestasjon, grunnskule elevar, intervensjon, structural equation modeling

ACKNOWLEDGEMENT

This thesis is part of the Active Smarter Kids study, that was carried out at the former Sogn og Fjordane University college, now a part of the Western Norway University of Applied Sciences (HVL), Campus Sogndal, Norway, in collaboration with the Norwegian School of Sports Sciences (NSSS), Oslo, Norway, in the period 2014-2017. The ASK project was funded by The Research Council of Norway, the Sogn og Fjordane University College, NSSS, and Gjensidige foundation.

I am truly grateful for the opportunity to be a PhD-student and a part of the ASK group, and I would like to thank all the members of the project group for their contributions to this thesis. Yngvar Ommundsen, professor at the Department of Coaching and Psychology at NSSS and my main supervisor: You are a great inspiration, both professionally within the research field and as a supervisor. Thanks for sharing your knowledge and experience throughout all stages of the project. Also thanks for your presence, our many long SKYPE calls (when I have asked for short chats), your very quick, thorough, and motivating feedback on drafts, and your encouragement –you have let me mature academically in my own pace. Vegard Fusche Moe, associate professor at the HVL and my co-supervisor: You have an outstanding ability to ask the important conceptual questions; your philosophical views and input have made me think and re-think my research questions and hypothesis. Thank you for always having an open door, your valuable advices, and your kind interest in my work with the thesis. Eivind Aadland, associate professor at the HVL (and my unofficial "24/7" co-supervisor): You have been my toughest critic, with your knowledge and experience in statistics, physical activity, as well as writing. Thank you for all our discussions during the evening meals after long days of writing or data analyses - you always have an answer to my questions. Geir Kåre Resaland, associate professor at the HVL and project coordinator: "You rock!" Thank you for all your enthusiasm and effort for making ASK happen. Sigmund Alfred Anderssen, professor at the Department of Sports Medicine, NSSS, and primary investigator: Thank you for advices during all stages of the work with the thesis. I will always keep in mind your reminders of the importance of celebrating the milestones and taking well-earned breaks.

Furthermore, I would like to thank my fellow PhD candidates in the ASK project, Turid Skrede, Laura Souminen, and Mette Stavnsbo, for sharing ups and downs and for being such great persons! During your months out of office, you were truly missed. Øystein Lerum, formerly research assistant and now PhD candidate, the man who fix everything with a smile: thanks for always answering all sorts of computer-related technical questions, and all other questions, actually. Ronja Vangsnes, my reliable and always positive co-leader for the cognition test team: You made the periods of data collection and plotting so much easier. Thank you! Kolbjørn Selvåg Brønnick, neuropsychologist and professor: thank you for sharing your knowledge on neuropsychological assessment, the training of test personnel, and feedback on drafts. Your contribution when designing the test battery was crucial. Arne Lervåg, professor 2 at HVL: thank you for excellent guidance and invaluable assistance on structural equation modeling. Such analyses would not have been possible without your knowledge.

I would also like to thank the Faculty of Teacher Education and Sports and the Institute of Sports, the librarians, and the Fou section at the HVL campus Sogndal. Thanks to my colleagues at the Institute of Sports who make the working day lively; I appreciate our work environment! A special thanks to the directors of studies, Kari Aaberge and Frode Fretland, for understanding and goodwill regarding the working conditions during this period. I have appreciated it!

During my PhD period, I have had the privilege to be a part of the Department of Coaching and Psychology at NSSS. I have always looked forward to my visits at NSSS and our seminars at Norefjell, and I have appreciated to get to know you. Thank you all for including me, and thank you Kristin and Nicholas for always making an office desk available for me, and for inviting me to events.

I am grateful to the children and their families, principals, and teachers who gave their time to the ASK study. Many thanks also to all the master's and bachelor's students from the former Sogn og Fjordane University College who participated in the data collections.

Finally, I would like to thank friends and family for all the support. Iselin, my best friend: thank you for your interest in the project and for always giving me access to your apartment in Oslo. I am grateful to my parents-in-law, Britt and Atle, my parents, Sissel and Kristian, for taking care of our girls when needed. Without your effort, it would not have been possible for us to attend conferences. Eivind, our eight continuous years of PhD-education is actually approaching the end. In addition to your professional support, I am deeply in gratitude for all your backing, for all the effort you have laid down at home, and all the experiences you have given our daughters when I have been working. A special thanks to our dear daughters, Silje and Marie, for your patience and understanding. You have been my biggest motivation; we did finish "the book" together and will now be able to spend much more time together!

Sogndal, 18th of August 2017

Katrine Nyvoll Aadland

LIST OF PAPERS

This thesis is based on the following papers:

Paper I :

Aadland, K. N., Moe, V. F., Aadland, E., Anderssen, S. A., Resaland, G. K., & Ommundsen, Y. (2017). Relationships between physical activity, sedentary time, aerobic fitness, motor skills and executive function and academic performance in children. *Mental Health and Physical Activity, 12*, 10-18. doi:10.1016/j.mhpa.2017.01.001

Paper II

Aadland, K. N., Ommundsen, Y., Anderssen, S. A., Brønnick, K. S., Moe, V. F., Resaland, G. K., Skrede, T., Stavnsbo, M., & Aadland, E. (2017). Effects of the Active Smarter Kids (ASK) Physical Activity School-based Intervention on Executive Functions: A Cluster-Randomized Controlled Trial. *Scandinavian Journal of Educational Research*, 1-15. doi:10.1080/00313831.2017.1336477

Paper III

Resaland, G. K., Aadland, E., Moe, V. F., Aadland, K. N., Skrede, T., Stavnsbo, M., Souminen, L., Steene-Johannesen, J., Glosvik, Ø., Andersen, J.R., Kvalheim, O., Engelsrud, G., Andersen, L.B., Holme, I. M., Ommundsen, Y., Kriemler, S., van Mechelen, W., McKay, H., Ekelund, U., & Anderssen, S. A. (2016). Effects of physical activity on schoolchildren's academic performance: The Active Smarter Kids (ASK) cluster-randomized controlled trial. *Preventive Medicine, 91*, 322-328. doi:10.1016/j.ypmed.2016.09.005

Paper IV

Aadland, K. N., Ommundsen, Y., Aadland, E., Brønnick, K. S., Lervåg, A., Resaland, G. K., & Moe, V. F. (2017). Executive Functions Do Not Mediate Prospective Relations between Indices of Physical Activity and Academic Performance: The Active Smarter Kids (ASK) Study. *Frontiers in Psychology, 8*(1088). doi:10.3389/fpsyg.2017.01088

Paper V

Aadland, K. N., Aadland, E., Andersen, J.R., Lervåg, A., Moe, V.F., Resaland, G. K., & Ommundsen, Y. (Submitted). Does self-regulation mediate the relationship between school-based physical activity and academic performance in numeracy in ten-year-old children? The Active Smarter Kids (ASK) Study.

ABBREVIATIONS

ANCOVA	analysis of covariance
ASK	Active Smarter Kids
BDNF	brain-derived neurotropic factor
BMI	body mass index
CBRS	Child Behavior Rating Scale
CFI	Comparative Fit Index
CI	confidence interval
CONSORT	the Consolidated Standard of Reporting Trials
cpm	counts per minute
cRCT	cluster randomized controlled study
ERP	event-related brain potential
ES	effect size
FIML	full maximum likelihood estimation
fMRI	functional magnetic resonance imaging
ICC	intraclass correlation coefficient
IGF-1	insulin-like growth factor 1
KTK	Körperkoordinationtest für Kinder
Movement ABC-2	Movement Assessment Battery for Children -2
MRI	magnetic resonance imaging
MVPA	moderate-to-vigorous physical activity
NDET	the Norwegian Directorate for Education and Training
RCT	randomized controlled study
RMSEA	Root Mean Squared Error of Proximation
SD	standard deviation
SED	sedentary time
SEM	structural equation modeling
SRMR	Standardized Root Mean Squared Residual
TMT-b	the Trail Making Test part B
VEGF	vascular endothelial growth factor
VO_{2max}	maximal oxygen consumption
VO_{2peak}	peak oxygen consumption
WISC-IV	Wechsler Intelligence Scale for Children, fourth edition

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INTRODUCTION

Participation in physical activity during childhood is important for healthy development, both physically (Poitras et al., 2016) and mentally (Lubans et al., 2016). It is recommended that children participate in at least 60 minutes of daily physical activity of moderate and vigorous intensity, which should stimulate among others aerobic fitness and motor skills (Helsedirektoratet, 2014; WHO, 2010). Development of such skills is important, as both aerobic fitness and motor skill proficiency are shown to be important for later participation in physical activity (Barnett, Van Beurden, Morgan, Brooks, & Beard, 2009; Castelli & Valley, 2007).

A growing body of evidence suggests that children derive cognitive benefits from participating in physical activity, and those experiences in physical activity are shown to affect many elements of physical and cognitive growth, from brain structure to academic performance (Donnelly et al., 2016; Mura, Vellante, Nardi, Machado, & Carta, 2015; Singh, Uijtdewilligen, Twisk, van Mechelen, & Chinapaw, 2012; Vazou, Pesce, Lakes, & Smiley-Oyen, 2016). Schools influence children from an early age and offer superior settings for providing children with opportunities to engage in physical activity (Diamond & Lee, 2011). Few studies with sufficient statistical power have investigated the effects of physical activity interventions incorporated into the public schools' curricula, on executive function and academic performance (Donnelly et al., 2016).

The main aim of this thesis was to investigate the relationships between the indices of physical activity to executive function and academic performance, and further examine if the potential effects of physical activity on academic performance were mediated by improvements in executive function. The term "indices of physical activity" is used as a generic term for physical activity, aerobic fitness, and motor skills. This thesis is part of the ***Active Smarter Kids study (ASK)***, a multicomponent cluster randomized controlled trial (cRCT), investigating the effect of daily physical activity on academic performance as a main outcome. The study also included several secondary outcomes, such as executive function, lifestyle-related risk factors related to non-communicable diseases, quality of life, and a qualitative section investigating embodied experiences of physical activity (Resaland et al., 2015). Therefore, this thesis is overcoming some of the limitations in the current evidence base by using a cRCT with a large representative sample (n = 1129) of fifth grade children from the Sogn og Fjordane county in Norway, to answer the research questions posed. The included papers provide results from different designs and report cross-sectional associations, prospective associations, and effects of a cRCT.

I will start this introduction with a brief description of important terms. I will thereafter sum up the current evidence and research gaps for the relationships between the indices of physical activity to executive function and academic performance, and finally, present my research questions.

Conceptualizing indices of physical activity, executive function, and academic performance

Physical activity is often defined as “any bodily movement produced by skeletal muscles that results in energy expenditure” (Caspersen, Powell, & Christenson, 1985, p. 126). Within the field of physical activity and cognition, there is a growing interest in the mental benefit of physical activity. A distinction within this field exists, which emphasizes the characteristics of the physical activity concerning: (a) the overall amount of physical activity (the dose), defined in terms of intensity, frequency, and duration, and (b) the type of physical activity performed, such as the motor complexity and context of physical activity (Pesce, 2012; Tomporowski, McCullick, Pendleton, & Pesce, 2015). Furthermore, the research field is concerned with the effects of both acute and chronic physical activity (Tomporowski et al., 2015). The term “acute” physical activity is used for a short single bout of physical activity (typically 10–40 minutes), whereas “chronic” physical activity is used for multiple physical activity sessions over longer periods (often between 6 and 30 weeks) (Tomporowski, Lambourne, & Okumura, 2011; Verburgh, Konigs, Scherder, & Oosterlaan, 2013).

Physical activity is multifaceted and is a complex behavior to assess, and there is no clear best practice. Many studies use self-report instruments, which are subject to measurement error, as it is difficult for a person to accurately recall movement details from the past (Corder, Ekelund, Steele, Wareham, & Brage, 2008). Accelerometry is the most used objective method to assess physical activity in children (Corder et al., 2008). An accelerometer is a small lightweight instrument most often worn at the hip, which quantifies the bodily movement over a longer period (most often seven days), as it measures acceleration of the body, reported as the arbitrary unit “counts”. The counts are translated into an estimate of physical activity intensity (Corder et al., 2008), such as for example time in moderate-to-vigorous physical activity (MVPA). However, the cut-points used to translate the counts into minutes of physical activities of different intensities vary across studies, which affects study comparability (Cain, Sallis, Conway, Van Dyck, & Calhoon, 2013). This variability among studies also relates to other data reduction algorithms, including the epoch length (the number of seconds over which accelerometer data are summarized), rules for non-wear time (determination of when the accelerometer has been removed), criterion for hours per day to constitute a valid day, and criterion for days to constitute a valid measurement (Cain et al., 2013), which further complicates comparison among studies.

As a distinct dimension of physical activity, sedentary behavior can be defined as “any waking behavior characterized by an energy expenditure ≤ 1.5 metabolic equivalents while in a sitting, reclining, or lying posture” (Tremblay et al., 2017, p. 540).

Physical fitness can be defined as “a set of attributes that are either health- or skill-related” (Caspersen et al., 1985, p. 126), and these are attributes that a person has or achieves. The components of physical fitness can be related to health, such as aerobic fitness (also termed cardiorespiratory fitness), muscular strength, body composition, and flexibility, or the components can be related to athletic ability (Caspersen et al., 1985). This thesis addresses the particular components of physical fitness, aerobic fitness and motor skills.

Aerobic fitness is “the overall capacity of the cardiovascular and respiratory systems and the ability to carry out prolonged strenuous exercise” (Ortega, Ruiz, Castillo, & Sjostrom, 2008, p. 2). Direct measurement of maximal oxygen consumption (VO_{2max}) during a graded maximal exercise test to exhaustion is generally considered the gold standard indicator of aerobic fitness (Shephard et al., 1968). However, in large-scale studies, obtaining VO_{2max} is very time-consuming and therefore not feasible. Indirect methods, such as for example the 20-m shuttle run test (Leger, Mercier, Gadoury, & Lambert, 1988) or the Andersen test (Andersen, Andersen, Andersen, & Anderssen, 2008) are therefore frequently used. The scores from these indirect tests can be used to estimate VO_{2max} (Aadland, Terum, Mamen, Andersen, & Resaland, 2014; Andersen et al., 2008; Ortega et al., 2008). Performance on these tests has obvious face validity, and the Andersen test has shown superior performance as an indicator of metabolic health compared to VO_{2max} (Aadland, Kvalheim, Rajalahti, Skrede, & Resaland, 2017). In contrast to measurement of physical activity, which expresses a highly variable behavior within an individual over days, aerobic fitness expresses an attribute that are fairly stable over a long period of time (Ekelund et al., 2007).

Motor skills can be defined as “learned sequences of movement that are combined to produce a smooth, efficient action in order to master a particular task” (van der Fels et al., 2015, p. 697). Therefore, motor skills are not only the movements; they also includes cognitive processes involved in generating movements (Cameron, Cottone, Murrah, & Grissmer, 2016). “Motor skills” is a broad term that can include, gross motor skills (e.g., running, jumping, and agility), fine motor skills (e.g., dexterity), bilateral body coordination (whole body coordination tasks), and object control (e.g., aiming and catching) (van der Fels et al., 2015). Motor skills can be assessed with several standardized test batteries, such as the Movement Assessment Battery for Children -2 (Movement ABC) (Henderson, Sugden, & Barnett, 2007) or the Körperkoordinationtest für Kinder (KTK) (Kiphard & Schilling, 2007).

Executive function can be defined as “the cognitive processes necessary for goal-directed cognition and behavior” (Best, 2010, p. 331), with fundamental functions generally defined to involve inhibition, working memory, and cognitive flexibility. These functions are described as moderately correlated with each other, but separable in adults, referred to as the unity and the diversity of executive functions (Friedman & Miyake, 2017; Miyake et al., 2000). In children, age-related differences in the contribution of inhibition, working memory, and cognitive flexibility have been observed (Brocki & Bohlin, 2004; Huizinga, Dolan, & van der Molen, 2006; Lee, Bull, & Ho, 2013; Lehto, Juujarvi, Kooistra, & Pulkkinen, 2003; St Clair-Thompson & Gathercole, 2006), indicating that executive functions become more differentiated as childhood progresses. Inhibition improves the most during the preschool years, while both working memory and cognitive flexibility improve the most later (Best, Miller, & Jones, 2009). Executive functions are linked to frontal lobe activity (Etnier & Chang, 2009), or more specifically, the prefrontal cortex, due to its coordinating role across diverse brain areas (Friedman & Miyake, 2017).

Inhibitory control involves the ability to “control one’s attention, behavior, thoughts, and/or emotions, to override a strong internal predisposition or external lure” (Diamond, 2013, p. 19.3). Two aspects of inhibitory control are inhibitory control of attention (interference control) and self-control (controlling behavior, such as, to stay on-task). Complex response inhibition requires working memory (Best & Miller, 2010). Inhibitory control can be assessed using laboratory tasks, where an individual is not supposed to react to the prepotent stimuli. Examples of such tasks are the Stroop test (Golden, 1978; Lezak, Howieson, Bigler, & Tranel, 2012) and modified versions of the Eriksen flanker task (Pontifex, Saliba, Raine, Picchietti, & Hillman, 2013). In the Stroop test, the printed words (name of colors written in incongruent colors) serve as prepotent stimuli (you want to read the words); however, the task is to name the color of the ink. This task results in a slower response, as well as more errors (Lezak et al., 2012). Working memory involves “holding information in mind and mentally working with it” (Diamond, 2013, p. 19.8) over brief periods of time (Best et al., 2009). The simplest working memory test is Digits Backward, which tests how many bits of information an individual can hold in mind and manipulate by repeating a sequence of numbers in reverse order (Lezak et al., 2012). Cognitive flexibility involves the ability to change perspectives, being flexible to adjust to changing demands, and take advantage of sudden, unexpected opportunities. Furthermore, cognitive flexibility overlaps with creativity, task switching, and set shifting (Diamond, 2013). The process of cognitive flexibility is dependent of working memory and inhibitory control (Best & Miller, 2010). Cognitive flexibility can be assessed using verbal fluency tasks where an individual is asked to name as many words as possible that start with a given letter (phonemic fluency) or name words within a category, for example, animals (semantic fluency) (Lezak et al., 2012). Furthermore, for example, the Trail Making Test (TMT) measures the mental set shifts, where an individual must alternate between two different tasks (Lezak et al., 2012). A challenge with all the measurements of executive function is the task-impurity problem (Best & Miller, 2010; Cassidy, 2016; Friedman & Miyake, 2017; Miyake et al., 2000). As the executive functions control lower level cognitive processes during tasks of executive function, these nonexecutive processes will be included in the measurements.

An overview of the concept of executive function, how the aspects of executive function are interrelated, as well as relevant related terms to executive function is provided by Diamond (2013) and shown in figure 1. As can be seen from the figure, self-regulation overlaps with inhibitory control. Self-regulation is a comprehensive construct that involves the ability to regulate cognition, behaviors, and emotions (von Suchodoletz et al., 2013). The relationship between executive functions and self-regulation is described as bidirectional, where executive functions are psychological abilities that contribute to self-regulation, and where the executive functions are dependent on self-regulation through their control of attention and arousal (Blair, 2016). Taking advantage of the theoretical modeling by Diamond (2013) (figure 1) a primary goal of this thesis is to examine the relationships between the indices of physical activity to executive functions and academic performance, treating executive function as a cognitive outcome as well as a cognitive mediator in the relationship between indices of physical activity and academic performance. Further, taken into consideration that self-regulation also comprises behavioral self-regulation (represented by the behavior in the classroom) and emotional self-regulation (represented by school related well-being) a secondary purpose was to examine these two assets as well as mediators.

Academic performance can broadly represent all factors that are important for school success, such as cognitive skills and attitudes, academic behavior, and academic achievement (Rasberry et al., 2011). As the cognitive skills are represented by executive functions, and academic behavior by behavioral-self regulation in this thesis, academic performance is equal to the academic achievement, representing standardized test scores in subject areas, such as mathematics, reading, and language. Consequently, academic performance reflects a global measure of processing (Tomporowski et al., 2011).

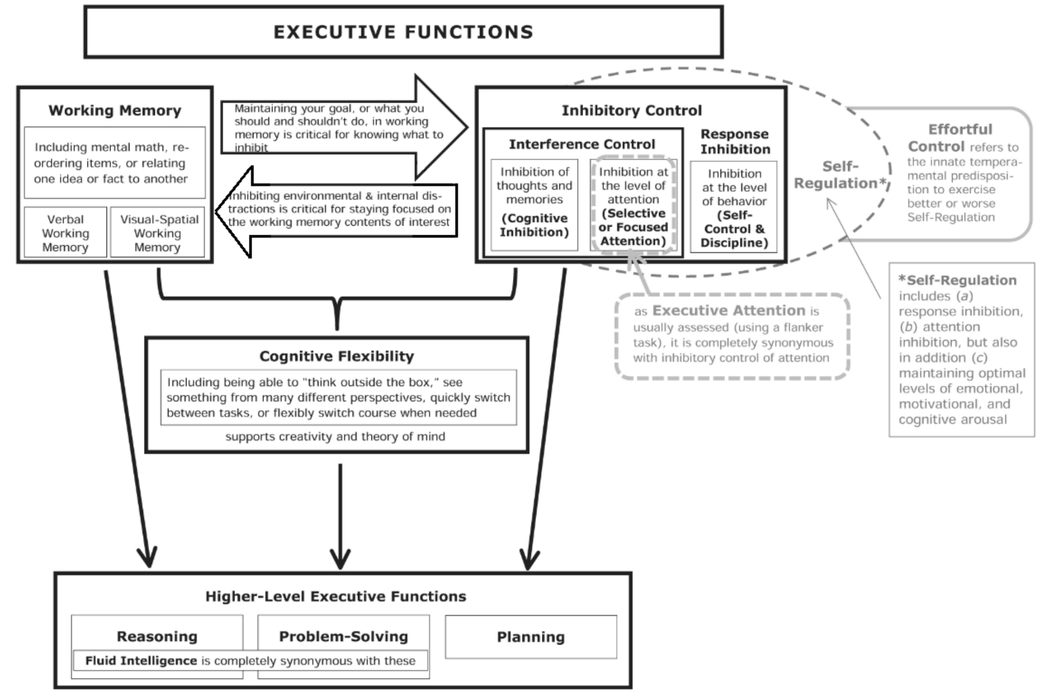


Figure 1. Diamond's concept of executive function and it's relation to self-regulation. Adapted from Diamond (2013, p. 19.18).

Linking physical activity to executive function and academic performance – theoretical models

The brain's plasticity and complex intertwined networks of several important substrates enable a host of mechanisms in which physical activity can affect executive function and academic performance. Although research has mainly been examining the effects of either acute or chronic physical activity on cognitive outcomes, their effects are integrated (Pesce, 2009). The theoretical models presented in this section will be linked to cognitive outcomes in general and not explicitly to executive function or academic performance. However, the largest effects of physical activity on cognitive outcomes are proposed to be selective to tasks requiring executive function, often termed the executive function hypothesis (Barenberg, Berse, & Dutke, 2011; Colcombe & Kramer, 2003). Changes in these executive functions from physical activity are suggested to underlie improvements in academic performance (Donnelly et al., 2016; Howie & Pate, 2012; Tomporowski et al., 2015). Importantly, the presented theoretical explanatory models are not mutually exclusive (Voss, 2016).

Acute physical activity theories

Within cognitive psychological theories, a prevailing assumption is that physical activity acts as a stressor that affects cognition in the same way as other stressors, such as anxiety (McMorris, 2016b). Stress can be considered as "an intervening variable, referring to a state of unacceptable divergences between perceived demands and capabilities to adapt" (Sanders, 1983 p. 62). Stress and arousal are both concepts referring to the energy mobilization of the organism. In **arousal theories**, stress and arousal are related to each other in a U-function. Here, the optimal level of arousal results in low stress, while both arousal which is too low and too high, lead to increased stress. This is based on the Yerkes-Dodson inverted-U function of the relationship between arousal and performance (figure 2a). However, the classical study by Yerkes and Dodson (1908) also revealed that the task difficulty was of importance for the relationship; in simple tasks, the relationship between arousal and performance might be linear (figure 2b) (Diamond, Campbell, Park, Halonen, & Zoladz, 2007).

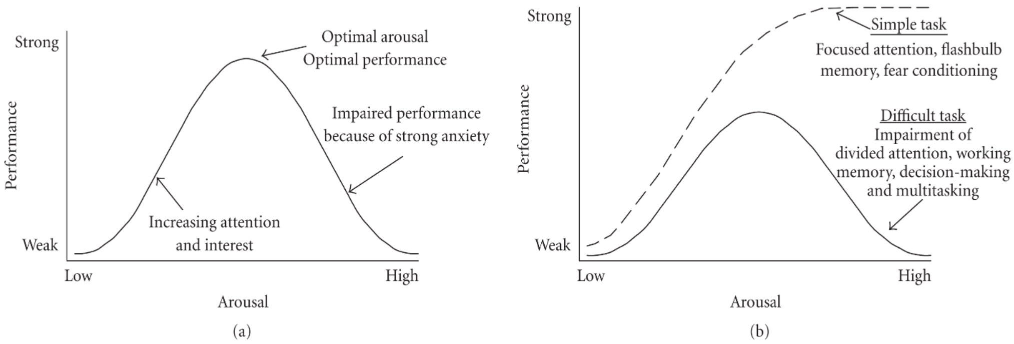
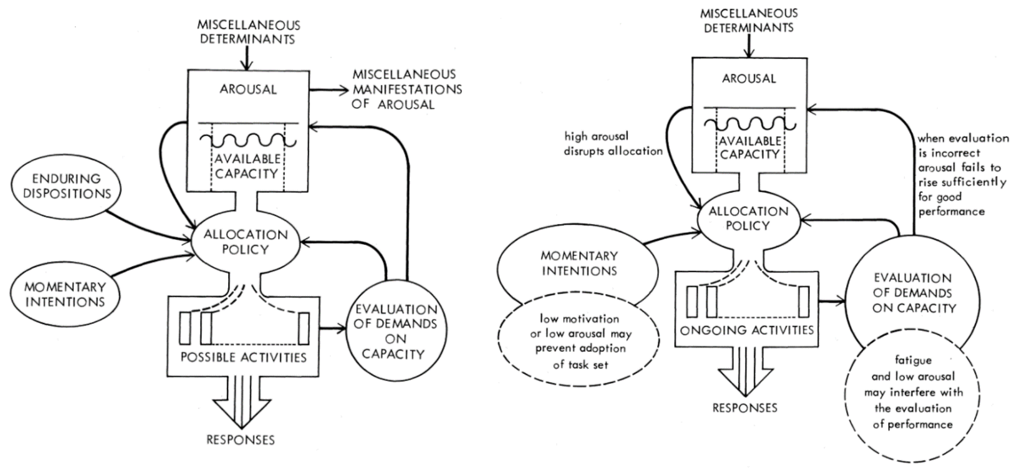


Figure 2. The Yerkes-Dodson law where (a) shows the commonly represented version and (b) the original version. Adapted from Diamond et al. (2007, p. 3).

Providing a rationale for the inverted U relationship for arousal and performance, Easterbrook (1959) claimed that when arousal increases, the focus of attention becomes narrower. Therefore, irrelevant cues are excluded up to an optimal level of arousal, resulting in improved performance, and above the optimal level, relevant cues are excluded, resulting in poorer performance. Transferred to the effect of acute physical activity on cognitive performance, physical activity of moderate intensity is hypothesized to induce the optimal level of arousal and consequently improved cognitive performance. However, for simple cognitive tasks, physical activity of higher intensity might be needed to induce the optimal level of arousal.

The cognitive energetic theories, also termed **allocatable resources theories**, combine arousal theories with information processing models (Hockey, 1997). One of the major conceptual frameworks for human information processing is resource-driven models. In these models, task performance is dependent on: (a) the amount of available resources, (b) the resources required to perform a task, and (c) the amount of resources allocated to the different processes involved in the task (Audiffren, 2009). Examples of such capacity models are the models by Kahneman (1973), Sanders (1983), and Hockey (1997).

Kahneman (1973) presented a capacity model for attention, which assumes that there is a general limit on the capacity to perform mental work (figure 3). In this model, the amount of available resources is determined by the level of arousal, which again is determined by both the demands imposed by the activity an individual engages in and the different sources of arousal (e.g., acute physical activity or anxiety) (termed miscellaneous sources). More capacity is available when the arousal is moderately high than when arousal is low. If an individual engages in activities that requires higher capacity than available, the performance on the task will be reduced or fail. Two reasons for failed performance are: (1) there is not enough capacity to meet the demands, and (2) the available capacity is channeled to other tasks by the allocation policy. The model also includes a feedback mechanism (the evaluation of demands), which regulates the arousal to a sufficient level to meet the demands of the ongoing activities. By using Kahneman's model, it is hypothesized that acute physical activity can increase the available resources, by inducing increased physiological arousal. If, however, the mental workload required to perform the physical activity is too high, the physical activity can impair cognitive performance, due to the interference between the tasks (Audiffren, 2009). This interference can be introduced by both a high intensity of the physical activity and the complexity of the physical activity, such as cognitive and motor demands.



(a) (b)

Figure 3. Kahneman's capacity model for attention (a). Adapted from Kahneman (1973, p.10), with effects of high and low arousal in attention and performance (b). Adapted from Kahneman (1973, p. 30).

Advancing the capacity model by Kahneman, the model by Sanders (1983) suggests that the available resources are provided not only through arousal, but also through activation and effort (figure 4). In Sanders' model, arousal is seen as readiness to process input, and activation as a motor readiness to respond. The effort mechanism controls and coordinates the arousal and activation, and is responsible for selecting a response (McMorris, 2016b). According to Sanders' model, acute physical activity can increase both arousal and activation, which results in altered input and output processing, respectively. Furthermore, the physical activity can affect the decisional processes through the effort mechanism (Audiffren, 2009). Hockey's model (1997) focuses on the management of effort from the individuals to control the effectiveness of task behavior under stress. This model includes two levels of control: (1) the automatic control of well-learned skills, which often requires no active regulation or effort (loop A), and (2) an effort-based compensatory control mechanism, which maintains performance under disturbance of stressors (Loop B). The action monitor compares the target outcomes with the current outcomes and adjusts the resources allocation if a discrepancy is detected. If a discrepancy exists, Hockey suggests that this can be solved through increased allocated resources or downregulation of the task goal and outcome (Hockey, 1997). Therefore, physical activity that competes with the cognitive tasks for resources and effort will result in a shift to an easier strategy (Audiffren, 2009).

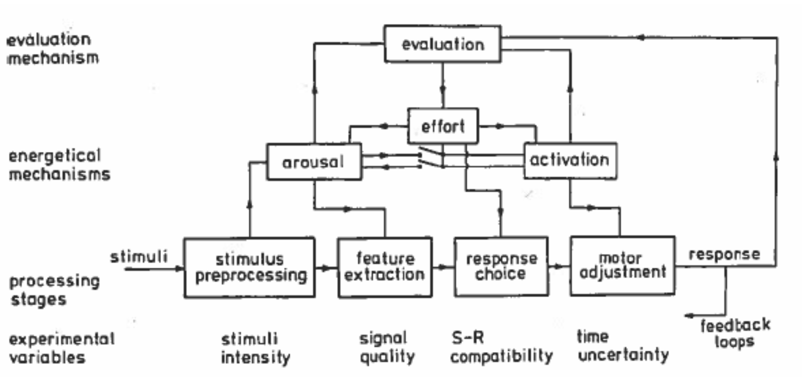


Figure 4. Sander's cognitive-energetical model. Adapted from Sanders (1983, p. 79).

It has been suggested that the stress induced by acute physical activity results in diverse physiological changes in the brain, which, due to the blood-brain barrier, are difficult to directly assess in humans. Therefore, much research is founded on animal studies or investigation of plasma concentration in humans which, at best, estimates the concentrations in the brain (McMorris, Turner, Hale, & Sproule, 2016). **The catecholamines hypothesis** states that during physical activity, the hypothalamus and brain stem activates the sympathoadrenal system (a part of the automatic nervous system), which releases catecholamines (McMorris, 2009; McMorris & Hale, 2012). Important catecholamines are noradrenaline (norepinephrine), dopamine, 5-HT (serotonin), and adrenaline (epinephrine), which function as neurotransmitters in the brain. The intensity of the physical activity might be important, as low intensity can inhibit cognitive performance due to limited activation in brain areas, and intensity which is too high can result in high concentrations of neurotransmitters imposing neural noise, and in turn, decreased cognitive performance (McMorris, 2009; McMorris & Hale, 2012).

Acute physical activity also results in an activation of the hypothalamic-pituitary-adrenal axis by the hypothalamus, which ends in synthesis and secretion of the stress hormone cortisol. Under moderate stress, cortisol controls arousal. However, when stress becomes high, cortisol is no longer able to control arousal, and the individual becomes over-aroused (McMorris, 2009). Consequently, when the intensity of the physical activity is high, or the duration is long, the cortisol concentration becomes high, which has negative effects on cognition (McMorris et al., 2016).

Chronic physical activity theories

Best (2010) promoted three pathways by which chronic physical activity can affect executive function: (a) through the cognitive effort required to perform complex motor tasks (the motor skill hypothesis), (b) through the cognitive demands inherent in engaging physical activities and group games, and (c) through physiological changes in the brain resulting from any type of aerobic physical activity.

The cardiovascular (aerobic) fitness hypothesis proposes that the effects of chronic physical activity on cognitive outcomes work through an increase in aerobic fitness (Colcombe & Kramer, 2003; Etnier, Shih, & Piepmeier, 2016; Schmidt, Jager, Egger, Roebers, & Conzelmann, 2015; Voss, 2016). Following this theory, Barenberg et al. (2011) suggested that a certain intensity level of physical activity might be needed to affect executive function. Moderate-to-vigorous physical activity can improve aerobic fitness (Armstrong, Tomkinson, & Ekelund, 2011), and may, therefore, be of importance. As a result, studies have manipulated the dose of physical activity, trying to reveal a dose-response relationship between physical activity and cognition. While the cardiovascular fitness hypothesis suggests that the strain of physical activity is important in affecting cognition, **the hypothesis regarding the type of physical activity** emphasize the cognitive or coordinative demands inherent in the physical activity (Pesce, 2012). **The cognitive demands** inherent in physical activities can be enhanced by, for example, performing group activities or coordinative demands. Group activities require social interaction, such as cooperation, anticipation of the behavior of both teammates and opponents, and adaptation to an ever-changing environment. As these physical activities require the use of goal-directed behaviors, similar to goal-directed behaviors in executive function tasks, it has been hypothesized that such skills acquired during physical activity can transfer to tasks of executive function (Best, 2010; Tomporowski et al., 2011).

The motor skills hypothesis suggests that activities that require motor coordination stimulates brain structures that are also important in performing cognitive tasks (Best, 2010; Voss, 2016). The cerebellum, which sub serve motor function, and the prefrontal cortex, which is important for executive function, are closely interrelated (Diamond, 2000). This interrelation is shown by: (1) the co-activation of the prefrontal cortex, the cerebellum, and the basal ganglia during several motor and cognitive tasks, (2) their similar developmental timetable (Diamond, 2000), and (3) their common underlying processes, such as sequencing, monitoring, and planning (Roebers et al., 2014; van der Fels et al., 2015). The close interrelation between the cerebellum and the prefrontal cortex is also assumed within the framework of **embodied cognition**. In embodied cognition, no duality exists between the motor and cognitive functions. Here, thoughts are seen as an output of the motor system, to facilitate the development of motor programming and action control. This framework views the cerebellum, which does not differentiate between movement and thoughts, as the critical component (Koziol, Budding, & Chidekel, 2012).

Both (repetitive) aerobic and cognitively challenging chronic physical activity are suggested to facilitate **neuroplasticity** in certain brain structures, which in turn results in altered executive functions (Hotting & Roder, 2013). Neuroplasticity is "the capacity for the nervous system to modify its organization to altered demands and environments" (Bavelier & Neville, 2002 p. 443). The physiological mechanisms affected by different types of physical activity are suggested to be different (Best, 2010; Hotting & Roder, 2013), but all concern changes in neurotransmitters, neurothrophins, and vasculature. The mechanisms are difficult to investigate, as the effects of physical activity on the brain go through complex multi mediational chains.

Chronic physical activity is hypothesized to increase the concentration of neurotrophic factors, such as brain-derived neurotropic factor (BDNF), vascular endothelial growth factor (VEGF), and insulin-like growth factor 1 (IGF-1) (Cotman, Berchtold, & Christie, 2007; Hotting & Roder, 2013). These factors work together in modulating the effects of chronic physical activity on brain plasticity and function. BDNF and IGF-1 are hypothesized to be the most important in inducing effects of physical activity on learning (Cotman et al., 2007; McMorris, 2016a), while IGF-1 and VEGF are suggested to be important for neurogenesis (formation of new neurons) and angiogenesis (formation of new blood vessels) (Cotman et al., 2007). For neurogenesis, VEGF promotes proliferation, while BDNF promotes survival and incorporation into the neural architecture (Thomas, Dennis, Bandettini, & Johansen-Berg, 2012).

Chronic physical activity is, furthermore, suggested to facilitate synaptic plasticity in the hippocampus, through an increase in synaptic proteins and increased dendrite density (Cotman et al., 2007; van Praag, 2009), underlying learning, and memory (Gomez-Pinilla & Hillman, 2013). In addition, increased angiogenesis, that can result in changed blood flow and overall oxygen and nutrition supply, is suggested as an effect of chronic physical activity (Cotman et al., 2007; Hotting & Roder, 2013; van Praag, 2009).

Integrated effects of acute and chronic physical activity on cognition

Pesce (2009) modeled how the effects of acute and chronic physical activity on cognitive outcomes are integrated (figure 5). This model considers the importance of moderator variables, such as individual constraints (physical fitness, motor coordination skills, and cognitive expertise) and task constraints (physical activity intensity, physical activity complexity, and cognitive tasks complexity) when explaining the effects of acute physical activity on cognitive performance. Participation in chronic physical activity can affect all the individual constraints, linking chronic physical activity to the relationship between acute physical activity and cognition.

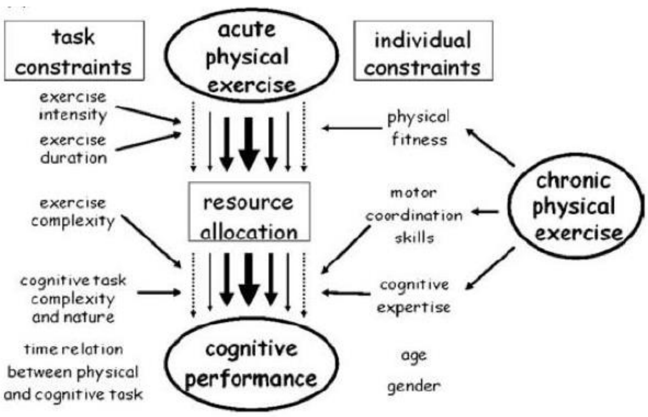


Figure 5. Pesce's integrated model of acute and chronic physical activity. Schematic representation of the effects of individual and task constraints on the acute exercise-cognition relation, with particular reference to the individual constraints deriving from chronic exercise: errors represent the relations hypothesized in the literature. Adapted from Pesce (2009, p. 216).

Examining relationships between indices of physical activity, executive function, and academic performance - a mediation framework

Changes in executive function induced by physical activity are proposed as mechanisms for improved academic performance (Donnelly et al., 2016; Howie & Pate, 2012; Tomporowski et al., 2015). For example, Howie and Pate (2012) hypothesized a model for the causal links in their systematic review, where cognitive function (herein executive function) acts as a mediator in the relationship between physical activity and academic performance. A mediator can be defined as "a variable that is in a causal sequence between two variables" (MacKinnon, Fairchild, & Fritz, 2007, p. 2). Despite a rapid increase in the number of studies investigating the relationship of physical activity to executive function and academic performance, most evidence is cross-sectional and only investigates single links. To my knowledge, only the cross-sectional study by Rigoli, Piek, Kane, and Oosterlaan (2012) has tested a mediation model. They found that motor coordination (aiming and catching) had an impact on academic performance through working memory in adolescents. Although not directly testing a mediation model, Roebers et al. (2014) found that executive function was an important factor in explaining the link between fine motor skills and academic performance, as the observed link between fine motor skills and later school performance, was no longer significant when executive function was added to the model.

An illustration of the mediating approach for the variables of interest in this thesis is shown in figure 6. In this simple mediation model, *a* represents the relationship between the indices of physical activity and change in executive function, and *b* represents the relationship between change in executive function and change in academic performance. The indirect effect of physical activity on change in academic performance through change in executive function is quantified as the product of *a* x *b* (*ab*), and a mediation exists if this product is significant. The *c'* represents the relationship of physical activity to change in academic performance adjusted for change in executive function (the direct effect) (Hayes, 2009; Little, 2013; MacKinnon et al., 2007).

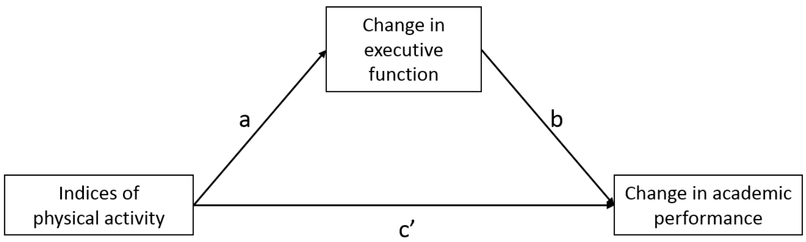


Figure 6. An illustration of the relationship between physical activity, executive function, and academic performance in a mediation framework.

Baron and Kenny (1986) proposed a causal steps approach to test the effects of intervening variables. However, the view of the causal steps approach has been criticized (Cerin & MacKinnon, 2009; Hayes, 2009). One criticism is that there needs to be a direct relationship between the independent variable and the outcome. Hayes (2009) emphasizes that if you do not examine indirect effects due to absence of a direct effect, important mechanisms can be overlooked. It is possible for indirect effects to exist, despite no direct effect (Cerin & MacKinnon, 2009; Hayes, 2009).

To claim mediation, it is necessary to show that change in academic performance is a result of change in executive function. Therefore, a true test of mediation needs to be performed on longitudinal data (Cole & Maxwell, 2003; Little, 2013) with more than two measurement time points for the mediators and the outcome variables (Maric, Wiers, & Prins, 2012). Including two measurement time points, termed a half-longitudinal design (Cole & Maxwell, 2003; Little, 2013), has a large advantage over cross-sectional mediation analysis, as it can control for prior levels in the mediator and the outcome variables. However, in such a model, an important assumption is made: that the relationship between *a* and *b* (measured at the same time point) would have been the same if several measurement points were available (Cole & Maxwell, 2003; Little, 2013). Additionally, within a randomized controlled trial (RCT) design, only two measurement time points (baseline- and follow-up measures) are often available. For mediation analysis within a RCT with two measurement time points, the analysis of covariance (ANCOVA) is recommended (Valente & MacKinnon, 2017).

Evidence for the links in the mediation model

Providing an overview of the evidence for the links between indices of physical activity and executive function and academic performance is a challenging task. The relationships are examined using a broad range of outcome variables within different settings. I will ,therefore, first present evidence from laboratory studies (or very controlled settings) that have high internal validity. Evidence from studies conducted within the school setting, having higher external validity, is presented second. In accordance with the view that the effects of participation in acute and chronic physical activity are integrated, both types of studies will be presented. For each link presented, I have related the different indices of physical activity (i.e., measures of physical activity, aerobic fitness, and motor skills) to the outcome.

The indices of physical activity and executive function link

In children, weak evidence exists for positive effects of acute physical activity on **attention** (Janssen, Toussaint, van Mechelen, & Verhagen, 2014; Tine & Butler, 2012). Measures of brain function, such as event-related brain potentials (ERPs), provides information about underlying cognitive operations during information processing, as they assess the brain activation that occurs between the stimulus engagement and the response execution (Hillman, Erickson, & Kramer, 2008; Hillman, Kamijo, & Scudder, 2011; Khan & Hillman, 2014). Findings from such studies have shown that acute physical activity of moderate intensity has advantageous effects on neuroelectric indices expressing cognitive capacity to allocate attentional resources (for example, the amplitude of the P3 [also called P300 or P3b]) (Drollette et al., 2014; Hillman, Buck, Themanson, Pontifex, & Castelli, 2009; Pontifex et al., 2013). The effect of acute physical activity on attention is shown to be most beneficial for children with lower cognitive control (Drollette et al., 2014). Furthermore, the effects on attention were selective to the most demanding executive function tasks (incongruent tasks) (Hillman, Pontifex, et al., 2009), suggesting that the positive effects on attention may underlie the positive effects of acute physical activity on core **executive functions** (Chen, Yan, Yin, Pan, & Chang, 2014; Hillman, Pontifex, et al., 2009). The effects of acute physical activity on executive functions are described as moderate (effect size (ES) = 0.52) (Verburgh et al., 2013). Effects on inhibition are found following bouts of walking at moderate intensity (Drollette, Shishido, Pontifex, & Hillman, 2012; Hillman, Pontifex, et al., 2009), jogging in groups (Chen et al., 2014), and cognitively engaging and playful forms of physical activity (Jager, Schmidt, Conzelmann, & Roebers, 2014), compared to resting control conditions. These effects are shown to persist for somewhere between 20 to 40 minutes after completion of acute physical activity (Hillman, Pontifex, et al., 2009; Jager et al., 2014). In addition to the effect on inhibition, Chen et al. (2014) also found effects of jogging on working memory and cognitive flexibility, effects that were not present following the cognitively engaging and playful forms of physical activity in the study by Jager et al. (2014). Another study found no intervention effects on the core executive functions following three different acute physical activity conditions, physical activity games, aerobic physical activity, and cognitive games, compared to a control condition (Jager, Schmidt, Conzelmann, & Roebers, 2015).

For chronic physical activity, the meta-analysis by Vazou et al. (2016) found a positive moderate effect (ES = 0.46) of physical activity interventions on measures of cognitive functions in children (only two studies) and adolescents. However, the overall effect was derived from studies using different types of physical activity, such as aerobic physical activity, cognitively engaging physical activity, and coordinative demanding physical activity. Cross-sectional studies using objective measures of physical activity have shown associations between MVPA and attention (Booth et al., 2013; Syvaoja, Tammelin, Ahonen, Kankaanpaa, & Kantomaa, 2014). One of these, also found that MVPA was associated with attention two years later (Booth et al., 2013).

The evidence for changes in **brain structure,** due to participation in chronic physical activity in children, is scarce. Chronic effects of physical activity on brain structure are indicated by cross-sectional research using magnetic resonance imaging (MRI), revealing that children with higher aerobic fitness (≥ 70th percentile VO_{2max}) have larger volumes of the basal ganglia and hippocampus, which are structures in the brain important for executive control and memory, respectively

(Chaddock, Erickson, Prakash, Kim, et al., 2010; Chaddock, Erickson, Prakash, VanPatter, et al., 2010), compared to children with lower aerobic fitness (≤ 30th percentile VO_{2max}). Higher aerobic fitness has also been associated with greater white matter integrity, which might indicate faster conduction of neural signals in regions important for executive function (Chaddock-Heyman, Erickson, et al., 2014).

The chronic effects of physical activity on **brain function** are demonstrated by research using ERP, revealing that children with higher aerobic fitness allocate greater attentional resources and have faster processing speeds compared to their lesser fit peers (Hillman, Buck, et al., 2009; Hillman, Castelli, & Buck, 2005; Khan & Hillman, 2014; Pontifex et al., 2011). These findings reflect increased inhibitory and working memory capacities (Chaddock, Pontifex, Hillman, & Kramer, 2011). Functional MRI (fMRI) studies, extend these ERP studies, as they provide images of brain function through proxies, such as blood flow response, detecting activated networks (Khan & Hillman, 2014; Voss, 2016). Such studies have shown that children with higher aerobic fitness, compared to lesser fit peers, are better able to modulate activation of neural networks, such as the prefrontal cortex, involved in performing executive function tasks (Chaddock-Heyman, Hillman, Cohen, & Kramer, 2014; Chaddock, Erickson, et al., 2012; Khan & Hillman, 2014; Voss et al., 2011). Possible explanations for the association between aerobic fitness and activation in the prefrontal cortex might be that aerobic fitness is associated with better oxygen transport and metabolism in the brain, in turn supporting more efficient function of neurotransmitters and neural circuits in this region (Voss, 2016).

For motor skills, inconsistent relationships to executive function are described across domains of motor skills and across reviews. The systematic review by van der Fels et al. (2015) concluded that there is strong evidence for no relationship between gross motor skills and bilateral body coordination and executive function, and insufficient evidence for the relationship between object control and executive function. Two other reviews, however, have found a positive relationship between motor skills and executive function in typically developing children (Cameron et al., 2016; Haapala, 2013). Furthermore, a recent cross-sectional study showed that gross motor skills and tests of cognitive functions were correlated (Geertsen et al., 2016).

Randomized controlled physical activity interventions conducted as afterschool programs have revealed benefits of physical activity on behavioral measures of executive functions coupled with both ERP and fMRI measures (Chaddock-Heyman et al., 2013; Davis et al., 2011; Hillman et al., 2014; Kamijo et al., 2011; Krafft et al., 2014; Monti, Hillman, & Cohen, 2012; Schaeffer et al., 2014). These studies also provide some evidence for a dose-response relationship between physical activity and executive function (Davis et al., 2011; Hillman et al., 2014). Although these interventions all included physical activity games with social interaction and motor skill execution, effects of the intervention beyond the physical activity dose were not directly addressed. Studies investigating the effects of cognitive and coordinative demands of physical activities have revealed that such an approach is viable to affect executive function (Crova et al., 2014; Gallotta et al., 2015; Pesce et al., 2013; Pesce et al., 2016; Schmidt et al., 2015). These studies have mainly manipulated the content of children's physical education programs, and are therefore presented later.

The indices of physical activity and academic performance link

Effects of acute physical activity have been observed for reading comprehension (Hillman, Pontifex, et al., 2009; Pontifex et al., 2013) and mathematic performance (Pontifex et al., 2013) following moderate intensity physical activity compared to a seated control condition. Using different intensities of physical activity (50 and 75% of heart rate reserve), Duncan & Johnson (2014) found that physical activity improved spelling, irrespective of intensity, that only moderate intensity physical activity improved reading, and that both intensities resulted in lower mathematics scores compared to a control condition.

The evidence for a relationship between chronic physical activity and academic performance is considered weaker than for cognitive outcomes, and studies report mixed findings (Donnelly et al., 2016). Results from cross-sectional studies using objective measures of physical activity show inconsistent associations with academic performance (Booth et al., 2014; Esteban-Cornejo et al., 2014; Hansen, Herrmann, Lambourne, Lee, & Donnelly, 2014; Kwak et al., 2009; Lambourne et al., 2013; LeBlanc et al., 2012; Syvaoja et al., 2013). Longitudinally, Booth et al. (2014) have shown that MVPA at the age of 11 generally predicted academic performance two and five years later. For sedentary time, the type of behavior seems important for its relationship to academic performance. While screen time is shown to be negatively associated with academic performance, non-screen time is shown to be positively associated with academic performance (Carson et al., 2015; Corder et al., 2015; Esteban-Cornejo, Martinez-Gomez, et al., 2015; Syvaoja et al., 2014). Unfortunately, objective measures cannot separate screen and non-screen sedentary time.

For aerobic fitness, the majority of cross-sectional studies supports a positive association with academic performance (Castelli, Hillman, Buck, & Erwin, 2007; de Greeff et al., 2014; Donnelly et al., 2016; Eveland-Sayers, Farley, Fuller, Morgan, & Caputo, 2009; Hansen et al., 2014; Rauner, Walters, Avery, & Wanser, 2013; Van Dusen, Kelder, Kohl, Ranjit, & Perry, 2011; Wittberg, Cottrell, Davis, & Northrup, 2010). Some have found a dose-response relationship (Van Dusen et al., 2011), where the slope between aerobic fitness and academic performance plateaus at a certain level of aerobic fitness (Hansen et al., 2014). The cross-sectional study by Lambourne et al. (2013) provides some evidence for the aerobic fitness hypothesis, as physical activity was partly indirectly related to academic performance in mathematics via aerobic fitness. Following up on the cross-sectional evidence for an effect of physical activity on brain function, Hillman et al. (2012) suggest that the P3 in ERP measures may be a neuroelectric biomarker for academic performance, as the P3 amplitude accounted for unique variance in reading and mathematics performance in their study. Moreover, more fit children are shown to have more mature brain structures that are linked to better performance in mathematics, compared to lesser fit children (Chaddock-Heyman et al., 2015). However, a longitudinal study, did not find an association between aerobic fitness and academic performance one and two years later (Haapala et al., 2014).

The evidence is insufficient to determine the relationship of motor skills to academic performance (van der Fels et al., 2015). Supporting an unclear relationship, two recent studies showed inconsistent findings, with a positive association between gross motor skills and mathematics and reading (Geertsen et al., 2016), and no association between agility and academic performance (Fernandes et al., 2016). Poorer motor skills have been associated with poorer reading and mathematics longitudinally (Haapala et al., 2014).

The executive function and academic performance link

Executive function is important for learning, and its relevance for academic performance is empirically documented (Barenberg et al., 2011; Best, Miller, & Naglieri, 2011; Bull & Lee, 2014; Bull & Scerif, 2001; Cantin, Gnaedinger, Gallaway, Hesson-McInnis, & Hund, 2016; St Clair-Thompson & Gathercole, 2006). Mathematics and reading are both complex skills that have been suggested to reflect executive function-skills such as selecting and coordinating several executive function components (Best et al., 2011). Even though the content in mathematics and reading is very different, their patterns of correlations to executive function across age are similar (Best et al., 2011). This similarity indicates that the same cognitive processes are important to both reading and math.

Effect(s) of school-based physical activity interventions on executive function and academic performance

The evidence summarized so far has provided important knowledge of the relationship between the indices of physical activity to executive function and academic performance in children outside the school setting. However, the transfer of these findings to how physical activity affects performance at school is challenging. Evidence from the school setting provides more direct real-world implications for the effects of acute and chronic physical activity on executive function and academic performance. These studies, therefore, inform strategies for integrating physical activity during the busy school day.

Several studies have investigated the effects of **short physical activity breaks** in the classroom during academic lessons on on-task behavior, attention, and information processing (Budde, Voelcker-Rehage, Pietrassyk-Kendziorra, Ribeiro, & Tidow, 2008; Carlson et al., 2015; Ma, Le Mare, & Gurd, 2014, 2015; van den Berg et al., 2016). These acute effects may be a prerequisite to learning and consequently academic performance. Different approaches are shown effective, where four minutes of high-intensity physical activity reduced off-task behavior (Ma et al., 2014) and improved attention (Ma et al., 2015), and 10 minutes of bilateral coordination tasks improved selective attention (Budde et al., 2008), compared to control conditions. Furthermore, teacher implemented rate of physical activity breaks of 10 minutes during one school year, has been associated with increased MVPA and teacher-reported on-task and attentive behavior (Carlson et al., 2015). However, the study of van den Berg et al. (2016) found no effects for neither 12 minutes of aerobic physical activity, coordinative physical activity, or strength training on attention and information processing in 10–13-year-old children.

Others have integrated **short bouts of physical activity with academic content** and shown improved on-task behavior (Grieco, Jowers, Errisuriz, & Bartholomew, 2016; Mahar et al., 2006), or a prevention of the reduction in on-task behavior evident in sedentary educational lessons (Bartholomew & Jowers, 2011; Grieco, Jowers, & Bartholomew, 2009). Interestingly, Grieco et al. (2016) found that the intervention games performed while sedentary also affected the amount of time for on-task behavior by not showing a decrease in on-task behavior, as observed in the control condition. However, both low-to-moderate and moderate-to-vigorous intensity of physical activity improved the on-task behavior, suggesting that the physical activity itself (and not just the shift in activity) is important for on-task behavior. The effects of acute bouts of physical activity on on-task performance are shown to be most beneficial for those children least on-task (Ma et al., 2014;

Mahar, 2011; Mahar et al., 2006). Furthermore, the *Physical Activity Across the Curriculum* cRCT found effects of two daily 10-minute bouts of physical activity integrated into the academic instruction over three years on children's academic performance, compared to control children (Donnelly et al., 2009). However, as the study was unpowered for that outcome, a new cRCT *Academic Achievement and Physical Activity Across the Curriculum*, defining academic performance as the main outcome was conducted. This study found no effects on academic performance after three years of intervention, which is possibly explained by an insufficient dose, as the children received 45 minutes/week less physical activity than prescribed (Donnelly et al., 2017).

Other studies have provided children with **physically active educational lessons**, included in the curricula over one or more school years. *The Encouraging Activity to Stimulate Young (EASY) Minds* cRCT investigated the effect of movement-based learning in the mathematics program of three lessons (60 minutes) per week for six weeks (Riley, Lubans, Holmes, & Morgan, 2016). Children participating in the intervention had increased overall physical activity during the school day and in the mathematics lessons and increased on-task behavior compared to the control children. However, no intervention effect was observed for mathematics performance. In *the Fit & Vaardig op School* cRCT, physically active educational lessons with a focus on repetition of academic content were provided three times a week (20–30 minutes) for 22 weeks each year over two years. Children in the intervention schools did not have improved executive function (de Greeff et al., 2016) or reading scores, but had significantly greater gains in mathematics and spelling compared to control schoolchildren (Mullender-Wijnsma et al., 2016). Similarly, Erwin, Fedewa, & Ahn (2013) found improved mathematics and reading performance after 20 weeks of 20+ minutes of physical activity in academic lessons with academic content compared to control. Comparing the effects of two interventions of mathematical teaching incorporated with fine motor or gross motor activity to a control condition (three lessons at 60 min per week), the cRCT by Beck et al. (2016) found a greater improvement in mathematics performance in children participating in the fine motor intervention immediately after the sex-week intervention. However, no significant effects of the interventions were present eight weeks after the intervention. Furthermore, the study suggested that the effect of the intervention on mathematics worked through improved gross motor skills and working memory, though they emphasized shortcomings in their statistical approach.

Several studies have investigated effects on executive function and academic performance by manipulating **physical education.** Concerning the dose of physical education, *the Childhood Health, Activity, and Motor Performance School Study Denmark* quasi-experimental study, which tripled the dose to 270 minutes per week of physical education, did not yield significant differences in academic performance across the intervention and control schoolchildren over a period of two to six years (Bugge et al., 2017). However, the intensity in physical education may be of importance, as *the EDUcation for FITness* RCT found that only the intervention of highest intensity resulted in improved cognitive performance and academic performance after four months with increased physical education (Ardoy et al., 2014).

Others have investigated the effect of manipulating the cognitive demands of the activities in physical education (or physical activity) on executive function and academic performance. By using an approach involving two different single bouts of physical education, Pesce, Crova, Cereatti, Casella, and Bellucci (2009) revealed that both team games and aerobic circuit training facilitated memory storage, but that only the team game physical education also affected immediate recall. For chronic physical activity, studies have shown that cognitive demands may have effects beyond improvements in aerobic fitness. Schmidt et al. (2015) investigated the effect of two interventions differing in cognitive engagement (high: team games; low: aerobic exercise) to a control condition, on executive function over a period of six weeks. Although both interventions increased the aerobic fitness, only the team game intervention improved executive function. Corresponding to this finding, the quasi-experimental study by van der Niet et al. (2016) found effects on executive function following a five-month physical activity program during recess (30 minutes, twice a week) including both aerobic exercise and cognitively engaging physical activities on executive function. Children participating in the intervention showed greater improvements in inhibition and working memory compared to the control group children, without an improvement in physical fitness.

The effect of cognitively demanding physical activities might vary due to individual constraints. Pesce et al. (2013) found that typically developing children obtained better scores on attention by means of cognitively demanding physical education, whereas children with motor impairment gained more from physical education without the cognitive demands. Furthermore, Crova et al. (2014) observed superior effects on inhibition in overweight children compared to their lean peers following a physical education intervention with enhanced cognitive demands. Supporting the importance of the cognitive demands, and adding evidence for the importance of motor skill demands, Pesce et al. (2016) revealed larger effects of a six-month playful coordinative and cognitive enriched physical education program on motor coordination and inhibition compared to traditional physical education. The cRCT by Gallotta et al. (2015) compared the effects of two five-month interventions (traditional physical activity and coordinative physical activity) to a control (no physical activity) on attention in normal weight and overweight/obese children. Children, irrespective of weight status, showed higher levels of attention in both physical activity interventions, compared to the children in the control group, with superior improvement in children participating in the coordinative physical activity intervention.

Some studies have investigated the efficiency of a multicomponent physical activity intervention. *The Action schools! BC* intervention study aimed to provide children at intervention schools with 150 minutes of physical activity per week, through physical activity opportunities across six action zones: school environment, extracurricular, family and community, school spirit, scheduled physical education, and classroom physical activity (Ahamed et al., 2007). This study found that a daily dedication of 10 minutes to physical activity did not decrease the intervention children's academic performance compared to the control children. Since comparing studies across different educational systems is challenging, results from multicomponent studies from Scandinavian countries are of special relevance. *The LCoMotion-Learning, Cognition and Motion* cRCT, investigated the efficiency of an intervention including physical activity in academic subjects, scheduled physical activity during recess, physical activity homework, and active transportation (only a short period), together comprising 60 minutes of physical activity each school day in 12–14-year-old Danish adolescents (Tarp et al., 2016). They found no effects on executive function and math performance, possibly explained by the low implementation fidelity. In Norway, *Aktiv skole* implemented physically active educational lessons, physically active breaks, and physical active homework adding 195 minutes of physical activity to the mandatory 135 minutes per week (Kvalø, Bru, Brønnick, & Dyrstad, 2017). Similar to the Danish study, the study failed to find significant effects on executive function. Accordingly, there are no multicomponent interventions that have been able to show an effect of physical activity on executive function and academic performance.

Research gap

As evident from the literature review above, great diversity in methodology and outcome measures makes it difficult to draw conclusions about the relationships between the indices of physical activity and executive function and academic performance. The current evidence base has certain limitations, as the majority of studies are cross-sectional, few studies are adequately statistically powered, many studies have used self-reported measures of physical activity levels, and there are large variations in sample characteristics (Donnelly et al., 2016; Howie & Pate, 2012; Singh et al., 2012). Furthermore, physical activity interventions in the school setting have shown promise for physically active academic lessons (both of short bouts and whole lessons) to improve academic performance. These studies also shows large variances in sample size, intervention duration, implementation, the theoretical framework used, and outcomes; additionally, few studies are RCTs (Martin & Murtagh, 2017; Norris, Shelton, Dunsmuir, Duke-Williams, & Stamatakis, 2015). Consequently, there is a lack of trials investigating the effectiveness of physical activity interventions, that are incorporated into the school curricula, on executive function and academic performance.

Studies assessing the independent relationships between the indices of physical activity to executive function and academic performance while also examining the relationship between executive function and academic performance are lacking (Haapala, 2013; Khan & Hillman, 2014). Although aerobic fitness arguably is a direct measure of the physiological strain induced by MVPA, these parameters represent different constructs. Physical activity is a behavior, whereas aerobic fitness is a personal attribute with a genetic component (Rowland, 2005; Schutte, Nederend, Hudziak, Bartels, & de Geus, 2016), meaning that it is important to determine their independent relationships with executive function and academic performance. Examination of the genuine relationship between motor skills performance and individual aspects of executive functions are also important to clarify. Moreover, research is needed to better understand physiological and motor-cognitive assets embedded in various forms of physical activity that may help explain the relationship to executive function and academic performance (Best 2010; Donnelly et al., 2016; Tomporowski et al., 2015). As some previous studies have failed to account for confounding factors in their examinations (Donnelly et al., 2016), there is a need for studies that examine the relationship between the indices of physical activity and executive functions and academic performance, adjusting for factors such as age, body fat, pubertal status, and socio-economic status.

As evident in the literature overview presented previously, few studies have examined the prospective relationship between the indices of physical activity to both executive functions and academic performance. Such an approach gives opportunities to also examine if executive function mediates the relationship between the indices of physical activity and academic performance, which is a much-operationalized hypothesis in the literature.

Finally, there exists no clear pattern between the level and type of physical activity and specific subjects such as mathematics, reading, or spelling (Donnelly et al., 2016). Therefore, more research is needed to explore the relationship between level and type of physical activity and specific subjects.

Aims and research questions

The overall aim of this thesis was to investigate the relationship between the indices of physical activity to executive function and academic performance, and to examine if executive function mediated the relationship between physical activity and academic performance. The papers included in the thesis provide results from different designs, reporting cross-sectional associations, prospective associations, and effects from a cRCT. More specifically, this thesis aims to answer the following research questions:

1) What are the relationship between objectively measured physical activity and executive function and academic performance?
    a. What are the cross-sectional **(paper I)** and prospective **(paper IV)** associations between physical activity and executive function and academic performance?
    b. How does the ASK school-based physical activity intervention affect executive functions and academic performance? **(papers II and III)**
2) Does executive function mediate the relationship between objectively measured physical activity and academic performance?
    a. Does executive function mediate the prospective relationship between physical activity and academic performance? **(paper IV)**
    b. Do executive function, behavioral self-regulation, or school related well-being mediate the effect of the ASK intervention on numeracy in the lower third performing children in numeracy? **(paper V)**
3) What are the relationships between aerobic fitness and motor skills and executive function and academic performance?
    a. What are the cross-sectional **(paper I)** and prospective **(paper IV)** associations between aerobic fitness and motor skills to executive function and academic performance?
    b. Does executive function mediate the prospective relationship between aerobic fitness and motor skills to academic performance? **(paper IV)**

MATERIALS AND METHODS

Overall design, study sample, and data collection

The ASK study (Resaland et al., 2015) was a parallel group (intervention group vs. control group, 1:1 ratio) cRCT conducted in Sogn og Fjordane county, Norway, between August 2014 and June 2015 (figure 7). The unit of randomization was the participating schools, with randomization performed by a neutral third party (Centre of Clinical Research, Haukeland University Hospital, Norway).

We invited all sixty schools in the county that fulfilled the inclusion criteria of at least seven fifth-grade children enrolled. All schools, encompassing 1202 fifth-grade children, agreed to participate (figure 8). Three schools (one control school and two intervention schools) from the same municipality dropped out of the study following randomization. In total, 1145 of the 1175 invited children from 57 schools agreed to participate, 82.1% of the population of 10-year-olds in the county. Valid data were provided from 1129 children, who received allocated intervention. Seven children moved out of the area before follow-up.

Figure 7. The Sogn og Fjordane county.

Two periods of data collection were administered. The baseline assessments were conducted in mid-August to mid-October 2013, and follow-up assessments were conducted in mid-April to mid-June 2014. The accelerometer data were collected in mid-April to mid-June 2014 (baseline) and 2015 (follow-up).

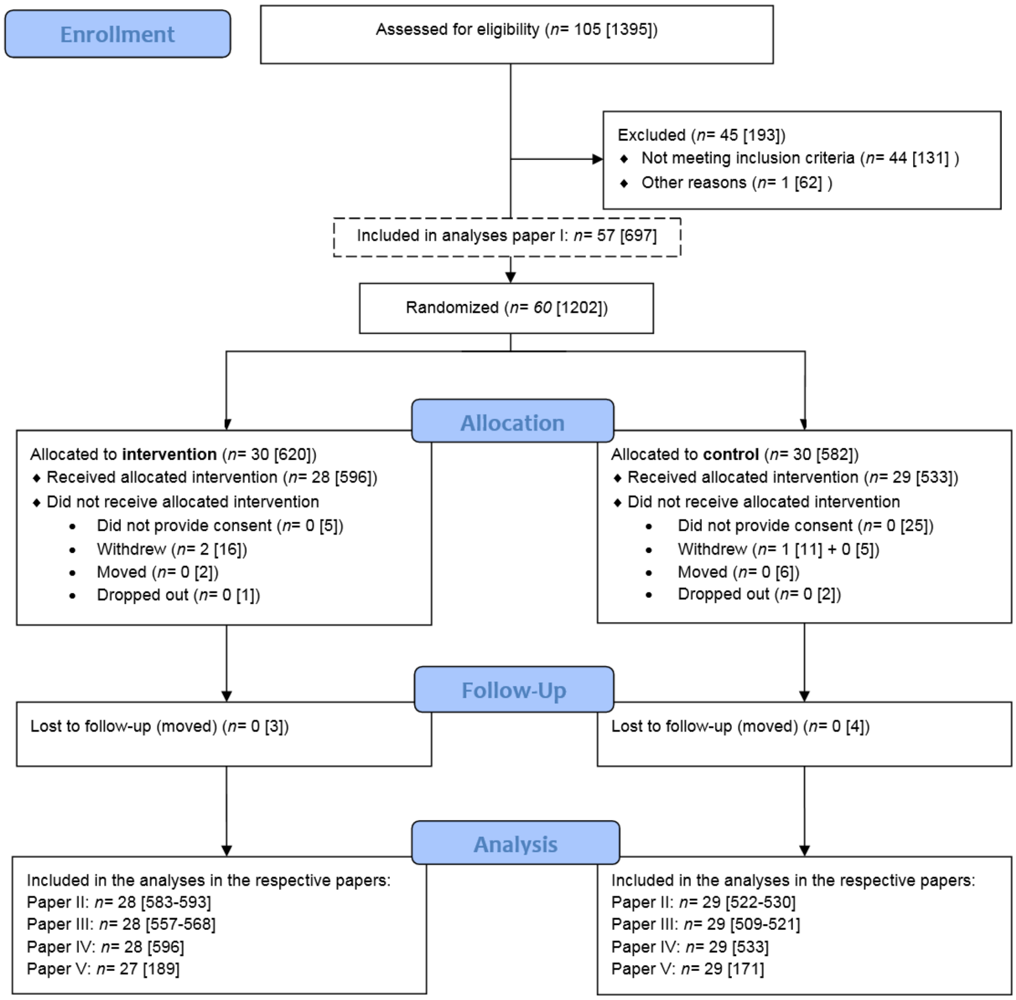


Figure 8. Flow chart of the recruitment process and overview of included children in each paper of the thesis (school [children]).

The intervention program

The ASK intervention was a part of the mandatory school curriculum for all children attending the intervention schools. It was led by the classroom teachers and consisted of three components, generating an additional 165 minutes/week of physical activity: (1) physically active educational lessons (3 x 30 minutes/week) in the subjects Norwegian, mathematics, and English, (2) physical activity breaks during classroom lessons (5 minutes/school day), and (3) physical activity homework

(10 minutes/school day) (figure 9). The research group developed the intervention in collaboration with teachers at the intervention schools. Our aim was to create a number of varied physical activity activities that could be carried out in small groups and which encouraged an inclusive and joyful learning environment (see www.askstudy.no for examples of physical activity activities). Two of the three intervention components, the physical activity educational lessons and the physical activity homework, incorporated academic learning tasks in the physical activity (e.g., rope jumping while spelling English vocabulary words), adding cognitive load to the activity. Approximately 25% of the daily physical activity in the ASK intervention was intended to be of vigorous intensity. This was defined as “children would be sweating and out of breath.” Intervention schools were provided with equipment for use in the intervention activities and the children received a skipping rope and a tennis ball for physical activity homework. To ensure that the teachers were empowered, supported, and qualified to deliver the ASK intervention, we conducted three instructional seminars ahead of the start of the study for the teachers at the intervention schools. Additionally, we provided two regional refresher sessions during the intervention period. Finally, we provided teachers in the intervention schools with email- and telephone-support, as well as a password-protected homepage (www.askstudy.no) that supplied teachers with information, videos, and physical activity lessons.

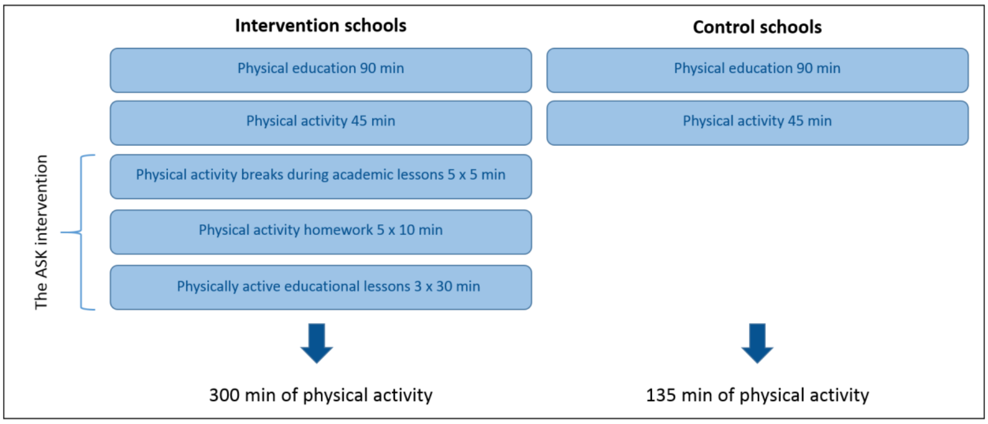


Figure 9. The ASK intervention model with minutes per week for the different components.

Children from both intervention schools and control schools participated in national curriculum-prescribed 90 minutes/week of physical education and 45 minutes/week of physical activity (total 135 minutes/week). It was specified to the control schools that they should carry out the amount of physical activity and physical education that they would have done, regardless of the ASK study.

Ethics

The procedures and methods used in the ASK trial conformed to the ethical guidelines of the World Medical Association´s Declaration of Helsinki and its subsequent revisions (WMA, 2013). The study protocol was approved by the Regional Committee for Medical and Health Research Ethics South East (appendix). We obtained written informed consent from each child´s parent(s) or guardian(s) prior to entry into the study.

Measures

Anthropometry, pubertal status, and socio-economic status

Body mass (weight, kg) was measured using an electronic scale (Seca 899, SECA GmbH, Hamburg, Germany) with children wearing light clothing. Stature (height, cm) was measured with portable Seca 217 (SECA GmbH, Hamburg, Germany) stadiometers. We calculated body mass index ($kg \cdot m^{-2}$) as weight (kg) divided by the height squared (m^2). Body fat was measured using four skinfold thickness sites (biceps, triceps, subscapular, and suprailiac) using a Harpenden skinfold caliper (Bull; British Indicators Ltd., West Sussex, England) according to the criteria described by Lohman, Roche and Martorell (1991). The Harpenden skinfold caliper has been tested for validity and reliability in children (Yeung & Hui, 2010). Children self-assessed their pubertal stage with the Tanner method (Tanner, 1962) using a scale of colored images proposed by Carel and Leger (2008). We used breast and genital development for girls and boys, respectively. Socio-economic status (defined as the highest education level obtained by the mother or father) (Sirin, 2005) was reported by the parents or guardians.

Physical activity and sedentary time

Physical activity and sedentary time were measured by Actigraph accelerometers (ActiGraph GT3X+, LLC, Pensacola, Florida, USA), which are being widely applied and extensively tested for validity and reliability in children and youth (De Vries et al., 2009). The children were instructed to wear the accelerometer on the right hip over seven consecutive days at all times, except during water activities or while sleeping. Our criterion for a valid day was a wear-time of ≥ 480 minutes/day accumulated between the hours of 06:00 and 24:00; a wear-time of ≥ 180 minutes/day accumulated between the hours of 09:00 and 14:00 was the criterion for a valid school day. Periods of ≥ 20 minutes of zero counts were defined as non-wear time (Esliger, Copeland, Barnes, & Tremblay, 2005). A total of ≥ 4 (out of 7) days and ≥ 3 (out of 5) school days were applied as criteria for a valid measurement. The outcomes for physical activity were total physical activity level (average counts/minutes) (papers I–IV), percent (papers I and IV) and minutes per day (papers II and III) of MVPA (cut-point 2296 counts per minute (cpm)) and sedentary time (0–100 cpm) (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008; Trost, Loprinzi, Moore, & Pfeiffer, 2011). All analyses were performed using data accumulated over 10-second epochs. We analyzed all accelerometry data using Kinesoft analytical software (http://kinesoft.org/).

Adherence to the protocol for physical activity

Teachers reported total activity for all three intervention components (physical activity educational lessons, physical activity breaks, and physical activity homework) and compulsory physical activity lessons and physical education on a weekly basis using a pre-defined survey (papers II and III).

Aerobic fitness

Aerobic fitness was measured with an intermittent practical running field test (the Andersen-test (Aadland et al., 2014; Andersen et al., 2008)). The Andersen-test was administered according to standard procedures. The children were tested indoors on a wooden or rubber floor in groups of 10–20 children. The test was performed over 10 minutes. The children ran in a to-and-fro movement from one end line to another (20 m apart) in an intermittent manner, with 15-s work periods and 15-s breaks (standing still) for a total duration of 10 minutes. The distance covered was the outcome for the analysis and was recorded by adult test assistants who counted for one or two children each. Prior to testing, we provided all teachers a video demonstrating the Andersen-test, which they were asked to show the children. Furthermore, the children performed approximately 5 minutes of warm-up to familiarize themselves with the test, after the test was explained and demonstrated by the test-leader. To enable comparing of aerobic fitness level across studies, VO_{2peak} was calculated using the equation suggested by Aadland et al. (2014).

Motor skills

Motor skills were measured using a battery of three tests: (1) Catching with One Hand (Catching); (2) Throwing at a Wall Target (Aiming); and (3) Shuttle Run, 10 x 5 metres. Tests 1 and 2 constituted the subgroup Aiming and Catching from the Movement Assessment Battery for Children 2 (Movement ABC-2), age band 3 (11–16 years) (Henderson et al., 2007), and test 3 came from the Eurofit test battery (Council of Europe, 1993). In accordance with the standard testing procedure for the Movement ABC-2, the children performed five practice attempts in each task (1 and 2) before testing. No practice was given prior to the Shuttle Run test (3). A composite score of motor skills is used in paper I (all variables standardized by sex) and paper II (standardized individual scores), whereas single scores are used in paper IV.

Executive function

We measured key executive functions identified by Miyake et al. (2000): inhibition, working memory, and cognitive flexibility, by using four pen and paper tests. The tests were administered individually in a quiet room at the children´s schools, during the school day, with the guidance of trained research assistants and in accordance with the standard instructions. The four tests were completed in 15–20 minutes.

Inhibition was assessed with (1) the Stroop Color and Word Test (Golden, 1978). This test has three trials: (a) reading the color names printed in black ink, (b) naming the color of the ink (red, blue, and green) printed with four X's (XXXX), and (c) naming of the colors of printed words rather than reading the words (incongruent trial). The scoring criterion is number of items read or named in 45 seconds (Lezak et al., 2012). To assess cognitive flexibility, we used one verbal (Verbal Fluency) and one non-verbal test (the TMT (see 4)). In (2) the Verbal Fluency test, the children were asked to name as many animals as possible in 60 seconds. The score was the total number of animals listed (Spreen & Strauss, 1998). Working memory was assessed with (3) a Digit Span test (both Digits Forward and Backward) from the Wechsler Intelligence Scale for Children, fourth ed. (WISC-IV) (Wechsler, 2003). Both tests consist of pairs of random numbers of an increasing sequence length, which the test leader read aloud at the rate of one number per second. In the forward task, the children were asked to repeat each sequence exactly as it was given, and in the backward task, they were asked to repeat the sequence back in reverse order (Lezak et al., 2012). The scores were the number of correct repeated sequences for both the forward and backward task and in total. (4) The TMT was given in two parts. In Part A, the children were instructed to draw a line to connect consecutively numbered circles as fast as possible without lifting the pencil from the paper. In Part B, they were instructed to alternate between consecutively numbered and lettered circles (Lezak et al., 2012; Spreen & Strauss, 1998). We used the Reitan scoring method for the TMT, where we noted the errors as they occurred so that the children completed the task without errors (Reitan & Wolfson, 2004). The score of this test was the total time required to complete each part.

All tests of executive functions are validated for use in children, and have been shown to be appropriate for measuring executive functions in 10-year-old children (Stroop (Peru, Faccioli, & Tassinari, 2006), Verbal Fluency (Ardila, Ostrosky-Solís, & Bernal, 2006; Riva, Nichelli, & Devoti, 2000), WISC-IV (Wechsler, 2003), and the Trail Making Test part B (TMT-b (Reitan & Wolfson, 2004)). Before testing, a licensed neuropsychologist educated researchers and their assistants in the construction of the test battery, testing procedures, and the theoretical underpinnings of executive function.

The single score for each test, as well as a composite score of the color word condition of the Stroop Color Word Test, the total verbal fluency score, the backward digit span of the WISC-IV, and TMT-b, were used in the analyses in paper I (standardized by sex before calculation of composite score) and paper II. In papers IV and V, a latent variable was composed of the color word condition of the Stroop Color Word Test, the backward digit span of the WISC-IV, and TMT-b.

Academic performance

Academic performance in numeracy, reading, and English was measured using specific standardized Norwegian national tests designed and administered by the Norwegian Directorate for Education and Training (NDET). The tests have shown evidence of good validity and reliability by NDET and are aligned with the competencies demanded from all schools by the national curriculum (Resaland et al., 2015). The numeracy test measured children's ability to understand numbers and measurements, and measured their skills in statistics. The reading test measured children's ability in basic Norwegian reading skills such as finding information in a text, interpreting, and understanding the text, and reflecting on and considering its form and content. The English test measured children's ability to find information and understand the main content and some details in simple texts. The three academic performance tests were conducted to map whether a children's achievements were in accordance with national curricular goals. The three different tests were administered on three different days at both baseline and follow-up. The numeracy test was computer-based, while the other two were paper and pencil tests. The children had 60 minutes to complete the English test and 90 minutes to complete the other two. The scores were reported as standardized points, with a mean of 50 and a standard deviation (SD) of 10. Standardized points on single tests were used in papers I, III, and IV, as well as a composite score in papers II and III. Paper IV used standardized points in numeracy only.

Behavioral self-regulation

We assessed behavioral self-regulation with the 10 items from the Child Behavior Rating Scale (CBRS) (Bronson, Goodson, Layzer, & Love, 1990), identified to describe child behavioral self-regulation in a classroom setting (Gestsdottir et al., 2014). Teachers were asked to rate children's classroom behavior on a five-point Likert scale ranging from 1 (never) to 5 (always) to indicate how frequently a given behavior occurred. The CBRS is a reliable and valid tool that has been used in multiple studies in Western countries (Lim, Rodger, & Brown, 2010; von Suchodoletz et al., 2013). A mean score of the CBRS was used for the descriptive statistics, and a latent behavioral self-regulation variable from the 10 items was used in the mediation analysis (paper V).

School related well-being

Quality of life was assessed by self-reporting using the Kidscreen-27 questionnaire (Ravens-Sieberer et al., 2007), which consists of 27 items covering the following five quality of life dimensions: (1) physical well-being (five items); (2) psychological well-being (seven items); (3) parent/guardians' relations & autonomy (seven items); (4) social support & peers (four items); and (5) school environment (five items). The Kidscreen-27 questionnaire has been validated in Norwegian children (JAndersen et al., 2015; Haraldstad, Christophersen, Eide, Nativg, & Helseth, 2011). For descriptive statistics, a T-score was obtained according to the developer's manual, where a mean of 50 and a SD of 10 define normality for children in Europe. A higher score indicates better school related well-being. For the mediation analysis, we composed a latent school related well-being variable from the four items concerning school environment (Questions: 1. "Have you been happy at school?" 2. "Have you got on well at school?" 3. "Have you been able to pay attention?" 4. "Have you got along well with your teachers?") (Paper V).

Power calculations

The study was designed to detect an ES (Cohen´s D) of 0.35 between the two groups for change in academic performance (main outcome). The ES was based on findings from previous studies (Sibley & Etnier, 2003). An intraclass correlation coefficient (ICC) of 0.15 (observed clustering of academic performance during the previous school year (2013–2014)) was applied to account for the cRCT design, leading to a design effect of 4.54. For further details, see Resaland et al. (2015).

Statistical analyses

The children's characteristics are provided as the means and SDs or frequencies.

Linear mixed model

Cross-sectional associations (paper I) and effects of the intervention (papers II and III) were determined using a linear mixed model, including the random intercept of school to account for the multilevel structure of the data.

The associations analyses (paper I) were performed in two steps: (1) Bivariate associations between the independent and dependent variables were determined using the Pearson correlation coefficient (r); (2) Multiple regression analyses were performed with executive functions and academic performance as dependent variables, including MVPA, sedentary time, aerobic fitness, and motor skills, as well covariates as independent variables. The covariates included were age, skinfold thickness, pubertal stage, birth weight, and socio-economic status, as they have been shown to affect the independent and dependent variables (Best & Miller, 2010; Davis & Cooper, 2011; Esteban-Cornejo, Tejero-Gonzalez, Sallis, & Veiga, 2015; Kalkut, Han, Lansing, Holdnack, & Delis, 2009; Kolle, Steene-Johannessen, Andersen, & Anderssen, 2010; London & Castrechini, 2011; Richards, Hardy, Kuh, & Wadsworth, 2001). To examine the role of sex as a moderator for the examined associations, the interaction between sex and all independent variables were included in the fully adjusted models. As significant interactions by sex were observed for aerobic fitness (aerobic fitness*sex) and motor skills (motor skills*sex), all analyses were conducted for girls and boys separately. A p-value < 0.10 was applied to indicate statistically significant interaction terms (Twisk, 2006). For ease of interpretation, all variables were standardized before the analysis; therefore, all results are reported as standardized regression coefficients.

Intervention effects (papers II and III) were analyzed using an intention-to-treat analysis, which included all children from whom we obtained baseline or final measures of executive functions (paper II) and academic performance (paper III). Missing data were imputed from relevant variables by means of multiple imputations using a Markov Chain Monte Carlo procedure. We also performed secondary (per protocol) analysis with schools that demonstrated high compliance with the protocol (intervention schools performing ≥ 80% of prescribed physical activity and control schools performing < 120% of curriculum prescribed physical activity (135 minutes/week of PA and physical education)). Effect estimates were derived from testing the main effects of group on change in executive functions (paper II) and academic performance (paper III), (dependent variables), while including group and baseline scores as independent variables. Accordingly, effects estimates are based on an ANCOVA model. We tested the between-group difference in change (T2–T1) in physical activity using minutes per day spent in sedentary time (papers II and III), low intensity physical activity (paper III), and MVPA (papers II and III), including baseline scores and change in wear time as covariates. Between-group differences in change in aerobic fitness and motor skills were also tested, including baseline scores as covariates (paper II). All effect estimates are reported as regression coefficients (β) and 95% confidence intervals (95% CI), along with p-values and the ICC for the cluster effect of schools.

Subgroup analyses were performed to assess the moderation effect of several variables in the intervention's effect on academic performance (paper III). Moderation effects for change in academic performance (dependent variable) were determined by testing a categorical subgroup*group interaction, after controlling for the main effects of group and subgroup. Variables in the model were academic performance (at T1; tertiles), sex, socio-economic status, and baseline school time physical activity and total physical activity level (total physical activity (cpm; tertiles), percent of sedentary time, percent of MVPA). For moderators other than academic performance, baseline academic performance was a covariate in the model.

All analyses in papers I–III were performed using the SPSS software, version 23 (IBM SPSS Statistics for Windows, Armonk, NY: IBM Corp., USA). A p-value of ≤ 0.05 was used as the level of statistical significance.

Structural Equation Modeling

Mediation analyses were conducted with structural equation modeling (SEM), with full information maximum likelihood estimation (FIML). A strength of SEM is the availability of global fit that can evaluate complex mediation models that involve a large number of linear equations, such as several mediators, potential confounders, or dependent variables (MacKinnon & Pirlott, 2015; Tomarken & Waller, 2005). It furthermore allows one to include both latent variables and observed variables. A latent variable is an underlying construct that cannot be directly observed, but is represented and estimated by a number of observed (measured) indicators (Kline, 2016; Little, 2013). Latent variables are corrected for bias attributable to random error and construct-irrelevant variance (Tomarken & Waller, 2005), and therefore improve the measurement of the construct (MacKinnon & Pirlott, 2015). We composed latent variables of all mediators: executive function (papers IV and V), behavioral self-regulation, and school related quality of life (paper V).

To estimate mediation in the prospective relationships (paper IV), the half-longitudinal mediation approach as explained by Cole & Maxwell (2003) and Little (2013), was used. As it is possible for a predictor to have an indirect effect on academic performance through executive function, without a direct effect between the two (Hayes, 2009), we tested the full mediation models and did not use the causal steps approach by Baron and Kenny (1986). We used seven predictor variables (cpm, MVPA, sedentary time, aerobic fitness, Shuttle Run, Aiming, and Catching) and three outcome variables (numeracy, reading, and English), resulting in 21 different mediation models. Each mediation model was conducted in two steps, advancing in complexity: (1) mediation models including covariates, by adding a regression from each covariate to all dependent and independent variables, and (2) mediation models examining sex-specific differences, by conducting a multi-group analysis (covariates included). The covariates included were age, sex, skinfold thickness, pubertal status, and socio-economic status, as they have been shown to affect the dependent and independent variables (Best & Miller, 2010; Davis & Cooper, 2011; Esteban-Cornejo, Tejero-Gonzalez, et al., 2015; Kalkut et al., 2009; Kolle et al., 2010; London & Castrechini, 2011). Furthermore, as we merged children from an intervention and a control group into one cohort, we also controlled for group allocation.

To estimate mediation of executive functions, behavioral self-regulation, and school related well-being in the cRCT design (paper V), the ANCOVA model recommended by Valente & MacKinnon (2017) was used. The ANCOVA model assesses change in the mediator and outcome variables, by including the baseline scores as covariates. Compared to other approaches, such as difference score, residualized change score, and cross-sectional models, the ANCOVA model provides the best mediated effect in terms of type 1 error rates, bias, confidence interval coverage, and power (Valente & MacKinnon, 2017). To reduce the complexity of the mediation model, we made five parcels from the 10 items in the CBRS. The parcels were composed by a balanced approach described by Little (2013), and as we had two measurement time points, we used the average loading across the time points to rank the items.

To account for children nested within schools, the complex command with robust maximum likelihood (MLR) estimator was used in all mediation analyses. A significant *ab* product indicated mediation. Several researchers argue for the use of bootstrap estimation of the indirect effect, as it considers their non-normal distribution (Little 2013) and constructs asymmetric confidence intervals for the indirect effect. In bootstrapping, resamples are constructed based on the original sample and new *a* and *b* are estimated on these data sets. The *ab* is calculated on the repeated bootstrap samples, and the confidence interval for the parameters are used to determine if the *ab* is significant. If the confidence interval produced from this procedure does not include zero, a mediation exists (Little, 2013; MacKinnon et al., 2007). However, the bootstrap command in Mplus does not allow for cluster, and therefore these results were seen as secondary and only performed in paper IV.

Multiple fit indices in addition to the chi-square test statistic, were used to assess model fit: the Comparative Fit Index (CFI), the Root Mean Squared Error of Approximation (RMSEA), and the Standardized Root Mean Squared Residual (SRMR). We used a non-significant χ^2, and the cutoff recommendations of CFI > 0.95, and RMSEA and SRMR < 0.05 as indications of good model fit to the data (Geiser, 2013).

Measurement invariance (metric and scalar) was tested for the latent variables across time (papers IV and V), sex (paper IV), and group (paper V). Criteria used to test differences between nested models (configural, metric, scalar) were ΔCFI of -0.010, ΔRMSEA of 0.015, and ΔSRMR of 0.010 (scalar) as recommended by Chen (2007) for sample size N > 300.

The analyses were implemented through the Mplus program, version 7.4 (Muthén and Muthén, 1998–2015). A p-value of ≤ 0.05 was used to indicate statistical significance in all analyses.

SUMMARY OF RESULTS

Children's characteristics

The characteristics of the children in the ASK study are shown in table 1. No statistical differences between the intervention and control schoolchildren were observed for any of the variables included in table 1 ($p \geq 0.153$) (see papers II and III for children's baseline characteristics per group).

Table 1. Baseline characteristics of the children as means and standard deviations (SDs) or frequencies.

	Girls		***Boys***		***Total***	
Variable	***n***	***M (SD)/ %***	***n***	***M (SD)/ %***	***N***	***M (SD)/ %***
Age (years)	541	10.2 (.3)	588	10.2 (.3)	1129	10.2 (.3)
BMI	531	18.1 (3.0)	564	18.0 (3.0)	1095	18.1 (3.0)
Skinfold thickness (mm)	527	58.4 (29.3)	557	42.2 (20.9)***	1084	50.1 (26.6)
Pubertal stage (Tanner) (%)	526		555		1081	
Stage 1	116	21.4	193	32.8***	309	27.4
Stage 2	345	63.8	303	51.5	648	57.4
Stage 3, 4 and 5	65	12.2	59	10.0	124	11.0
Socio-economic status (%)	511		558		1049	
≤ Upper secondary school	156	28.8	193	32.8	349	30.9
< 4 years of university/college	156	28.8	164	27.9	320	28.3
≥ 4 years of university/college	199	36.8	201	34.2	400	35.4
PA-levels (full day)						
Counts per minute (cpm)	484	691 (236)	521	773 (299)***	1005	733 (274)
SED (% all day)	484	60.2 (5.9)	522	59.5 (6.5)	1006	59.8 (6.2)
MVPA (% all day)	484	8.9 (2.7)	522	10.5 (3.5)***	1006	9.7 (3.3)
Aerobic fitness (m)	511	868.6 (85.8)	534	915.9 (112.6)***	1045	893.8 (103.1)
Estimated VO_{2peak} (ml/kg/min)	510	48.9 (6.9)	534	55.2 (7.3)	1044	52.3 (8.0)
Motor skills						
Shuttle Run (s)	527	23.6 (2.2)	556	22.7 (2.3)***	1083	23.1 (2.5)
Aiming (n)	532	3.8 (1.9)	561	4.2 (1.9)***	1093	4.0 (1.9)
Catching (n)	507	3.3 (2.9)	526	4.8 (3.1)***	1033	4.1 (3.1)
Executive function						
Stroop Color Word test (n)	525	26.6 (5.8)	563	25.1 (6.0)***	1088	25.8 (5.9)
Verbal Fluency (n)	528	16.0 (4.6)	567	16.0 (4.7)	1095	16.0 (4.6)
WISC-IV backward (n)	526	6.3 (1.4)	567	6.1 (1.3)**	1093	6.2 (1.3)
TMT-b (s)	512	114.9 (40.8)	529	128.6 (53.3)***	1051	121.9 (48.1)
Academic performance						
Numeracy	518	50.3 (8.9)	562	52.1 (9.9)***	1080	51.3 (9.5)
Reading	513	49.7 (9.4)	553	49.2 (10.0)	1066	49.4 (9.7)
English	515	48.6 (9.0)	547	50.1 (10.5)*	1062	49.4 (9.8)

Note: BMI = body mass index; PA = physical activity; SED = sedentary time; MVPA = moderate-to-vigorous physical activity; WISC-IV = Wechsler Intelligence Scale for Children fourth edition; TMT-b; Trail Making Test part B. * $p \leq .05$ for the difference between girls and boys; ** $p \leq .010$ for the difference between girls and boys; *** $p \leq .001$ for the difference between girls and boys.

Paper I: Associations

Relationships between physical activity, sedentary time, aerobic fitness, motor skills and executive function and academic performance in children.

Aadland, K.N., Moe, V.F, Aadland, E., Anderssen, S.A., Resaland, G.K. & Ommundsen, Y. (2017). *Mental Health and Physical Activity, 12, 10–18.*

AIM: To examine the independent associations of moderate-to-vigorous physical activity and sedentary time, aerobic fitness, and motor skills to executive function and academic performance in 10-year-old children.

RESULTS: Moderate-to-vigorous physical activity was not associated with any measures of executive function or academic performance in neither girls or boys when controlling for confounding factors (age, skinfold thickness, pubertal status, birthweight, and socio-economic status). Sedentary time was positively associated with WISC-IV backwards in girls, and with the Stroop Color Word Test, the TMT-b (inversed variable, as shorter time indicates better performance), the composite score of executive function, and performance in English in boys. For aerobic fitness, sex-specific associations emerged, where aerobic fitness was positively related to executive function and academic performance in boys only. Motor skills were positively associated with executive function in both girls and boys and with academic performance in girls (table 2).

Table 2. Independent associations between MVPA, sedentary time, aerobic fitness, and motor skills with executive functions (A) and academic performance (B) in girls and boys, adjusted for age, skinfold thickness, pubertal status, socio-economic status, and birth weight.

A)	Stroop CW	Verbal Fluency	WISC-IV B.	Trail Making B	Executive Function
	β [CI]	β [CI]	β [CI]	β [CI]	β [CI]
Girls (n = 357)					
MVPA	0.01 [-0.16, 0.18]	0.06 [-0.11, 0.23]	0.15 [-0.03, 0.32]	-0.03 [-0.20, 0.13]	0.09 [-0.07, 0.26]
Sedentary time	0.14 [-0.03, 0.30]	0.03 [-0.14, 0.19]	0.19* [0.02, 0.35]	-0.02 [-0.18, 0.15]	0.13 [-0.03, 0.29]
Aerobic fitness	0.03 [-0.11, 0.16]	-0.12 [-0.26, 0.02]	0.01 [-0.13, 0.16]	-0.06 [-0.20, 0.08]	-0.01 [-0.15, 0.12]
Motor Skills	0.24*** [0.12, 0.35]	0.05 [-0.07, 0.17]	0.16** [0.04, 0.09]	-0.19** [-0.31, -0.07]	0.25*** [0.13, 0.36]
ICC	0.11	0.01	0.06	0.01	0.03
Boys (n = 340)					
MVPA	0.04 [-0.12, 0.20]	0.01 [-0.16, 0.17]	0.14 [-0.03, 0.30]	-0.10 [-0.26, 0.06]	0.11 [-0.05, 0.27]
Sedentary time	0.19* [0.04, 0.34]	-0.06 [-0.22, 0.10]	0.08 [-0.08, 0.23]	-0.21** [-0.37, -0.06]	0.17* [0.02, 0.31]
Aerobic fitness	0.17* [0.02, 0.31]	0.03 [-0.12, 0.18]	0.16* [0.01, 0.32]	-0.17* [-0.32, -0.02]	0.21** [0.07, 0.36]
Motor skills	0.22*** [0.09, 0.34]	0.03 [-0.10, 0.16]	-0.02 [-0.15, 0.11]	-0.13* [-0.26, -0.00]	0.14* [0.02, 0.26]
ICC	0.04	0.00	0.04	0.03	0.06

B)

	NT English	NT reading	NT numeracy	Academic performance
	β [CI]	β [CI]	β [CI]	β [CI]
Girls (n = 357)				
MVPA	0.06 [-0.11, 0.23]	0.00 [-0.17, 0.17]	0.07 [-0.10, 0.24]	0.06 [-0.11, 0.22]
Sedentary time	0.14 [-0.03, 0.30]	0.09 [-0.08, 0.25]	0.05 [-0.11, 0.22]	0.11 [-0.06, 0.27]
Aerobic fitness	-0.02 [-0.16, 0.12]	-0.08 [-0.22, 0.06]	-0.02 [-0.16, 0.12]	-0.05 [-0.18, 0.09]
Motor skills	0.14* [0.02, 0.25]	0.13* [0.01, 0.25]	0.16** [0.05, 0.28]	0.16** [0.05, 0.28]
ICC	0.06	0.06	0.13	0.10
Boys (n = 340)				
MVPA	0.11 [-0.05, 0.28]	0.10 [-0.06, 0.26]	0.01 [-0.14, 0.16]	0.08 [-0.08, 0.24]
Sedentary time	0.22** [-0.07, 0.37]	0.13 [-0.02, 0.28]	-0.02 [-0.16, 0.12]	0.12 [-0.02, 0.26]
Aerobic fitness	0.07 [-0.09, 0.22]	0.12 [-0.02, 0.28]	0.21** [0.08, 0.35]	0.17* [0.02, 0.31]
Motor skills	-0.05 [-0.18, 0.07]	-0.05 [-0.17, 0.07]	0.03 [-0.08, 0.15]	-0.03 [-0.15, 0.09]
ICC	0.14	0.10	0.19	0.17

Note. β = standardized regression coefficient; [CI] = 95% confidence interval; Stroop CW = Stroop Color Word; WISC-IV B. = WISC-IV Backwards; NT = national test; MVPA = moderate-to-vigorous physical activity; ICC = intraclass correlation coefficient, *p ≤ 0.05; **p ≤ 0.01; ***p ≤ 0.001.

Paper II: Effects of the intervention on executive function

Effect of the Active Smarter Kids (ASK) physical activity school-based intervention on executive functions: a cluster-randomized controlled trial.

Aadland, K.N., Ommundsen, Y., Anderssen, S., Brønnick, K.S., Moe, V.F., Resaland, G.K., Skrede, T., Stavnsbo, M., Aadland, E. (2017). *Scandinavian Journal of Educational Research, 1–15.*

AIM: To determine the effects of a seven-month curriculum-prescribed physical activity intervention on executive functions in 10-year-old children.

RESULTS: Intention-to-treat analyses revealed no significant effect of the ASK intervention on executive functions (table 3). There were no significant differences between groups for change in accelerometry measured physical activity during school hours or during the whole day. Similarly, no significant differences were observed for aerobic fitness or motor skills. Total physical activity reported by the intervention and control schools over the intervention period was 288 (21) and 157 (35) minutes/week, respectively. Accordingly, the reported difference between the schools (131 minutes/week) was 20% less than prescribed, mainly due to children in the control schools being more physically active than had been anticipated. Per protocol analyses showed significant intervention effects on the composite score of executive functions, the TMT-b, and the composite score of motor skills (table 4).

Table 3. Effects of the intervention on executive functions (intention-to-treat analyses).

Variable	n	β (CI)	p	ICC
Stroop Color Word test (n)				
Imputed file	1119	.31 (-.32–.95)	.333	.02
Completers only	1067	.30 (-.35–.95)	.356	.02
Verbal Fluency (n)				
Imputed file	1123	.17 (-.31–.64)	.491	.00
Completers only	1063	.17 (-.31–.65)	.484	.00
WISC-IV backward (n)				
Imputed file	1120	.01 (-.18–.21)	.893	.02
Completers only	1061	.02 (-.18–.21)	.871	.02
TMT-b (sec)				
Imputed file	1111	-.63 (-4.26–3.01)	.736	.00
Completers only	1005	-1.27 (-5.00–2.46)	.492	.01
Executive function (composite score)				
Imputed file	1107	.06 (-.03–.16)	.191	.02
Completers only	971	.11 (-.04–.27)	.157	.04

Note: β = regression coefficient; CI = 95% confidence interval; ICC = intraclass correlation coefficient; WISC-IV = Wechsler Intelligence Scale for Children fourth edition; TMT-b; Trail Making Test part B.

Table 4. Effects of the intervention on executive functions (per protocol analyses).

Variable	n	β (CI)	p	ICC
Stroop Color Word test (n)	850	.44 (-.33 – 1.21)	.255	.02
Verbal Fluency (n)	847	.29 (-.27–.85)	.317	.00
WISC-IV backward (n)	843	.09 (-.15–.32)	.459	.02
TMT-b (sec)	804	-4.60 (-8.44 to –.76)	.019	.00
Composite score of executive function (1 SD)	776	.14 (.02–.26)	.023	.02
MVPA (school hours) (min)	819	1.19 (-2.43–4.82)	.510	.30
SED (school hours) (min)	819	3.84 (-9.23–1.55)	.157	.23
MVPA (full day) (min)	819	-.42 (-6.03–5.19)	.880	.14
SED (full day)(min)	819	5.71 (-2.49–13.91)	.166	.04
Aerobic fitness (m)	769	-.05 (-17.71–17.62)	.996	.14
Motor skills (1 SD)	755	.15 (.01–.29)	.034	.04

Note: β = regression coefficient; CI = 95% confidence interval; ICC = intraclass correlation coefficient; WISC-IV = Wechsler Intelligence Scale for Children fourth edition; TMT-b = Trail Making Test part B; SED = sedentary time; MVPA = moderate-to-vigorous physical activity; SD = standard deviation.

Paper III: Effects of the intervention on academic performance

Effects of physical activity on schoolchildren's academic performance: The Active Smarter Kids (ASK) cluster-randomized controlled trial.

Resaland, G.K., Aadland, E., Moe, V.F., Aadland, K.N., Skrede, T., Stavnsbo, M., Suominen, L., Steene-Johannesen, J., Glosvik, Ø., Andersen, J.R., Kvalheim, O.M., Engelsrud, G., Andersen, L.B., Holme, I.M., Ommundsen, Y., Kriemler, S., van Mechelen, W., McKay, H.A., Ekelund, U., Anderssen, S.A. (2016). *Preventive Medicine, 91, 322–328.*

AIM: To investigate the effect of a seven-month, school-based cRCT on academic performance in 10-year-old children.

RESULTS: No significant effects of the intervention on any academic performance measure in the intention-to-treat analyses (figure 10) were found. There were no significant differences between groups for change in physical activity during school hours or during the whole day. In subgroup analyses, a significant effect of the intervention was found on numeracy for children in the lowest tertile in numeracy at baseline. Compared to the intention-to-treat analyses, the per protocol analyses showed that the intervention's effect decreased for all measures, except for English, where the effect became statistically significant.

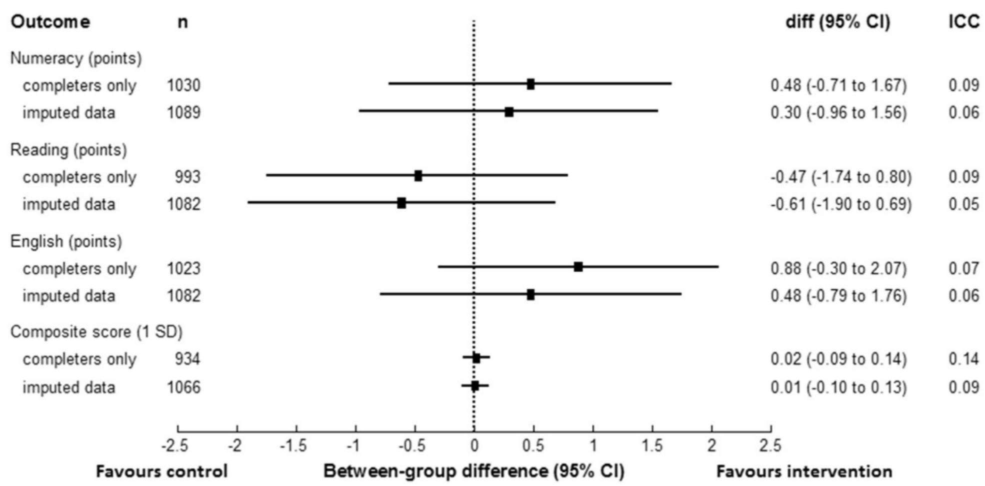


Figure 10. The intervention's effect on academic performance (intention-to-treat analyses): completers only vs. imputed data (all children with pre- or post-data for a given variable). The composite score is expressed as the standardized mean of standardized individual scores. 95% CI = 95% confidence interval; ICC = intraclass correlation coefficient; SD = standard deviation.

Paper IV: Executive function as a mediator in prospective relationships

Executive functions do not mediate the prospective relationship between indices of physical activity and academic performance: The Active Smarter Kids (ASK) study.

Aadland, K.N., Ommundsen, Y., Aadland, E., Brønnick, K.S., Lervåg, A., Resaland, G.K. & Moe, V.F. (2017). *Frontiers in Psychology, 8, 1–12.*

AIM: To investigate if executive function mediated the prospective relationships between the indices of physical activity and academic performance in 10-year-old children.

RESULTS: Generally, the indices of physical activity (objectively measured MVPA and sedentary time, aerobic fitness, and motor skills) did not predict either executive function or academic performance when controlling for covariates. Only one out of 21 tested mediation models was significant (table 5). Executive function partially mediated the relationship between performance on the Shuttle Run test (motor skill) and performance in numeracy (figure 11). None of the mediation models were statistically different for girls and boys.

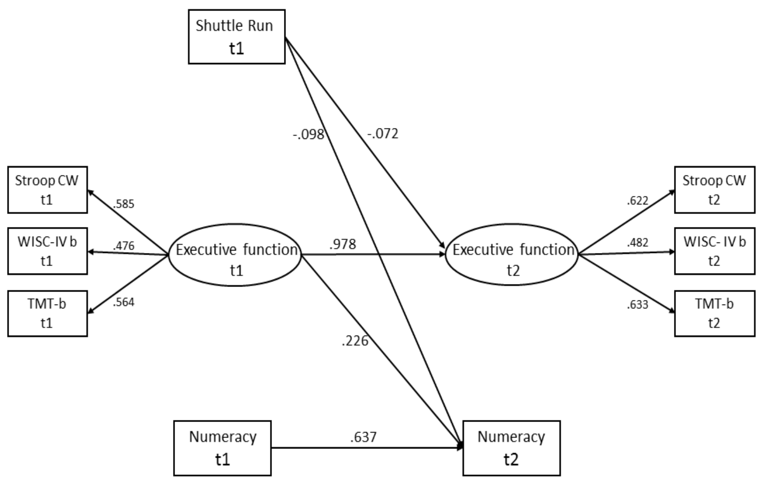


Figure 11. The half-longitudinal mediation model of the relationship between Shuttle Run and academic performance in numeracy. All path coefficients are significant and reported as standardized β-estimates. The covariates age, sex, tanner, body fat, socio-economic status, and group allocation are adjusted for in the model, but not shown. t1= baseline; t2 = follow-up; Stroop CW = Stroop Color Word; WISC-IV backward = Wechsler Intelligence Scale for children backward; TMT-b = the Trail Making test part B.

Table 5. Standardized coefficients for the paths and goodness of fit indices for the half-longitudinal mediation models controlled for covariates.

Model	*a* β	*b* β	*axb* B	*c'* β	χ2 (df)	CFI	RMSEA (95% CI)	SRMR
NUMERACY								
cpm	-.081	.245***	-.020	.027	47.386 (45)	.999	.007 (.000–.022)	.017
MVPA	.003	.244***	.001	.035	46.553 (45)	.999	.006 (.000–.022)	.017
SED	-.048	.246***	-.012	-.022	48.433 (45)	.999	.009 (.000–.023)	.017
Aerobic fitness	-.023	.241***	.010	-.006	41.430 (45)	.998	.012 (.000–.025)	.017
Shuttle Run	-.072*	.226***	-.016*	-0.098***	57.946 (45)	.996	.017 (.000–.028)	.017
Aiming	.000	.245***	.000	-.004	52.645 (45)	.997	.013 (.000–.026)	.017
Catching	-.033	.233***	-.008	.026	47.712 (45)	.999	.008 (.000–.023)	.017
READING								
cpm	-.005	.187***	.001	-.004	47.126 (45)	.999	.007 (.000–.022)	.017
MVPA	.002	.187***	.000	-.004	46.451 (45)	.999	.006 (.000–.022)	.017
SED	-.050	.187***	-.009	.018	48.513 (45)	.999	.009 (.000–.023)	.017
Aerobic fitness	-.026	.166***	-.004	.055	49.091 (45)	.999	.009 (.000–.024)	.017
Shuttle Run	-.066	.169***	-.011	-.069*	53.192 (45)	.997	.013 (.000–.026)	.018
Aiming	-.006	.190***	-.001	-.012	50.791 (45)	.998	.011 (.000–.025)	.017
Catching	-.040	.183***	-.007	.012	45.726 (45)	1.000	.004 (.000–.024)	.017
ENGLISH								
cpm	-.005	.046	-.000	-.006	48.111 (45)	.999	.008 (.000–.023)	.017
MVPA	.002	.047	.000	-.009	47.456 (45)	.999	.007 (.000–.023)	.017
SED	-.049	.047	-.002	.056*	49.008 (45)	.999	.009 (.000–.023)	.017
Aerobic fitness	-.028	.056	-.002	-.030	49.396 (45)	.999	.010 (.000–.024)	.017
Shuttle Run	-.065	.046	-.003	-.002	53.242 (45)	.997	.013 (.000–.026)	.018
Aiming	-.005	.046	-.000	.000	51.329 (45)	.998	.012 (.000–.025)	.017
Catching	-.041	.048	-.002	-.005	46.347 (45)	1.000	.005 (.000–.022)	.017

Note. *a* = the path between the predictor and executive function at time point 2; *b* = the path between the executive function at baseline to the outcome at follow-up; *axb* = the indirect effect; *c´*= the path between the predictor and outcome; cpm = counts per minute; MVPA = moderate-to-vigorous physical activity; SED = sedentary time; * p ≤ .05; *** p ≤ .001.

Paper V: Self-regulation as a mediator

Does self-regulation mediate the relationship between school-based physical activity and academic performance in numeracy in ten-year-old children? The Active Smarter Kids (ASK) study

Aadland, K.N., Aadland, E., Andersen, J.R., Lervåg, A., Moe, V.F., Resaland, G.K. & Ommundsen, Y. (submitted).

AIM: To investigate if improved executive function, behavioral self-regulation, and school related well-being mediated the effect of the ASK intervention on performance in numeracy for those performing poorest in numeracy at baseline.

RESULTS: Executive function, behavioral self-regulation, and school related well-being did not mediate the effect of the intervention on academic performance in numeracy (figure 12). The included children (lowest tertile at baseline in numeracy) performed significantly poorer on all tests for executive function, had significantly lower scores in the Child Behavior Rating Scale and the school dimension of the KidScreen questionnaire compared to the excluded children (the two other tertiles of the ASK sample) at baseline.

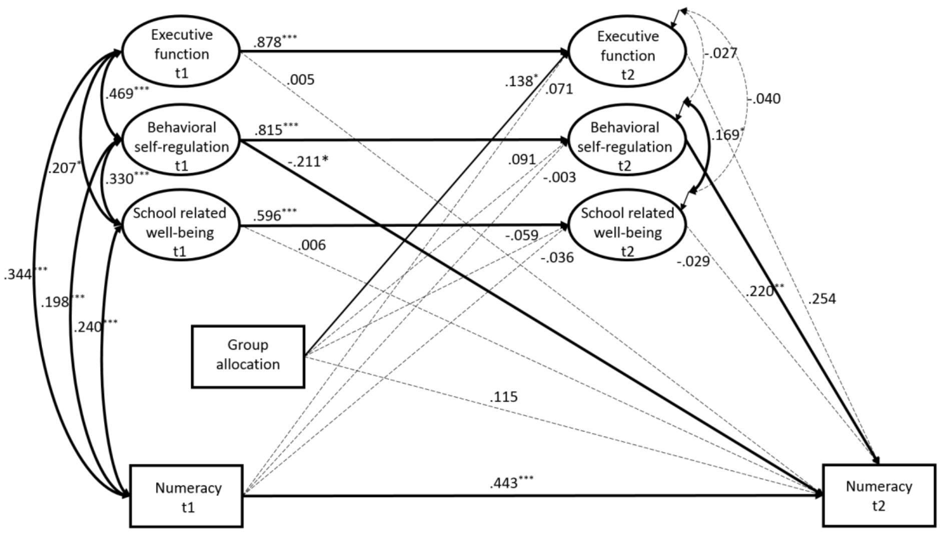


Figure 12. The mediational role of executive function, behavioral self-regulation, and school related well-being in the observed effect of the ASK intervention on performance in numeracy. t1= baseline; t2 = follow-up; * p ≤ .05; ** p ≤ .01; *** p ≤ .001. Dashed lines represent non-significant paths, solid lines represents significant paths.

DISCUSSION

In this first part of the discussion, the results of the five individual papers will be integrated and discussed with reference to the three main research questions. Thereafter, methodological issues of the current research are discussed, taking advantage of the conceptual model by Morgan, Young, Smith, and Lubans (2016).

Research question 1:

What are the relationships between objectively measured physical activity and executive function and academic performance?

Following the standards in the literature, we aimed to assess the relative importance of objectively measured physical activity to both executive function and academic performance (Khan & Hillman, 2014). Our cross-sectional results (paper I) suggest that MVPA does not relate independently to executive functions or academic performance after controlling for sedentary time, aerobic fitness, and motor skills, as well as confounding factors, in 10-year-old children. Relating this finding to the evidence base is challenging, due to the large diversity across studies, and, to my knowledge, no previous study has examined the independent relationship between objectively measured physical activity and behavioral measurements of executive functions and academic performance. Our findings contrast the systematic review results by Donnelly et al. (2016), which suggest evidence for a positive association between higher levels of physical activity and executive functions and academic performance. However, most of this evidence stems from studies in which aerobic fitness is used as a proxy for physical activity, possibly explaining the discrepant findings (see research question 3 for a discussion of relationships with aerobic fitness). Nevertheless, our finding is generally in agreement with Syvaoja et al. (2014), who, based on the same accelerometer cut-point for MVPA as used in the current thesis, found no associations between MVPA and measures of executive functions, beyond a positive relationship with attention. Conversely, Booth et al. (2013) observed a positive relationship between MVPA and executive function, using a higher cut-point for MVPA (Booth et al., 2013). As both Syvaoja et al. (2014) and Booth et al. (2013) found associations for some tasks, but not others, their studies suggest selective effects of physical activity on cognitive functions. Our lack of independent associations, however, were consistent across all tasks. The lack of an independent association of MVPA to academic performance in this thesis extends the inconsistent cross-sectional associations found in studies previously described. Some of these failed to show associations (Corder et al., 2015; Hansen et al., 2014; LeBlanc et al., 2012; Syvaoja et al., 2013), others have shown positive associations (Booth et al., 2014; Lambourne et al., 2013), and one study has shown negative associations (Esteban-Cornejo et al., 2014). Furthermore, the study by Kwak et al. (2009) found associations between vigorous physical activity and academic performance in girls only, adding the dimension of sex to the examined relationship. We tested interactions for MVPA by sex, but did not find any associations of MVPA with executive functions or academic performance in either sex group.

Findings from our prospective study (paper V) are consistent with our cross-sectional associations (paper I), as physical activity did not predict executive function or academic performance seven months later. The associations were consistent, although different statistical approaches were used. The prospective study used SEM with a latent variable of executive function. Our prospective findings contrast those from a large British cohort, where MVPA (determined using a higher cut-point) predicted executive function two years later (Booth et al., 2013) and academic performance both two and five years later (Booth et al., 2014). Accordingly, it is possible that our seven-month follow-up period was of insufficient length. Furthermore, as Booth et al. (2013) observed that the associations were different across different measures of executive function, it might be that our latent executive function variable, composed of three different executive function tests, did not reveal existing associations with single aspects of executive function. However, we argue that the use of a latent variable is a strength of the study, as it excludes measurement errors, and furthermore, avoids the task impurity problem described by others (Best & Miller, 2010; Cassidy, 2016; Friedman & Miyake, 2017; Miyake et al., 2000). The task of executive functions is to control lower level cognitive processes to goal directed cognition and behavior; as such, these nonexecutive processes are included in the performance of tests of executive functions. In a latent variable, however, only what is shared across the three tasks constitute the executive function variable, which most likely omits the influence of such nonexecutive processes (Miyake et al., 2000). However, the selection of tests to comprise the executive function factor are crucial. We believe that our tests reflected the framework by Miyake et al. (2000) chosen for this thesis, where each test measured one aspect of executive function (inhibition, working memory, and cognitive flexibility). Furthermore, the tests are validated and shown appropriate for the age group (Peru et al., 2006; Reitan & Wolfson, 2004; Wechsler, 2003). One of the tests (the Verbal Fluency task), however, made a small contribution to the executive function factor and was excluded from the variable.

Collectively, our cross-sectional and prospective findings do not support a relationship between objectively measured MVPA and executive functions and academic performance. These findings do not give support to the physiological hypothesis, where physical activity is proposed to affect executive functions throught physiological changes in the brain, such as angiogenesis and increased blood volume, and an upregulation of neurotrophins and growth factors (Best, 2010; Cotman et al., 2007; Hotting & Roder, 2013; van Praag, 2009). We cannot, however, exclude that we were not able to reveal associations that exist, due to methodological issues and measurement errors in our variables. Even though accelerometer-determined physical activity is more reliable than self-report, it does have well-known limitations (Corder et al., 2008; Ekelund et al., 2007). Our measure of MVPA levels over four to seven days might be an insufficient snapshot of a child's complex and variable physical activity behavior (Ekelund et al., 2007), despite the reliability (ICC) of the accelerometry of ~0.70–0.80 for three to seven days of monitoring in children (Aadland & Johannessen, 2015). Accordingly, the inclusion of a large sample size, and the inclusion of several known confounding variables in our analyses, such as age, sex, skinfold thickness, pubertal status, and socio-economic status, lend credibility to our findings.

The two effect papers aimed to investigate if a multicomponent school-based physical activity intervention affected executive functions (paper II) and academic performance (paper III). The intention-to-treat analyses showed no significant effects on either outcome. Importantly, we observed no significant difference between the children in the intervention and control schools in overall physical activity levels, MVPA, or sedentary time measured objectively using accelerometers. As our premise was that physical activity would cause a change in executive functions and academic performance, this is one probable reason we were unable to detect measurable benefits of the intervention. An important reason for the lack of contrast in physical activity between groups seems to be high levels of physical activity in the control group, a finding that is not uncommon in physical activity trials (Waters, Reeves, Fjeldsoe, & Eakin, 2012). It is also possible that the amount of physical activity prescribed for the ASK intervention was insufficient to affect the physiological mechanisms (e.g., increased neurogenesis and angiogenesis) proposed as a pathway for how physical activity might affect executive functions (Barenberg et al., 2011; Best, 2010). Compared to previous RCTs that have revealed positive effects of physical activity interventions on executive functions (Davis et al., 2011; Hillman et al., 2014), the dose used in the ASK intervention was clearly smaller. Furthermore, both Davis et al. (2011) and Hillman et al. (2014) observed a dose-response relationship between physical activity and executive function and academic performance (Davis et al., 2011). The lack of effect on executive function in our study might explain the lack of an effect on academic performance, as changes in executive functions are hypothesized to be cornerstones for gains in academic performance (Donnelly et al., 2016; Howie & Pate, 2012; Tomporowski et al., 2015). Corresponding to our study, the study by Bugge et al. (2017) did not find effects on academic performance following an intervention of 270 minutes per week of physical education, which is close to the prescribed dose in the ASK study (300 minutes per week). The intensity of the ASK intervention may also have been insufficient. Ardoy et al. (2014) showed effects on cognitive functions and academic performance only following an intervention that increased both intensity and frequency, but not following the intervention that increased only the frequency. However, the large sample size, including 28 intervention schools with the teachers in charge of intervention delivery, made it difficult to control the implementation of the intervention to the same extent as others (Davis et al., 2011; Hillman et al., 2014). Consistent with our study, other studies incorporating physical activity into the curriculum have failed to provide evidence for the effect of their school based physical activity interventions on executive functions (de Greeff et al., 2016; Kvalø et al., 2017; Tarp et al., 2016) and academic performance (Ahamed et al., 2007; Donnelly et al., 2017; Riley et al., 2016; Tarp et al., 2016). Importantly, some of these studies reported a poor implementation of the intervention (Donnelly et al., 2017; Tarp et al., 2016).

Interestingly, sub-group analysis revealed effects of the ASK intervention on performance in numeracy for children in the lowest tertile of numeracy performance at baseline (paper III). Because this group, similar to the overall group, did not increase their physical activity level above that of the control group, this effect may be more a result of how physical activity was integrated into the curriculum, rather than a result of the amount of physical activity. The physically active educational lessons were a cornerstone and a novel part of the intervention, where curricular content that involved solving problems or addressing questions was embedded within physical activities. This approach to learning may have affected those who were less literate in numeracy. Within the framework of embodied cognition, the physical activity combined with academic tasks, might have provided memory cues positively affecting the retrieval of the acquired knowledge (Chandler & Tricot, 2015) (see paper III p. 327 for more detailed discussion). Our finding does, to some extent, support Donnelly et al. (2016), suggesting that physical activity integrated into the academic learning activities has a stronger effect on academic performance than physical activity breaks. However, as we used a multicomponent intervention, our findings cannot be attributed to single components of the intervention. Nevertheless, the importance of the effect on performance in numeracy for this subgroup deserved a more thorough investigation to provide information about possible mediators for the effect. The findings from these analyses are discussed under research question 2.

The studies included in this thesis (except paper V), did also examine the links between objectively measured sedentary time and executive function and academic performance. Briefly, our cross-sectional findings (paper I) showed that objectively measured sedentary time was positively related to working memory in girls, and to cognitive flexibility, the composite score of executive function, and academic performance in English in boys (see paper I, p. 16 for further discussion of previous studies). However, prospectively (paper IV), objectively measured sedentary time did not predict executive function or academic performance (except English) seven months later. However, an important limitation of these analyses was the lack of any measures of the context and type of sedentary behavior. In the literature, screen time (negative associations) and non-screen sedentary time, for example, reading for fun and school work (positive associations), show opposite associations with academic performance (Carson et al., 2015; Corder et al., 2015; Esteban-Cornejo, Martinez-Gomez, et al., 2015; Syvaoja et al., 2014), pointing to type rather than amount of sedentary behavior, as essential for academic performance. Our findings should, therefore, be interpreted with this limitation in mind. Lastly, as for total physical activity and MVPA, the lack of a reduction in sedentary time in the intervention group compared to the control group explains the lack of an effect of the intervention on executive functions (paper II) and academic performance (paper III).

Altogether, this thesis does not provide evidence that objectively measured MVPA is associated with executive function and academic performance cross-sectionally or prospectively. As we were not able to obtain solid contrasts between the intervention and control schoolchildren's physical activity levels, our premise for observing change in executive function and academic performance may seem limited. Lastly, the lack of information regarding type of sedentary behavior precludes any conclusion about the relationship between sedentary time and executive function and academic performance.

Research question 2:

Does executive function mediate the relationship between objectively measured physical activity and academic performance?

Previous research has mainly reported the relationship of physical activity to either executive function or academic performance in isolation. Furthermore, most of these studies have been cross-sectional. Extending previous research, we took advantage of a mediation paradigm (Cole & Maxwell, 2003; Little, 2013; Valente & MacKinnon, 2017), examining how physical activity is linked to change in academic performance through change in executive function. Our premise for doing so is the acknowledged hypothesis in the literature that physical activity affects academic performance through changes in executive function (Donnelly et al., 2016; Howie & Pate, 2012; Tomporowski et al., 2015). However, by testing this hypothesis using both a prospective (paper IV) and a randomized design (paper V), we did not provide evidence for a mediation of the physical activity-academic performance link by executive function.

The lack of evidence for a mediation effect in the prospective design (paper IV), can be explained by the finding that objectively measured physical activity did not predict executive function or academic performance seven months later (as discussed previously). Our null findings might also be explained by the use of a seven-month follow-up period, which might have been too short of a follow-up period to induce structural changes in the brain, or might have imposed noise. As a prerequisite for our prospective examinations, our baseline MVPA represents the child's supposed physical activity level during the follow-up period. However, we cannot rule out the possibility of fluctuations from the baseline measures. Levels of physical activity may have been less stable over the follow-up period (Jones, Hinkley, Okely, & Salmon, 2013), compared to aerobic fitness and motor skills, as they represent behaviors and not personal traits (see paper V, page 8 and 9 for a more detailed discussion). That both the mediation model in the randomized design (paper V) and the per protocol analyses (paper II) showed effects of the intervention on executive functions, contradicts the explanation that the follow-up period was too short.

In the randomized controlled design (paper V), we investigated the mediating role of executive function in a direct relationship that previously had been shown to be significant; the ASK intervention had a favorable effect on performance in numeracy for children in the lower third in academic performance in numeracy at baseline (paper III). In the mediation model, an effect of the intervention on executive function was observed in this subsample, an effect that was not evident in the overall ASK sample (paper II). The fact that the ASK intervention improved executive function, despite no differences in physical activity levels between intervention and control schoolchildren, suggests that the content of the intervention was of importance. The prevailing literature supports the value of cognitive demands inherent in physical activities in order to affect executive function (Best, 2010; Diamond, 2015; Tomporowski et al., 2015). The ASK intervention might have enhanced the cognitive demands of the physical activity in several ways (cf. the hypothesis regarding the type of physical activity), such as the integration of academic learning tasks, social interactions in the group activities, and motor skills demands (cf. the motor skills hypothesis) (see paper V, p. 14 and 15 for a more detailed discussion). The observed effect in this subsample of the ASK sample only, could also be attributed to the differences in characteristics for this sample compared to the other two tertiles. This subsample scored lower on all tasks of executive function, had lower scores on teacher rated behavioral self-regulation, and lower school related well-being compared to the other two tertiles, and had higher skinfold thickness compared to the highest tertile. Pesce (2009) hypothesized such individual constraints to be of importance for the effect of physical activity on cognitive performance (the integrated model shown in figure 5). As such, it is possible that the intervention content more optimally challenged these children in terms of cognitive demands, compared to the other children, which is of importance for improving executive function (Diamond & Lee, 2011; Pesce, 2009; Pesce et al., 2013).

Despite the intervention affecting executive function in the lowest performing children in numeracy, the change in executive function was not significantly related to change in academic performance in this group (paper V). This finding is the opposite of expectations, given that the relationship between executive function and academic performance is well documented in the literature (Best et al., 2011; Cantin et al., 2016; St Clair-Thompson & Gathercole, 2006), as also shown in paper I (table 2) and paper IV (the b path in table 3). However, it represents a conservative design to investigate change in the mediator on change in the outcome, as in the current case. Furthermore, in order to capture the effects of change in the executive function on change in numeracy, a longer follow-up period might be necessary.

Complementary to executive function, we also investigated if behavioral self-regulation and school related well-being mediated the effect of the ASK intervention on numeracy (paper V). Together, all three are seen as capturing different assets of self-regulation (von Suchodoletz et al., 2013). With reference to the hypotheses of effects of acute physical activity on arousal and attention, as well as the evidence of effects of acute physical activity in children outlined in the introduction, it could be hypothesized that components of the ASK intervention could improve classroom behavior (behavioral self-regulation). However, contrary to previous studies that have observed increased on-task behavior during or following physical activity bouts (Bartholomew & Jowers, 2011; Carlson et al., 2015; Grieco et al., 2016; Ma et al., 2014; Mahar et al., 2006; Riley et al., 2016), we did not observe any effects of the ASK intervention on behavioral self-regulation. The measurement for behavioral self-regulation and the timing of measurement might be an explanation for the discrepant findings. For example, Riley et al. (2016) reported increased time on-task during their physically active academic lessons based on observational data. Our measure, in contrast, focused on behavior in the classroom, reported by the teachers at baseline and follow-up. Consequently, we assessed the behavior in the classroom over a long period, where the majority of the academic lessons did not follow or include physical activity. As such, it is possible that we did not capture effects on behavioral self-regulation during or following the intervention components that were present. Furthermore, it is possible that our five-minute breaks were of insufficient duration or intensity, as previous studies revealing effects have used ten-minute breaks (Carlson et al., 2015; Grieco et al., 2016; Kibbe et al., 2011; Mahar et al., 2006) or four minutes of high intensity physical activity (Ma et al., 2014) (see paper V, page 17 for a more detailed discussion).

We hypothesized that the effect of our intervention on academic performance in numeracy could also be affected through a psychological mechanism in which school related well-being was triggered (Bailey, 2016). However, our intervention did not improve school related well-being, which is consistent with the quasi-experimental study by Käll, Malmgren, Olsson, Linden, & Nilsson (2015). This lack of effect could possibly be attributable to an insufficient dose, as Norris, Carroll, and Cochrane (1992) observed that duration and intensity of physical activity may be of importance to affect emotions such as satisfaction felt or well-being. Furthermore, it could also well be that our intervention activities and the mode of delivery did not stimulate positive peer-relationships, social identity, and belonging, which all are important for well-being (Bailey, 2016; Lubans et al., 2016; Orkibi & Ronen, 2017). Both types of physical activity, such as tailored activities regarding social and physical-motor competence, and mode of delivery, influence intervention effects (Morgan et al., 2016). It is possible that the children in the subgroup joined the physical activities with less social and physical competencies at their disposal for involvement in and mastery of the group activities. Therefore, the possible benefits of these activities for school related well-being might have been reduced by those factors (Lubans et al., 2016). According to the self-determination theory, psychological well-being depends upon satisfaction of basic needs, including, not only social relatedness, but satisfaction of the need of competence as well (Orkibi & Ronen, 2017; Ryan & Moller, 2017). The modes of delivery are discussed more in the section about facilitators and pedagogy under methodological considerations.

In conclusion, this thesis does not provide evidence that executive function mediates the relationship between physical activity and academic performance. The lack of mediation in the prospective study could be explained by the lack of prediction of executive function and academic performance by MVPA. Within the randomized controlled design, the lack of mediation could be due to the lack of relationship between change in executive function and academic performance. Neither behavioral self-regulation nor school related well-being mediated the effect of the ASK intervention on performance in numeracy, as no effect of the intervention was observed on the mediators.

Research question 3:

What are the relationships between aerobic fitness and motor skills to executive function and academic performance?

The relationships between physical activity to executive function and academic performance are explained by more than the “counts” from an accelerometer. By investigating how aerobic fitness and motor skills were related to executive function and academic performance, this thesis aimed to provide knowledge concerning two distinct research directions. First is the one that emphasizes the dose of the physical activity and its improvement in aerobic fitness (the aerobic fitness hypothesis). Second is the one that emphasizes the cognitive demands of the physical activity (herein the motor skill hypothesis).

Results regarding aerobic fitness in this thesis only provided cross-sectional associations between aerobic fitness (independent, with control for MVPA, sedentary time, and motor skills) and executive function and academic performance in boys (paper I). Aerobic fitness, a measure of the capacity to undertake aerobic work partly determined by the physical strain induced by MVPA, may, therefore, with its higher measurement precision than MVPA, add information to relationships between the physical activity level and executive functions and academic performance. Consequently, these findings do give some support for the theory that physical activity level might be a pathway for affecting executive function (cf. the physiological hypothesis by Best, (2010)). However, aerobic fitness predicted neither executive function nor academic performance seven months later (paper IV), which precluded us from testing the aerobic fitness hypothesis. The lack of prediction of the association of aerobic fitness with executive function and academic performance, contrasts previous longitudinal studies that revealed positive relationships between aerobic fitness and executive function (Chaddock, Hillman, et al., 2012; Niederer et al., 2011) and academic performance (Bezold et al., 2014; London & Castrechini, 2011; Wittberg, Northrup, & Cottrell, 2012). Furthermore, the ASK intervention did not result in differences in aerobic fitness between intervention and control schoolchildren, neither in the intention-to-treat nor in the per protocol analyses (paper II), which according to the aerobic fitness hypothesis is a prerequisite for change in executive function and academic performance. Corresponding to this, the FITKids trial, which found an effect on executive functions, observed an increase in aerobic fitness of ~4% (Hillman et al., 2014). This finding suggests that the ASK intervention may not have succeeded in significantly influencing children’s executive functions by means of change in their physiological state.

The thesis results suggest that the relationships between motor skills to executive function and academic performance are stronger than those of both MVPA and aerobic fitness. This conclusion is supported by the independent cross-sectional associations for motor skills to executive functions in both girls and boys, and to academic performance in girls (paper I). Furthermore, one of the motor skill tasks (the Shuttle Run) predicted both executive function and academic performance seven months later, (paper IV). Finally, the per protocol analyses showed that the ASK intervention improved both motor skills and executive function (paper II). This might suggest that the effect of the ASK intervention on executive functions in this analysis could be partially be explained by change in motor skills (paper II). Although the per protocol analyses were secondary analyses and therefore should be interpreted carefully, they were based on detailed teacher reports of physical activity completed weekly during the intervention. The teacher reports indicated high adherence to the intervention and clear contrasts between the groups (in contrast to the accelerometer-determined physical activity levels). We might suspect a (desirability) reporting bias for teacher reports, consistent with limitations of subjective physical activity reporting in general (Prince et al., 2008). An alternative explanation for the contrasting results between subjective and objective measures of physical activity might be that the two measures capture different aspects of physical activity. It is well known that accelerometers have severe limitations in obtaining accurate movement estimates of activities such as cycling, water-based activities, and performing upper-body movements in general. Therefore, the discrepant findings might indicate that the children were engaged in physical activities tapping qualitative characteristics, such as cognitive and coordinative demanding physical activities, for which accelerometers are insensitive. Some of the intervention content included activities that we expect accelerometers to capture poorly. In support for this hypothesis, intervention studies have shown that enriched physical education comprising challenges pertaining to cognition, social interaction, and motor coordination affect executive functions (Crova et al., 2014; Pesce et al., 2016; Schmidt et al., 2015; van der Niet et al., 2016). Moreover, some have shown effects on executive functions independent of gain in aerobic fitness (Crova et al., 2014; van der Niet et al., 2016). Therefore, regarding the effect on motor skills in the per protocol analysis, it is reasonable to conclude that the intervention was challenging in terms of motor tasks (see paper II, p. 11 for a more detailed discussion).

We observed sex-specific associations in our cross-sectional analyses (paper I) for aerobic fitness and motor skills to executive functions and academic performance. For aerobic fitness, our results are consistent with the study by Drollette et al. (2015), which found that higher aerobic fitness was associated with better working memory only in boys (7–10 years). We expanded on this finding, as our study showed significant associations of aerobic fitness with all three aspects of executive functions, as well as academic performance in numeracy. For motor skills, we found independent associations to academic performance in girls only. Both of our findings for aerobic fitness and motor skills contrast the study by Haapala et al. (2014), which found no associations between aerobic fitness and academic performance, and significant associations between motor skills and academic performance generally only in boys. However, the age difference of the included children (6–8 years olds vs. 10 years old in our study) might be an explanation for the discrepant findings. We speculate that maturation may play a role concerning the observed sex-specific relationships, as the executive functions in girls are shown to be more mature at age 11 compared to boys (Boelema et al., 2014). Therefore, one explanation for the lack of association between motor skills and academic performance in boys might be their later development of working memory (Boelema et al., 2014), as working memory has been shown to mediate the effect of motor skills on academic performance (Rigoli et al., 2012). Our prospective analyses (paper IV) however, did not find sex-specific differences.

We also tested the executive function hypothesis in the prospective relationship of aerobic fitness and motor skills to academic performance (paper IV). Consistent with the results for MVPA and sedentary time, executive function did not mediate the relationship between aerobic fitness and academic performance. For motor skills, however, executive function partially mediated the effect between one of the motor skills tests, the Shuttle Run test, and academic performance in numeracy. To my knowledge, only the cross-sectional study by Rigoli et al. (2012) has tested a similar mediation model. They found that motor coordination had an impact on academic performance through working memory in adolescents. Cross-sectional examination of our mediation models supports the executive function hypothesis, where indirect effects through executive functions were present in the relationships between both aerobic fitness and all tests of motor skills to academic performance in numeracy, reading, and English. However, cross-sectional studies lack a temporal relation between the exposure and the outcome, and are unable to demonstrate causation. The half-longitudinal approach applied in this thesis is a significant improvement compared to cross-sectional testing of mediation, as we were able to control for prior levels in the mediator and the outcome (Little, 2013).

The thesis findings regarding the relationship of motor skills to executive function and academic performance lend some support to the motor skills hypothesis, emphasizing the close parallelism and interaction between neural substrates of motor coordination (cerebellum) and executive functions (the prefrontal cortex) (Diamond, 2000; Koziol et al., 2012; Rigoli et al., 2012). Considering that a large number of cross-sectional associations (paper I) and mediation models (paper IV) were analyzed, which potentially may increase the type 1 error rate, our results regarding motor skills could be chance findings that should be interpreted carefully (Ioannidis, 2005). However, the results across the studies are to some extent consistent. Another limitation concerns our measure of motor skills. We used three single tests from two different standardized and validated test batteries; therefore, the measure was not a comprehensive measure of motor skills. Furthermore, the tests were used as a proxy for the exposure of motor skills demanding physical activity of the intervention. However, as the ASK study included many different measurements, a selection of motor skills tests was necessary, both for ethical reasons to reduce the burden for the children, and to meet with logistical challenges.

Overall, this thesis suggests that motor skills are more strongly related to executive function and academic performance than MVPA and aerobic fitness. Supporting this line of reasoning, motor skills were related to executive function and academic performance both in cross-sectional and prospective analyses. Furthermore, the improvement in executive function observed in the per protocol analyses following the ASK intervention was accompanied by an improvement in motor skills. For MVPA and aerobic fitness, cross-sectional relationships between aerobic fitness to executive function and academic performance were observed for boys only. An indirect effect through executive function was observed for motor skills (the Shuttle Run) and academic performance in numeracy.

Methodological considerations

In the following, I will use the conceptual model by Morgan et al. (2016) as guidance through the discussion of methodological consideration. As revealed in figure 13, Morgan et al. (2016) emphasize several aspects pertaining to intervention design and delivery that need to be taken into consideration to optimize the possibility for successful implementation and the uncovering of potential intervention effects. As this thesis includes several study designs, I will start this section with considerations of the different study designs. The section ends with a discussion of the statistical analyses used.

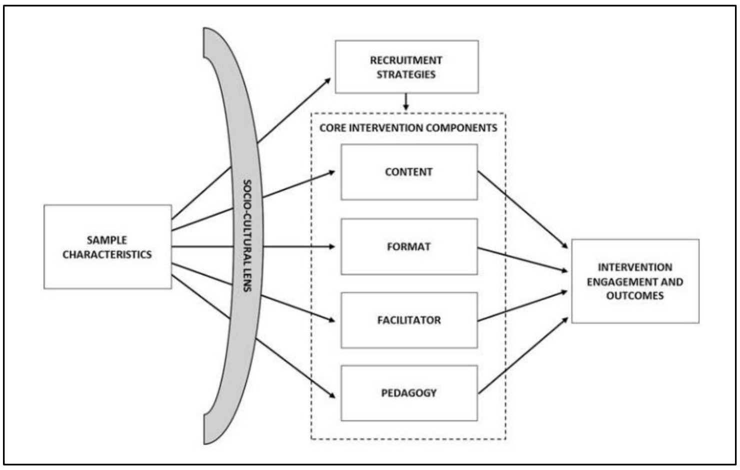


Figure 13. The conceptual model of socio-culturally relevant approach to the design and delivery of health behavior interventions targeting physical activity. Adapted from Morgan et al. (2016, p. 70).

Study design

The ASK study was a cRCT, with randomization performed by a neutral third party. Despite using a strong experimental design in the ASK study, only three of the included papers in this thesis investigate effects of the intervention within this design (papers II, III and V). The first paper was a cross-sectional explorative paper investigating how the variables of indices of physical activity and executive function and academic performance were related in terms of size and direction. Due to its cross-sectional design, the results from paper I cannot prove causation (Shadish, Cook, & Campbell, 2002). As we did not observe differences between the intervention and control schoolchildren's physical activity levels, aerobic fitness, and motor skills, the fourth paper analyzed the prospective mediation of executive function in a single cohort where the intervention and control schoolchildren were collapsed. This observational design also has limitations, as all changes can be related to events which co-occurred during the follow-up period (Little, 2013). Other threats regarding the validity of longitudinal studies include regression to the mean, retest effects, selection effects, selective attrition, and instrumentation effects (Little, 2013). However, we consider these threats of minor importance in our prospective paper. First, the selection effects and selective attrition were eliminated due to the use of a representative sample and low dropout (further discussed under sample characteristics). Second, as it is unreliable measurements which result in regression toward the mean, this threat was met by the latent SEM approach. Last, we obtained scalar invariance across time for our latent variables, indicating that instrumentation effects were not present. However, we do not know how retest effects have affected our results.

Recruitment and sample characteristics

A lot of effort was put into the recruitment process ahead of the rollout of the ASK intervention. The project was accepted by the professional executives of the most important educational authorities and organizations in the county of Sogn og Fjordane, as well as all county and municipal school leaders and principals. We arranged meetings with the parents at their schools, where we presented the study, including our aims and any possible hazards, discomfort, and inconvenience, and addressed any questions (Resaland et al., 2015). The recruitment process was successful, as all 60 schools fulfilling the inclusion criteria agreed to participate. After randomization, three schools from one municipality declined to participate. This resulted in an 82.1% response rate of the total population of 10-year-olds from the Sogn og Fjordane county. Valid data were provided from 1129 children (response rate 96.1% of those invited at the 57 schools), which met the requirement from the sample size calculations (468 children in each group) for detecting significant effects on academic performance (main outcome) (Resaland et al., 2015).

The study sample included 1129 ten-year-old children attending 57 elementary schools in Sogn og Fjordane county, Norway. Compared to Norwegian representative samples, the current sample seems to exhibit a similar level of academic performance and aerobic fitness, but possibly a somewhat increased physical activity level (Helsedirektoratet, 2012; Kolle et al., 2010). There are no available data for comparison of executive function to the general population. Therefore, we argue that our findings are generalizable to the general population of Norwegian 10-year-olds.

However, the sample included in the different papers varied, where the whole sample was represented in paper IV only (figure 8). In the effect studies (papers II and III), intention-to-treat analyses were performed both on imputed data ($n > 1066$) and with completers only ($n > 934$). In the cross-sectional paper (paper I), only children with valid measurements on all study variables were included; therefore, the sample size was substantially reduced from 1129 to 697 children. Attrition analyses showed that the included children performed significantly better on all tests of executive function and the academic performance tests in numeracy and reading. They also exhibited higher aerobic fitness and motor skills, possibly imposing a selection bias. In paper V, a subsample (the lowest third of performance in numeracy at baseline) ($n = 360$) was used. This sample was obviously selected, but analyses were performed between groups, and, as discussed previously, this selected sample might be of specific interest due to its characteristics.

Content

The content of the intervention was developed from previous studies, in collaboration with experienced international researchers in the field, and in collaboration with the intervention teachers (Resaland et al., 2015). Ideas of activities were shared among teachers and the research group through seminars and the webpage. Most likely, this approach created an ownership of the intervention that was important for the implementation, as also suggested by others (Riley et al., 2016). Conversely, there is always a risk that the freedom given to intervention teachers to design and develop some of the activities to fit with the local children's interests and experiences may make the intervention package less standardized across schools, yielding greater dissimilarity than optimal. As local contextual factors (teachers, classes, built environment, climate, etc.) are fundamentally important for the implementation and sustainability of the intervention, we regard the local adaptations of crucial importance, despite our reduced control over the intervention content. Additionally, particular challenges were met for the physical activity homework component. These were performed outside of school hours. Therefore, we and the teachers were not able to monitor what children actually did in terms of physical activity during these hours.

Format

The intervention model was incorporated into the school curriculum at the intervention schools, with teachers in charge of the delivery. The inclusion of many schools, in a county with large geographical distances, imposed challenges with respect to monitoring the adherence to the prescribed intervention protocol. This was a threat to the internal validity of the study. However, what apparently turned out to be a greater threat was the control schools being overly enthusiastic about physical activity. In hindsight, we should possibly have done more to restrict control schools from doing more physical activity than prescribed, to maintain the intended contrasts between the groups. Thirteen of the 29 control schools reported performing more physical activity than prescribed for them as control schools (> 120%). Due to the format of the study, it was impossible to compare our intervention to a sedentary control condition, which has been shown to reveal larger intervention effects of physical activity (Vazou et al., 2016). However, although it would be beneficial to compare physical activity to a sedentary control group to prove the intervention's efficacy, it would be both unethical and unacceptable to the schools, parents, and children to reduce the control children's physical activity level below their normal baseline. Such an artificial control condition would also question the external validity of the study, as it would be a study of reduced physical activity as much as increased physical activity. Nevertheless, the 45 minutes of physical activity included in the curriculum, is not mandatory in fifth grade (the schools can choose to include it in the fifth, sixth and/or seventh grade for a total of 76 hours throughout this period). Therefore, we could have restricted the control schools from doing this 45 minutes of physical activity. We considered this option during the planning of the intervention, but found it unacceptable to the schools and parents to make this change to their curriculum. Due to the intervention model and mode of delivery, the external validity of the studies included in this thesis is strong in terms of providing evidence of the generalizability of the intervention model to the school system in Norway and possibly worldwide (Flay et al., 2005; Gottfredson et al., 2015; Price, Hillyer, & van der Molen, 2013). Evidence of the feasibility of the interventions is given through the teacher reports, where only one school did not report the prescribed level of implementation.

When implementing a physical activity intervention in the school, it is possible that seven months is an insufficient period to detect changes in academic performance. Others have suggested that when doing research in school, a minimum of one school year is required, as the intervention needs time to settle (White & Arzi, 2005). In support of this, the study by Mullender-Wijnsma et al. (2016) found effects on academic performance after two years, but generally not after one year of physically active mathematics and language lessons. However, Donnelly et al. (2017) failed to show effects after three years of their physical activity intervention. During the three years of intervention, however, the intervention delivery was reduced each year, showing that is was difficult to sustain the delivery of the intervention long term. Teachers have reported that time constraints and interruption of academic lessons were the major barriers to implementing the physical activity (Donnelly et al., 2017; Tsai, 2009).

Facilitators and pedagogy

The characteristics and qualification of the facilitators of an intervention, the classroom teachers in our case, may have a large impact on the program efficacy (Morgan et al., 2016). We organized three instructional seminars for the intervention teachers ahead of the intervention. In line with Harter's Competence Motivation Theory (Harter, 1978), Achievement goal theory (Nicholls, 1989), and Deci and Ryan's self-determination theory (Ryan, 2002), we emphasized that teachers would benefit from facilitating an autonomy-supportive and mastery-focused climate when planning, organizing, and leading the intervention activities. Furthermore, we provided the teachers with several examples of how they might interact with the children in an autonomy-supportive and mastery-focused manner. As a result, intervention teachers would be better able to positively influence children's need for competence, autonomy, and relatedness and thereby their intrinsic motivation for taking part in the physical activities.

We believe that having the classroom teachers as facilitators was a strength of the ASK study, as they were familiar with the school context, they knew the learning goals for the subjects, and they knew the children in their classes. This type of knowledge is of importance when designing intervention activities tailored to the children. However, differences in terms of experience, values, and expertise in organizing and facilitating physical activity may have varied among the teachers. These may have yielded differences with respect to pedagogy across schools when planning and implementing the intervention activities. For example, although group activities create opportunities for cooperation, and facilitate belonging and mastery (Ryan & Moller, 2017), we cannot rule out the possibility that some teachers emphasized competition, rather than co-operation, during implementation of some of the intervention physical activities. For some children, such as the ones less physically-motor skilled, this may have led to a less positive experiences taking part in the intervention (Bergh et al., 2012).

Analyses

The analyses conducted in the papers included in this thesis are in accordance with the statistical analysis plan. We performed intention-to-treat analyses to assess the effectiveness of the ASK interventions (papers II and III) (Resaland et al., 2015). This approach maintains that groups are different only due to random variation, and allows for non-compliance (Hollis & Campbell, 1999; Polit & Gillespie, 2010; Yelland et al., 2015). As intention-to-treat analyses require a complete dataset, missing data were imputed from all available relevant variables by means of multiple imputations using a Markov Chain Monte Carlo procedure with 20 iterations. Although imputation is used to produce a conservative estimate of intervention effects, no imputation method can provide unbiased estimates (Hollis & Campbell, 1999). We assumed that the missing data were missing at random (MAR) (Polit & Gillespie, 2010). For transparency, an overview of missing data is provided in flow charts in accordance with the Consolidated Standard of Reporting Trials (CONSORT) guidelines for cRCT studies in each paper (Campbell, Piaggio, Elbourne, Altman, & Grp, 2012). All effect analyses were performed both on imputed data and with completers only (children providing data on both baseline and follow-up), with similar results.

As defined in the statistical analysis plan, we also performed secondary per protocol analyses (inclusion criteria specified under statistics in methods and materials) to assess the efficacy of the intervention (papers II and III) (Polit & Gillespie, 2010). In these analyses, the randomization was not maintained, therefore, the intervention and control group may differ in certain characteristics. In the per protocol analyses, it was mainly control schools that were excluded (n = 13), rather than intervention schools (n = 1). This contrasts with several other previous intervention studies and demonstrates that the intervention prescribed was feasible for the schools, but it was not possible to restrict the control schools to the mandatory physical activity and physical education during a school day. Per protocol analyses revealed effects of the ASK intervention on executive function and motor skills (paper II).

SEM was used for the mediation analyses as also described in the analysis plan (papers IV and V). An advantage of using a latent variable of executive function was the avoidance of the task-impurity problem reported by others (Best & Miller, 2010; Cassidy, 2016; Friedman & Miyake, 2017; Miyake et al., 2000), as discussed previously. A limitation with executive function variable was that it did not provide information about how the different aspects of executive function were related to the indices of physical activity in this thesis. Using latent variables of each dimension of executive function could have yielded other results, as randomized controlled trials have reported effects of indices of physical activity on only one aspect of executive function and not others (Pesce et al., 2016; Schmidt et al., 2015). To do so, several tests of each aspect of executive function would have been necessary (Miyake et al., 2000). However, that was not feasible for the ASK study.

The inclusion of latent variables as mediators increases their reliability and validity, and reduces biased estimates for the paths in the mediation model (Cole & Maxwell, 2003). The use of latent variables in mediation models is suggested to be a solution to decrease both type 1 and type 2 errors, as measurement error in variables can lead to biased estimates. If the predictor (e.g., physical activity) or outcome (e.g., academic performance) is measured with error, the *a* and *b* path will be underestimated, respectively. Therefore, unreliable predictors and/or outcome measures will result in underestimation of the indirect effect. If, however, the mediator is measured with error, both the *a* and *b* path will be underestimated, but the *c′* path will be overestimated (Cole & Maxwell, 2003).

A limitation in the Mplus software used for the mediation models is the lack of ability to include both the MLR and the bootstrapping command. We considered accounting for the cluster effect of schools (through the complex command, using MLR) to be more important than using the bias corrected bootstrapping command. In one paper, however, both analyses were performed, revealing similar results (paper IV).

All analyses (papers I–V) were adjusted for the effect of clustering of observations within schools. Furthermore, analyses of cross-sectional associations and prospective mediation included several covariates (age, pubertal status, skinfold thickness, socio-economic status (paper I and IV), birthweight (paper I), and group allocation (paper IV)). These were included, due to their relatedness to both the independent and dependent variables; age (Best & Miller, 2010; Esteban-Cornejo, Tejero-Gonzalez, et al., 2015; Kolle et al., 2010), body fat (Davis & Cooper, 2011; Kolle et al., 2010), pubertal status (Kalkut et al., 2009), birth weight (Richards et al., 2001) and socio-economic status (Coe, Peterson, Blair, Schutten, & Peddie, 2013; Hackman & Farah, 2009; Sirin, 2005). Socio-economic status is suggested to be the most influential factor on academic performance (Castelli et al., 2014), and was therefore controlled in all associations analyses. However, we acknowledge that using a socio-economic variable, including the highest education level obtained by the mother or father only, might be a limitation, as one measure of socio-economic status more likely overestimates the effects of socio-economic status (Sirin, 2005). However, self-reported parental education is a valid and stable measure of socio-economic status, because it tends to be the same over time, is highly correlated with parents' income, and finally, parent education and income produce similar associations with academic performance (Sirin, 2005).

Strengths and limitations

The strength of this thesis was the inclusion of a cRCT design which investigated the efficiency of a multicomponent school-based physical activity on both executive function and academic performance. Another strength was the strong implementation of the intervention among the intervention schools in accord with the intervention protocol (according to the teacher reports). Moreover, given that the intervention was developed and delivered by the classroom teachers, we argue that the study exhibits good external validity. The thesis further comprises a large sample size with few dropouts. The inclusion of an objective measurement of physical activity is a strength, even though inconsistent methodologies confuse the interpretations and comparability across studies (Cain et al., 2013). Furthermore, the inclusion of measurements of aerobic fitness and motor skills made it possible to examine the independent relationships between the different indices of physical activity to executive function and academic performance. The measures also served as exposure measures of the intervention, enabling investigation of the contribution of both the physical activity dose and the motor skills to executive function and academic performance.

This thesis also has several limitations. A major limitation was that we did not manage to maintain solid contrasts between the intervention and control conditions. Many control schools carried out more physical activity than prescribed. This may have led to an underestimation of intervention effects in the intention-to-treat analyses. Furthermore, the ASK study lacked direct measurement of aspects pertaining to the level of mental engagement and coordinative challenges during the intervention, as applied in the studies by Pesce et al. (2016), Schmidt et al. (2015), and Crova et al. (2014). Such measurements could have made it possible to specify the effects of different aspects of physical activity on executive function and consequently, academic performance. We also lacked measures of sleep, nutrition, IQ, and motivation, of which could be of importance for the analyzed outcomes, and are recommended in the literature (Beck et al., 2016; Castelli et al., 2014; Donnelly et al., 2016; Lubans et al., 2016). However, measurements of sleep in children are challenging, and a previous study has shown that children are not reliable record-keepers of sleep (Harrington, 2013).

Implications for research and education

For research, this thesis, as do several earlier studies, shows the complexity and challenges with interventions targeting physical activity in school settings. However, our physical activity intervention shows promise, and should encourage future interventions. More research of high quality is needed to gain knowledge about *how* to integrate physical activity during the school day, *what* type of physical activities are best suited to affect relevant outcomes, and for *whom* the interventions works.

This thesis supports the need for future studies to test effects of interventions comprising a broader repertoire of both the dose and type of physical activity to extend our knowledge about their impact on executive function and other assets of self-regulation and academic performance. This knowledge will be important in designing sustainable physical activity models with positive effects on children's executive function and academic performance. Moreover, research replicating our longitudinal mediation models with more than two time points or measurements is warranted to extend our findings.

For education, this thesis suggests that inclusion of more physical activity in the school curriculum does generally not improve academic performance, but neither does it have an adverse consequence. Importantly, it seems that this alternative didactic approach can reach, and raise the performance of, the children most in need, possibly lending credit to a physically active school as an initiative to counter social inequality. Given the general evidence base for the relationship between indices of physical activity, executive function, and academic performance, the few positive relationships and tendencies in the present thesis, and the well-known benefits of physical activity for health outcomes, increased physical activity during the school day probably has great potential for all children's health and development. I, therefore, recommend increased effort from politicians and school authorities to initiate sustainable interventions and models for children of all ages. While interventions might have a greater impact and cost effectiveness early in children's lives (Heckman, 2006), there is a continuous decline in physical activity during adolescence (Cooper et al., 2015), which indicates a broad target group of children from preschool to young adulthood.

Bailey (2016, p. 16) ended his review with; "Movement needs to step out of the gym and infiltrate the whole school day". I fully agree.

CONCLUSIONS

This thesis has three conclusions, each answering one of the research questions posed:

1) Objectively measured physical activity was not associated with executive function and academic performance in cross-sectional analyses, and did not predict executive function and academic performance seven months later. As the ASK intervention did not create solid contrasts between the intervention and control schoolchildren's physical activity levels, our premise for observing any effect of the intervention on executive function and academic performance was limited. However, the ASK intervention showed an effect on numeracy in a subsample (the lower third in numeracy at baseline) of the school children in our study, despite no differences in physical activity level.

2) Executive function did not mediate the relationship between objectively measured physical activity and academic performance. The main reasons for no mediation were that indices of physical activity were not associated with executive function and academic performance in the prospective mediation analysis, and that change in executive function was not associated with change in academic performance in the sub-group analysis in the cRCT design.

3) Stronger relationships between executive function and academic performance were observed for motor skills than for objectively measured physical activity and aerobic fitness. Furthermore, in secondary analyses, effects of the ASK intervention were observed for executive function and motor skills, suggesting that the motor demands in the ASK intervention may have been important for improvement in executive function. Lastly, the prospective relationship between motor skill (Shuttle Run) and academic performance in numeracy was mediated by executive function.

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PAPER I

Mental Health and Physical Activity 12 (2017) 10–18

Contents lists available at ScienceDirect

Mental Health and Physical Activity

journal homepage: www.elsevier.com/locate/menpa

Relationships between physical activity, sedentary time, aerobic fitness, motor skills and executive function and academic performance in children

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A R T I C L E I N F O

Article history:
Received 11 September 2016
Received in revised form
19 December 2016
Accepted 16 January 2017
Available online 19 January 2017

Keywords:
Cognition
Accelerometry
The Andersen-test
Motor coordination
Sex-differences

A B S T R A C T

Background: There is evidence for weak positive relationships between physical activity, aerobic fitness, and motor skills to executive functions and academic achievement. Studies assessing their relative importance to executive functions and academic performance are lacking. The purpose of this study was to examine the independent associations for moderate to vigorous physical activity and sedentary time, aerobic fitness, and motor skills with executive functions and academic performance in 10-year-old children.
Method: A linear mixed model was used to analyze cross-sectional data from 697 children from 57 schools in Norway.
Results: No relationships were observed between moderate to vigorous physical activity and executive functions or academic performance. The time spent sedentary was related to executive functions (standardized regression coefficient (β) 0.17–0.21, $p < 0.05$) and academic performance in English (β 0.22, $p < 0.05$) in boys. Aerobic fitness was associated with executive functions (β 0.16–0.21, $p < 0.05$) and academic performance (β 0.17–0.21, $p < 0.05$) in boys only. Motor skills were associated with most measures of executive functions in both girls (β 0.16–0.25, $p < 0.01$) and boys (β 0.13–0.22, $p < 0.05$) and academic performance in girls (β 0.13–0.16, $p < 0.05$).
Conclusions: The strongest independent associations were observed for motor skills to executive functions. Sex-specific associations were observed for aerobic fitness and motor skills. Thus, comprehensive physical activity targeted to increase both aerobic fitness and motor skills may have the potential to positively affect executive functions and academic performance.

1. Introduction

A physical active lifestyle during childhood seems to have a positive influence on the developing brain, in terms of brain structure and function. Hence, research on the role of physical activity to executive functions and academic performance shows promise (Donnelly et al., 2016; Khan & Hillman, 2014; Tomporowski, McCullick, Pendleton, & Pesce, 2015). While this research agenda has taken steps forward, more research is needed to better understand physiological and motor-cognitive assets embedded in various forms of physical activity that may help explain the relationships to executive functioning and academic performance (Best, 2010; Donnelly et al., 2016; Tomporowski et al., 2015). The current study aims to help fill this void by exploring the relationships of objectively measured physical activity level, sedentary time, aerobic fitness, and motor skills to executive functions and academic performance.

Executive functions can be defined as “the cognitive processes necessary for goal-directed cognition and behavior” (Best, 2010, p. 331) with core functions generally defined to involve inhibition and

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http://dx.doi.org/10.1016/j.mhpa.2017.01.001
1755-2966/

interference control, working memory and cognitive flexibility (Diamond, 2013; Miyake et al., 2000). At present, several theoretical lines of reasoning exists advocating that different modes of physical activity in terms of activity level (dose) and cognitive-motor challenge (type) may relate differently to the core executive functions. Supporting the view that level and type of physical activity may play a role, Best (2010) forwarded three mechanisms by which physical activity can affect executive functions: a) through physiological changes in the brain, b) through cognitive demands inherent in engaging games and c) through cognitive demands required to execute complex motor movement.

1.1. The role of physical activity level

Engaging in repetitive aerobic physical activity (e.g. running) can induce angiogenesis, increased blood volume, and upregulation of growth factors and neurothrophins (Best, 2010). Cross-sectional studies with objective measurements of physical activity have shown that moderate to vigorous physical activity (MVPA) has been associated with decreased reaction time (Syvaoja, Tammelin, Ahonen, Kankaanpaa, & Kantomaa, 2014) and improved executive attention (Booth et al., 2013). Furthermore, a sufficient level of MVPA can increase aerobic fitness (Armstrong, Tomkinson, & Ekelund, 2011), which might be a prerequisite to improve executive function (the cardiovascular fitness hypothesis) (Schmidt, Jager, Egger, Roebers, & Conzelmann, 2015). Current studies have found superior brain structure and function, coupled with increased performance on tasks of executive function in higher fit children compared to lower fit children (see Chaddock, Pontifex, Hillman, & Kramer, 2011; Donnelly et al., 2016; Khan & Hillman, 2014 for reviews). Although aerobic fitness arguably is a direct measure of the physiological strain induced by MVPA, these parameters represents different constructs (physical activity a behavior, and aerobic fitness a personal attribute with a genetic component) (Rowland, 2005; Schutte, Nederend, Hudziak, Bartels, & de Geus, 2016), meaning that it is important to determine their independent relationships with executive functions. Due to the increased measurement precision of aerobic fitness compared to physical activity (that inherently vary over time and is difficult to capture precisely) (Ekelund et al., 2007), the relationships of aerobic fitness to executive functions are expected to be stronger than those of physical activity.

Moderate to vigorous physical activity and sedentary time are separate dimensions of activity (Ekelund et al., 2007; Sedentary Behaviour Research Network, 2012) that may be associated with executive functions and academic performance in different ways. Sedentary time can be defined as any waking behavior while in a sitting or reclining posture requiring an energy expenditure $\leq$1.5 resting metabolic equivalents (Sedentary Behaviour Research Network, 2012). Few studies exists for the associations between sedentary behavior and cognitive health while accounting for levels of moderate to vigorous physical activity (Faulkner & Biddle, 2013) and evidence for the relationship between sedentary time and academic performance is lacking (Carson et al., 2016). Thus, more studies are needed on this area of research.

1.2. The role of type of physical activity

Gains obtained in motor skills performance through participation in group games and complex motor tasks may possibly induce neurogenesis in the hippocampus and physiological changes in the cerebellum. Furthermore, as group games and executive function tasks require similar cognitive skills, it is possible that skills acquired during complex motor tasks and cognitively demanding group games transfer to executive functions (Best, 2010). The close interrelationship between motor control and executive functions is furthermore underlined by 1) the co-activation between the prefrontal cortex, the cerebellum and the basal ganglia during several motor and cognitive tasks, 2) their similar developmental timetable (Diamond, 2000), and 3) their common underlying processes, such as sequencing, monitoring and planning (Roebers & Kauer, 2009; van der Fels et al., 2015).

Intervention studies manipulating the mental engagement in physical activity through enhancing the coordinative and cognitive demands have revealed superior effects on executive functions compared to physical activities without this enhancement (Crova et al., 2013; Pesce et al., 2016; Schmidt et al., 2015). For example, Pesce et al. (2016) showed that physical education with playful coordinative and cognitive enrichment improved inhibition, and that this improvement was mediated by motor coordination. In cross-sectional studies, weak positive associations have been found between motor skills and executive functions in children (Davis, Pitchford, & Limback, 2011; Roebers & Kauer, 2009). Studies reports inconsistency in which components of executive function that are affected by or associated with physical activity, which might be due to different components of executive function having different developmental trajectories (Best & Miller, 2010). Thus, examination of the genuine relationships between motor skills performance and individual aspects of executive functions are important to clarify.

1.3. Executive functions and academic performance

Executive functions are important for learning, and their relevance for academic performance in mathematics, English (reading, writing and spelling) and science is empirically documented (Barenberg, Berse, & Dutke, 2011; Best, Miller, & Naglieri, 2011; Bull & Scerif, 2001; St Clair-Thompson & Gathercole, 2006). As academic performance is a more global measure of cognition compared to executive functions, weaker relationships between physical activity, aerobic fitness, and motor skills to academic performance than to executive functions are expected. The current evidence has revealed positive, but weak, relationships for physical activity (Donnelly et al., 2016; Esteban-Cornejo, Tejero-Gonzalez, Sallis, & Veiga, 2015; Singh, Uijtdewilligen, Twisk, van Mechelen, & Chinapaw, 2012), aerobic fitness (Davis & Cooper, 2011; Donnelly et al., 2016; Lambourne et al., 2013), and motor skills (Haapala et al., 2014; Rigoli, Piek, Kane, & Oosterlaan, 2012), to academic performance. A major limitation, however, is that the evidence with few exceptions is based on self-reported physical activity levels. The results from cross-sectional studies using objective measures of physical activity are less consistent than the evidence on self-reported physical activity (Corder et al., 2015; Esteban-Cornejo et al., 2014; Kwak et al., 2009; Lambourne et al., 2013; LeBlanc et al., 2012; Syvaoja et al., 2013). Furthermore, there exists no clear pattern among the level and type of physical activity and specific subjects such as math, reading or spelling (Donnelly et al., 2016). Thus, exploring specific subjects may add knowledge to the evidence of the relationship between level and type of physical activity and academic performance.

Studies assessing the relative importance of physical activity, sedentary time, aerobic fitness, and motor skills to executive functions and academic performance, while also examining the relationship between executive functions and academic performance are lacking (Haapala, 2013; Khan & Hillman, 2014). Therefore, the purpose of the present study was to examine the independent associations for physical activity, sedentary time, aerobic fitness, and motor skills with executive function and academic performance in a sample of 10-year-old Norwegian girls and boys. From the hypotheses by Best (2010) and the current empirical evidence, we hypothesized that there would be 1) independent associations for physical activity level to executive functions and academic performance, 2) independent associations for motor skill to executive functions and academic performance, and that 3) the associations for motor skills would be stronger than those of physical activity, sedentary time, and aerobic fitness.

2. Methods

The Active Smarter Kids (ASK) study is a cluster-randomized controlled trial investigating the effect of 60 min daily school-based physical activity on academic performance as the main outcome. The present study used baseline data from this trial to investigate cross-sectional associations among the variables of interest. All fifth-grade children at schools in the county of Sogn og Fjordane, Norway, with at least seven fifth-grade children enrolled, were invited to participate in the ASK trial. Sixty schools, encompassing 1202 fifth-grade children, fulfilled this inclusion criteria, and agreed to participate. After randomization, three schools from the same municipality declined to participate. In total, 1145 (82.1% of the population of 10-year-old in the county) of the 1175 invited children from 57 school agreed to participate in the trial. This present study includes children with valid measures on all the included variables (697 children; 357 girls and 340 boys). This represents 61.7% of the total sample included in the ASK trail. The main reasons for missing data were sickness on one of the test days, exemption for participating on the national tests of academic performance, that a child (or their parents or guardians) did not return questionnaires, lack of valid measurements for physical activity, or that the child was unable to complete tests of executive functions (e.g. due to reading difficulties or color blindness). Fig. 1 provides an overview of the recruitment of the children and the numbers of missing data for each variable. For more thorough descriptions of the methods, see the design paper (Resaland et al., 2015).

2.1. Assessments

2.1.1. Physical activity and sedentary time

Physical activity and sedentary time were measured by ActiGraph accelerometers (ActiGraph GT3X+, LLC, Pensacola, Florida, USA), which are being widely applied and extensively tested for validity and reliability in children and youth (De Vries et al., 2009). Children were instructed to wear the accelerometer on the right hip over seven consecutive days at all times, except during water activities or while sleeping. A wear-time of ≥480 min/day for ≥ four days was applied as a criterion for a valid measurement. Periods of ≥20 min of zero counts were defined as non-wear time (Esliger, Copeland, Barnes, & Tremblay, 2005). The outcomes for physical activity were MVPA (cut-point 2296 counts per minute (cpm)) and sedentary time (0–100 cpm) (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008; Trost, Loprinzi, Moore, & Pfeiffer, 2011). All analyses were based on the accumulation of data over 10 s' epochs.

2.1.2. Aerobic fitness

Aerobic fitness was measured with an intermittent practical running field test (the Andersen-test (Aadland, Terum, Mamen, Andersen, & Resaland, 2014; Andersen, Andersen, Andersen, & Anderssen, 2008)). The Andersen-test was administered according to standard procedures. The children were tested indoors on a wooden or rubber floor in groups of 10–20 children. The test was performed over 10 min. Children ran from one end line to another (20 m apart) in an intermittent to-and-fro movement, with 15-s work periods and 15-s breaks (standing still) signaled by the test leader blowing a whistle. The distance covered was the outcome for

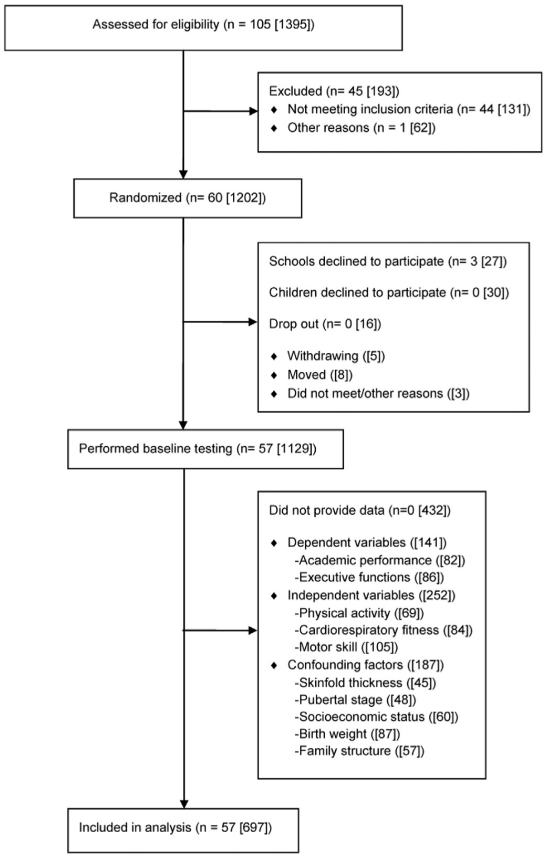

Fig. 1. Flow diagram of the recruitment of the children and the missing data (n = schools [children]).

the analysis and was recorded by adult test assistants who counted for one or two children each. Prior to testing, we provided all teachers a video demonstrating the Andersen test, which they were asked to show the children prior to testing. Furthermore, the children performed approximately five minutes of warm-up to familiarize with the test, after the test was explained and demonstrated by the test-leader. To enable comparing of aerobic fitness level across studies, VO_{2peak} was calculated using the equation suggested by Aadland et al. (2014).

2.1.3. Motor skills

Motor skills were measured using a battery of three tests: 1) Catching with One Hand, 2) Throwing at a Wall Target and 3) Shuttle Run, 10 × 5 m. Tests 1 and 2 constitute the subgroup Aiming and Catching from the Movement Assessment Battery for Children 2 (Movement ABC-2), ageband 3 (11–16 years) (Henderson, Sugden, & Barnett, 2007), and test 3 is from the Eurofit test battery (Council of Europe, 1993). In accordance with the standard testing procedure for the Movement ABC-2, the children performed five practice attempts in each tasks (1 and 2) before testing. No practice was given prior to the Shuttle Run test (3). A composite score of the three motor skills tests (all standardized by sex before calculation) was used in all analyses.

2.1.4. Executive functions

We measured the three key executive functions identified by Miyake et al. (2000) (inhibition, working memory and cognitive flexibility) using four pen and paper tests in the listed order (1–4). The tests were administered individually in a quiet room at the children's schools, during the school day, with the guidance of trained research assistants and in accordance with the standard instructions. The four tests were completed in 15–20 min.

Inhibition was assessed with **1)** the Stroop Color and Word Test (Golden, 1978). This test has three trials: a) reading color names printed in black ink, b) naming color of the ink (red, blue and green) printed with *XXXX*s, and c) naming of colors of printed words rather than reading the words (incongruent trial). The scoring criterion is number of items read or named in 45 s (Lezak, Howieson, Bigler, & Tranel, 2012). To assess cognitive flexibility, we used one verbal (Verbal Fluency) and one non-verbal test (The Trail Making Test (see 4)). In **2)** the Verbal Fluency test, the children were asked to name as many animals as possible in 60 s. The score was the total number of animals listed (Spreen & Strauss, 1998). Working memory was assessed with **3)** a Digit Span test (both Digits Forward and Backward) from the Wechsler Intelligence Scale for Children, fourth ed. (WISC-IV) (Weschsler, 2003). Both tests consist of pairs of random numbers of an increasing sequence length, which the test leader read aloud at the rate of one number per second. In the forward task, the children were asked to repeat each sequence exactly as it was given, and in the backward task, they were asked to repeat the sequence back in reverse order (Lezak et al., 2012). The scores were the number of correct repeated sequences for both forward and backward task and in total. **4)** The Trail Making Test was given in two parts. In Part A, the children were instructed to draw a line to connect consecutively numbered circles as fast as possible without lifting the pencil from the paper. In Part B, they were instructed to alternate between consecutively numbered and lettered circles (Lezak et al., 2012; Spreen & Strauss, 1998). We used the Reitan scoring method for the Trail Making Test, where we noted the errors as they occurred so that the children completed the task without errors (Reitan & Wolfson, 2004). The scores of this test were the total time required to complete each part. In addition to applying all individual variables as outcomes, a composite score based on all variables (Color-Word task of the Stroop Test, Verbal Fluency total, the Digit Backward for WISC-IV, and the Trail Making Test part B) was calculated (all variables were standardized by sex before calculation).

All tests of executive functions are validated for use in children, and have been shown appropriate for measuring executive functions in 10-year-old children (Stroop (Peru, Faccioli, & Tassinari, 2006), Verbal Fluency (Ardila, Ostrosky-Solís, & Bernal, 2006; Riva, Nichelli, & Devoti, 2000), WISC-IV (Weschsler, 2003), and the Trail Making Test part B (Reitan & Wolfson, 2004)).

2.1.5. Academic performance

Academic performance in 1) English, 2) reading and 3) numeracy were measured using specific standardized Norwegian National tests designed and administered by the Norwegian Directorate for Education and Training (NDET). The three different tests were administered on three different days. The tests have shown evidence of good validity and reliability by NDET and are aligned with the competencies demanded from all schools by the national curriculum (Resaland et al., 2015). The scores are reported as standardized points, with a mean of 50 and a standard deviation (SD) of 10. We used each variable separately, as well as a composite score of the three variables (standardized by sex before calculation), as outcome variables.

2.2. Potential confounders

Several potential covariates were adjusted for, as they have been shown to impact the independent and dependent variables; age (Best & Miller, 2010; Esteban-Cornejo et al., 2015; Kolle, Steene-Johannessen, Andersen, & Anderssen, 2010), body fat (Davis & Cooper, 2011; Kolle et al., 2010), pubertal status (Kalkut, Han, Lansing, Holdnack, & Delis, 2009), birth weight (Richards, Hardy, Kuh, & Wadsworth, 2001), and socio economic status (Coe, Peterson, Blair, Schutten, & Peddie, 2013). Body fat was measured using four skinfold thickness sites (biceps, triceps, subscapular and suprailiac) using a Harpenden skinfold caliper (Bull; British Indicators Ltd., West Sussex, England) according to the criteria described by Lohman, Roche, and Martorell (1991). The Harpenden skinfold caliper has been tested for validity and reliability in children (Yeung & Hui, 2010). Children self-assessed their pubertal stage with the Tanner method (Tanner, 1962) using a scale of colored images proposed by Carel and Leger (2008). We used breast and genital development for girls and boys, respectively. Birth weight and socio economic status (the highest education level obtained by the mother or father) were reported by the parents or guardians. For more details concerning the methodology, see the design paper (Resaland et al., 2015).

2.3. Ethics statement

The procedures and methods used in the ASK study conform to the ethical guidelines defined by the World Medical Association's Declaration of Helsinki and its subsequent revisions (WMA, 2013). The study protocol was approved by The Regional Committee for Medical Research Ethics. We obtained written consent from each child's parents or guardians prior to all testing.

2.4. Statistical methods

The children's characteristics are provided as the means and standard deviations (SD) or frequencies. Sex-differences, differences between included and excluded children and multiple regression analyses were determined using a linear mixed model, including the school as a random effect. The association analyses were performed in two steps. 1) Bivariate associations between the independent and dependent variables were determined using the Pearson correlation coefficient (r). 2) Multiple regression analyses were performed with executive functions and academic performance as dependent variables, including MVPA, sedentary time, aerobic fitness, and motor skills, as well as age, skinfold thickness, pubertal stage, birth weight and socio economic status as independent variables. To examine the role of sex as a moderator for the examined associations, the interaction between sex and all independent variables were included in the fully adjusted models. As significant interactions by sex were observed for aerobic fitness (aerobic fitness*sex) and motor skills (motor skills*sex), all analyses were conducted for girls and boys separately. For ease of interpretation, all variables were standardized before the analysis; thus, all results are reported as standardized regression coefficients. The residuals were normally distributed in all models. All analyses were performed using the SPSS software, version 23.0 (IBM SPSS Statistics for Windows, Armonk, NY: IBM Corp., USA). A p-value < 0.05 was used to indicate statistically significant main effects, whereas a p-value < 0.10 was applied to indicate statistically significant interaction terms (Twisk, 2006).

3. Results

3.1. Children's characteristics

The included children performed significantly better on all measures of executive functions ($p < 0.029$) and the tests in numeracy ($p = 0.001$) and reading ($p < 0.001$) compared to the excluded children. Furthermore, they exhibited better aerobic fitness ($p < 0.001$) and motor skills ($p < 0.031$), whereas physical activity levels were similar across the groups.

The children's characteristics are shown in Table 1. Girls performed better on all but one test (Verbal Fluency) of executive functions ($p \leq 0.004$), while boys did better on the tests in English ($p = 0.034$) and numeracy ($p = 0.018$). Furthermore, boys had higher physical activity levels ($p \leq 0.001$), better aerobic fitness ($p < 0.001$) and better motor skills ($p \leq 0.005$) compared to girls, whereas girls had higher skinfold thickness than boys ($p < 0.001$).

3.2. Sex as a moderating factor

Interaction effects of sex were observed between aerobic fitness and Verbal Fluency ($p = 0.049$), the composite score of executive functions ($p = 0.052$), numeracy ($p = 0.018$), reading ($p = 0.062$), and the composite score of academic performance ($p = 0.088$), and between motor skills and WISC-IV backwards ($p = 0.067$), English ($p = 0.035$), reading ($p = 0.049$), and the composite score of academic performance ($p = 0.028$).

3.3. Interrelationships among dependent and independent variables

The interrelationships between the composite scores of executive functions and academic performance were $r = 0.55$ ($p < 0.001$) for girls and $r = 0.52$ ($p < 0.001$) for boys. All interrelationships among the independent variables were statistically significant in both girls and boys (Table 2).

3.4. Executive function

Moderate to vigorous physical activity was positively associated with Verbal Fluency, WISC-IV backwards and the composite score of executive functions for boys in the bivariate analysis (Table 2). In the fully adjusted model, however, no associations were observed between MVPA and executive functions. For sedentary time, no significant associations were observed with executive functions in the bivariate analyses, however, positive associations emerged for sedentary time with WISC-IV backwards in girls (Table 3a), and the Stroop test, Trail Making B and the composite score of executive functions in boys (Table 3b). Aerobic fitness was positively associated with all measures of executive functions (except for Verbal Fluency in girls) in the bivariate analysis (Table 2). In boys, these associations remained significant (except for Verbal Fluency) in the fully adjusted model (Table 3b). Motor skills were positively associated with all measures of executive functions, with the exceptions of Verbal Fluency in both sexes and WISC-IV backwards in boys (Tables 2 and 3b), both in the bivariate and the fully adjusted model. Thus, sex-specific associations emerged for the relationship between aerobic fitness and executive functions.

3.5. Academic performance

In girls, neither MVPA nor sedentary time were related to academic performance in any model (Tables 2 and 3a). In boys, however, bivariate positive associations were observed between MVPA and the test in numeracy and between sedentary time and the test in English (Table 2). After adjustment, the association between sedentary time and the test in English was the only association that remained significant (Table 3b). For aerobic fitness, significant bivariate positive associations were found for all variables of academic performance, except for the test in reading for girls and the test in English for boys (Table 2). After adjustment, the significant associations for the test in numeracy and the composite score of academic performance persisted in boys, whereas no associations remained statistically significant in girls (Table 3a). Significant positive associations were observed between motor skills and all measures of academic performance in both the bivariate analyses and in the fully adjusted model for girls (Tables 2 and 3a). In boys, however, a significant positive association between motor skills and test in numeracy and a negative association between motor skills and the test in English was observed in the bivariate analysis (Table 2). None of these observations persisted as statistically significant in the fully adjusted model. In summary, the results show sex-specific associations between the independent variables and academic performance, with positive associations observed for motor skills in girls and aerobic fitness in boys.

4. Discussion

The main findings from this study were that 1) positive relationships for sedentary time, aerobic fitness, and motor skills with executive functions and academic performance were found, while no relationships were observed between MVPA and executive functions or academic performance. However, 2) sex-specific associations emerged for the relationships between aerobic fitness and executive functions and academic performance (only evident in boys), and between motor skills and academic performance (only evident in girls), whereas 3) relationships between motor skills and executive functions were nearly the same in both sexes. These results are in support of a possible impact of both physical activity level and the cognitive-motor challenge of physical

Table 1
Characteristics for the included children as means and standard deviations (SD) or frequencies.

Characteristic	Girls (n = 357)	Boys (n = 340)	Total (n = 697)
Age (year)	10.2 (0.3)	10.2 (0.3)	10.2 (0.3)
Skinfold thickness (mm)	59.0 (29.3)	40.8 (19.9)***	50.1 (26.7)
Socio economic status			
Upper secondary school	31.9	30.6	31.3
< 4 years of university/college	27.7	28.5	28.1
≥ 4 years of university/college	40.3	40.9	40.6
Tanner stage			
1	22.4	35.0	28.6
2	65.3	57.1	61.3
3, 4 and 5	12.3	7.9	10.2
NT English (score)	48.5 (9.4)	50.2 (10.4)*	49.4 (9.8)
NT reading (score)	50.1 (9.3)	49.9 (9.6)	50.0 (9.5)
NT numeracy (score)	51.0 (8.9)	52.9 (9.9)*	52.0 (9.4)
Stroop CW (n words)	27.1 (5.9)	25.4 (5.8)***	26.3 (5.9)
Verbal Fluency (n words)	16.4 (4.5)	16.1 (4.7)	16.2 (4.6)
WISC-IV Backwards (score)	6.4 (1.3)	6.1 (1.3)**	6.3 (1.3)
Trail Making B (s)	112.0 (38.1)	128.4 (54.6)***	120.0 (47.6)
Counts per minute	689 (240)	785 (315)***	736 (283)
MVPA (% all day)	8.8 (2.7)	10.6 (3.5)***	9.7 (3.3)
Sedentary time (% all day)	60.3 (5.9)	59.4 (6.5)	59.8 (6.2)
Aerobic fitness (m)	877 (85)	928 (112)***	902 (102)
Estimated VO_{2peak} (ml/kg/min)	49.1 (6.1)	55.8 (7.3)***	52.3 (7.5)
Shuttle-run (s)	23.3 (2.0)	22.3 (2.2)***	22.8 (2.2)
Aiming (n)	3.9 (2.9)	4.3 (1.9)**	4.1 (2.0)
Catching (n)	3.4 (2.9)	5.2 (3.1)***	4.2 (3.1)

Note. NT = national test; Stroop CW = Stroop Color Word; MVPA = moderate to vigorous physical activity; *$p \leq 0.05$ for the difference between girls and boys; **$p \leq 0.01$ for the difference between girls and boys; ***$p \leq 0.001$ for the difference between girls and boys.

Table 2
Bivariate associations (standardized regression coefficient) among and between independent and dependent variables for girls (above principal diagonal) and boys (below principal diagonal).

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Light PA	–	**0.53**	**0.29**	**0.45**	**-0.91**	0.01	0.04	-0.10	-0.00	-0.09	0.01	-0.08	-0.09	-0.08	0.01	-0.06
2. Moderate PA	**0.45**	–	**0.60**	**0.88**	**-0.78**	**0.14**	**0.15**	-0.03	0.00	0.03	-0.00	0.00	-0.06	-0.08	0.01	-0.05
3. Vigorous PA	0.08	**0.58**	–	**0.91**	**-0.62**	**0.25**	**0.21**	0.02	0.06	0.08	-0.10	0.10	0.09	0.03	**0.17**	**0.11**
4. MVPA	**0.27**	**0.85**	**0.92**	–	**-0.76**	**0.22**	**0.21**	-0.01	0.04	0.06	-0.06	0.06	0.03	-0.03	0.10	0.04
5. Sedentary time	**-0.86**	**-0.78**	**-0.55**	**-0.73**	–	**-0.11**	**-0.12**	0.07	-0.02	0.04	0.02	0.03	0.05	0.07	-0.06	0.02
6. Aerobic fitness	0.00	**0.25**	**0.31**	**0.32**	**-0.17**	–	**0.50**	**0.15**	-0.01	**0.16**	**-0.12**	**0.18**	**0.17**	0.10	**0.17**	**0.16**
7. Motor skills	0.00	**0.30**	**0.29**	**0.33**	**-0.18**	**0.54**	–	**0.26**	0.05	**0.20**	**-0.26**	**0.30**	**0.19**	**0.14**	**0.22**	**0.21**
8. Stroop CW	**-0.14**	-0.02	0.05	0.02	0.09	**0.24**	**0.28**	–	**0.16**	**0.27**	**-0.43**	**0.70**	**0.28**	**0.28**	**0.35**	**0.35**
9. Verbal Fluency	0.05	0.07	**0.12**	**0.11**	-0.09	**0.13**	0.10	0.10	–	**0.19**	**-0.18**	**0.58**	**0.30**	**0.33**	**0.21**	**0.32**
10. WICS-IV B.	-0.03	0.10	0.10	**0.11**	-0.04	**0.15**	0.09	**0.24**	0.05	–	**-0.27**	**0.65**	**0.30**	**0.32**	**0.32**	**0.36**
11. Trail Making B	**0.15**	0.01	-0.07	-0.04	-0.08	**-0.23**	**-0.22**	**-0.44**	**-0.18**	**-0.25**	–	**-0.71**	**-0.33**	**-0.36**	**-0.45**	**-0.43**
12. Executive Func.	-0.10	0.05	**0.13**	**0.11**	0.02	**0.29**	**0.27**	**0.70**	**0.52**	**0.60**	**-0.73**	–	**0.46**	**0.49**	**0.50**	**0.55**
13. NT English	**-0.15**	-0.04	0.03	0.00	**0.11**	0.01	**-0.01**	**0.33**	0.05	**0.29**	**-0.38**	**0.41**	–	**0.68**	**0.61**	**0.87**
14. NT reading	-0.09	0.02	0.06	0.05	0.04	**0.11**	0.05	**0.30**	0.10	**0.31**	**-0.38**	**0.43**	**0.70**	–	**0.64**	**0.89**
15. NT numeracy	0.03	**0.15**	**0.14**	**0.16**	-0.11	**0.23**	**0.17**	**0.32**	**0.21**	**0.36**	**-0.50**	**0.54**	**0.62**	**0.66**	–	**0.86**
16. Academic Perfor.	-0.08	0.05	0.08	0.08	0.02	**0.13**	0.08	**0.36**	**0.14**	**0.37**	**-0.48**	**0.52**	**0.88**	**0.90**	**0.86**	–

Note. Regression coefficients ≥ 0.11 (positive or negative) are significant ($p \le 0.05$) and in boldface. PA = physical activity; MVPA = moderate to vigorous physical activity; Stroop CW = Stroop Color Word; WISC-IV B. = WISC-IV Backwards; Executive Func. = composite score of executive functions; NT = national test; Academic Perfor. = composite score of academic performance.

Table 3
Independent associations between MVPA, sedentary time, aerobic fitness and motor skills with executive functions (A) and academic performance (B) in girls and boys, adjusted for age, skinfold thickness, pubertal status, socio economic status, and birth weight.

A)

	Stroop CW	Verbal Fluency	WISC-IV B.	Trail Making B	Executive Function
	β [CI]	β [CI]	β [CI]	β [CI]	β [CI]
Girls (n = 357)					
MVPA	0.01 [-0.16, 0.18]	0.06 [-0.11, 0.23]	0.15 [-0.03, 0.32]	-0.03 [-0.20, 0.13]	0.09 [-0.07, 0.26]
Sedentary time	0.14 [-0.03, 0.30]	0.03 [-0.14, 0.19]	0.19* [0.02, 0.35]	-0.02 [-0.18, 0.15]	0.13 [-0.03, 0.29]
Aerobic fitness	0.03 [-0.11, 0.16]	-0.12 [-0.26, 0.02]	0.01 [-0.13, 0.16]	-0.06 [-0.20, 0.08]	-0.01 [-0.15, 0.12]
Motor Skills	0.24*** [0.12, 0.35]	0.05 [-0.07, 0.17]	0.16** [0.04, 0.09]	-0.19** [-0.31, -0.07]	0.25*** [0.13, 0.36]
ICC	0.11	0.01	0.06	0.01	0.03
Boys (n = 340)					
MVPA	0.04 [-0.12, 0.20]	0.01 [-0.16, 0.17]	0.14 [-0.03, 0.30]	-0.10 [-0.26, 0.06]	0.11 [-0.05, 0.27]
Sedentary time	0.19* [0.04, 0.34]	-0.06 [-0.22, 0.10]	0.08 [-0.08, 0.23]	-0.21** [-0.37, -0.06]	0.17* [0.02, 0.31]
Aerobic fitness	0.17* [0.02, 0.31]	0.03 [-0.12, 0.18]	0.16* [0.01, 0.32]	-0.17* [-0.32, -0.02]	0.21** [0.07, 0.36]
Motor skills	0.22*** [0.09, 0.34]	0.03 [-0.10, 0.16]	-0.02 [-0.15, 0.11]	-0.13* [-0.26, -0.00]	0.14* [0.02, 0.26]
ICC	0.04	0.00	0.04	0.03	0.06

B)

	NT English	NT reading	NT numeracy	Academic performance
	β [CI]	β [CI]	β [CI]	β [CI]
Girls (n = 357)				
MVPA	0.06 [-0.11, 0.23]	0.00 [-0.17, 0.17]	0.07 [-0.10, 0.24]	0.06 [-0.11, 0.22]
Sedentary time	0.14 [-0.03, 0.30]	0.09 [-0.08, 0.25]	0.05 [-0.11, 0.22]	0.11 [-0.06, 0.27]
Aerobic fitness	-0.02 [-0.16, 0.12]	-0.08 [-0.22, 0.06]	-0.02 [-0.16, 0.12]	-0.05 [-0.18, 0.09]
Motor skills	0.14* [0.02, 0.25]	0.13* [0.01, 0.25]	0.16** [0.05, 0.28]	0.16** [0.05, 0.28]
ICC	0.06	0.06	0.13	0.10
Boys (n = 340)				
MVPA	0.11 [-0.05, 0.28]	0.10 [-0.06, 0.26]	0.01 [-0.14, 0.16]	0.08 [-0.08, 0.24]
Sedentary time	0.22** [-0.07, 0.37]	0.13 [-0.02, 0.28]	-0.02 [-0.16, 0.12]	0.12 [-0.02, 0.26]
Aerobic fitness	0.07 [-0.09, 0.22]	0.12 [-0.02, 0.28]	0.21** [0.08, 0.35]	0.17* [0.02, 0.31]
Motor skills	-0.05 [-0.18, 0.07]	-0.05 [-0.17, 0.07]	0.03 [-0.08, 0.15]	-0.03 [-0.15, 0.09]
ICC	0.14	0.10	0.19	0.17

Note. β = standardized regression coefficient; [CI] = 95% confidence interval; Stroop CW = Stroop Color Word; WISC-IV B. = WISC-IV Backwards; NT = national test; MVPA = moderate to vigorous physical activity; ICC = intra class correlation, $^{*}p \le 0.05$; $^{**}p \le 0.01$; $^{***}p \le 0.001$.

activity on executive functions and academic performance, and thus supports the hypotheses forwarded by Best (2010) and the first and second hypotheses put forward in this present study.

Our bivariate associations are generally consistent with the current evidence base (Booth et al., 2013; Carson et al., 2016; Donnelly et al., 2016; Esteban-Cornejo et al., 2015; Rigoli et al., 2012; Roebers & Kauer, 2009; Singh et al., 2012). However, when examining the independent associations for MVPA, sedentary time, aerobic fitness, and motor skills with executive functions and academic performance, only associations between motor skills and executive functions remained significant in the fully adjusted model for both sexes. Hence, the strongest independent associations were seen for motor skills with executive functions, suggesting that motor skills may have the strongest influence on executive functions, supporting our third hypothesis and the motor-cognitive challenge hypotheses by Best (2010). The associations observed between motor skills and executive functions and academic performance are in line with some previous findings, where the strongest relationships have been observed between the complex motor skills and higher order cognitive skills (Davis et al., 2011; van der Fels et al., 2015). This is furthermore supported by intervention studies, where participation in enhanced physical activity in regards to cognitive- and motor challenges, have been shown to have better effects on executive functions compared to physical activity without this enhancement (Crova et al., 2013; Pesce et al., 2016; Schmidt et al., 2015; Westendorp et al., 2014).

Our results suggests that MVPA does not relate independently to executive functions and academic performance after controlling for sedentary time, aerobic fitness, and motor skills. This finding provide evidence against the hypothesis that the level of physical activity may be a pathway to impact executive functions. However, although an objective measure provide a more accurate estimate of habitual physical activity compared to self-reported measures, it does not give a fully representative picture of a child's physical activity behavior, as physical activity is a complex behavior to capture accurately (Ekelund et al., 2007). Aerobic fitness, a measure of the capacity to undertake aerobic work partly determined by the physical strain induced by MVPA, may therefore, from its higher measurement precision, add information to relationships between the physical activity intensity level and cognitive outcomes. As the present study observed independent associations between aerobic fitness and all measures of executive functions and some measures of academic performance in boys, it partly supports that physical activity level in fact may be a pathway for improving executive functions (consistent with our first hypothesis). In line with this finding, previous studies have indicated increased efficiency in neural processing and changes in brain structures in children with greater aerobic fitness compared to their lower fit peers (Chaddock et al., 2011; Donnelly et al., 2016; Khan & Hillman, 2014). Of importance though, aerobic fitness has a strong genetic component (Schutte et al., 2016), meaning that children's phenotype may be more important than their physical activity levels for their level of aerobic fitness and consequently executive function and academic performance.

We found significant independent associations between sedentary time and working memory in girls and between sedentary time and both cognitive flexibility and the composite score of executive functions in boys. These results are partly consistent with previous studies. Syvaoja et al. (2014) found a significant positive association between sedentary time and sustained attention, however, in contrast to our study; they did not observe significant associations with working memory or cognitive flexibility. The lack of associations between sedentary time and academic performance observed in the present study, are in line with the study of Syvaoja et al. (2013), but contrary to conclusions by Carson et al. (2016) and Corder et al. (2015), who found a positive relationship between sedentary time and academic performance. Of importance though, sedentary time comprise several different sedentary behaviors, and screen time has been associated with lower academic performance, whereas non-screen time (reading/homework) has been associated with higher academic performance (Carson et al., 2016; Corder et al., 2015; Syvaoja et al., 2014). Thus, total sedentary time might be a poor measure of the relationship with academic performance, as screen- and non-screen sedentary time (e.g., school work) show opposite associations with academic performance indicating that associations between accelerometer-determined total sedentary time that do not provide any information on context and type of sedentary behavior should be interpreted carefully.

The independent associations for aerobic fitness and executive functions and academic performance in boys, and the independent associations between motor skills and academic performance in girls, suggests that physical activity level and motor-cognitive challenges may both be relevant pathways to affect executive functions and academic performance, but that possible sex-specific differences exists in 10-year-old children. To our knowledge, sex-specific associations among these variables have only been examined in one previous prospective study. Contrary to the present study, Haapala et al. (2014) did not reveal any statistically significant associations between aerobic fitness and academic performance, and weaker and nonsignificant associations between measures of motor performance and academic performance, in girls. These discrepancies may be explained by the different measures of aerobic fitness (maximal exercise test on a cycle ergometer vs an intermittent field running test) and motor skills. For motor skills, both used the shuttle run test (10×5 m), but while Haapala et al. (2014) included measures of balance and manual dexterity, the present study included aiming and catching (object control). Furthermore, as the age of the included children were different (1.–3. grade vs. 5. grade in the present study), we might speculate that maturation may play a role concerning these relationships. To exemplify, the lack of independent associations between motor skills and academic performance in boys in the present study, might relate to their later development of working memory, which has been shown to mediate the relationship between motor skills and academic performance (Rigoli et al., 2012). This hypothesis is supported by Boelema et al. (2014), who found better baseline performance and smaller maturational rates for working memory in girls than boys, thus suggesting that girls are more mature at age 11 (early adolescence). Yet, there is a gap in the literature on sex-differences in development of executive functions and the few studies that exist are inconsistent in their findings (Boelema et al., 2014). Another explanation for the observed sex-specific associations for aerobic fitness and motor skills to executive functions and academic performance might be differences in physical maturation between girls and boys. Although physical characteristics and performance in fundamental motor tasks in general are quite similar in prepubertal girls and boys (Malina, Bar-Or, & Bouchard, 2004), we found that boys exhibited increased aerobic fitness and motor skill level compared to girls. Yet, boys generally excel in tasks requiring power and speed, including running-, throwing-, and catching tasks (Malina et al., 2004; Venetsanou & Kambas, 2016), possibly partly because of increased participation in for example ball games (Barnett, van Beurden, Morgan, Brooks, & Beard, 2010). Thus, our observed sex differences for aerobic fitness and motor skills may be a result of the specific tests applied, rather than maturation. Still, we do not see how these differences could lead to sex-specific associations with executive functions and academic performance.

4.1. Strengths and limitations of the study

The main strength of this study was the inclusion of physical activity, sedentary time, aerobic fitness, and motor skills as independent variables, which made it possible to examine their independent relationships with executive functions and academic performance. Additionally, the relatively large sample size allowed us to test the sex-specific associations, which revealed sex-differences for the associations between both aerobic fitness and motor skills and executive functions and academic performance. However, the inclusion of multiple independent and dependent variables, along with several covariates, substantially reduced the sample size available for analyses (from 1129 to 697 children). Compared to Norwegian representative samples the current sample seems to exhibit a similar level of academic performance and aerobic fitness, but possibly a somewhat increased physical activity level (Helsedirektoratet, 2012; Kolle et al., 2010). Yet, of importance for the current association analyses, the sample variability in these variables are similar to the population estimates. Thus, we believe the associations reflect relationships evident in the general child population. Furthermore, the inclusion of several independent and dependent variables resulted in a great number of associations tested, which increased the risk of performing Type 1 errors. However, we emphasized that the patterns of associations being considered, rather than individual associations. By showing associations for individual variables as well as composite scores for both executive function and academic performance, we provide both an overall picture and more detailed information regarding the constructs analyzed. An additional strength of the study was the use of objective measurements of physical activity, even though inconsistent methodologies confuse the interpretations across studies (Cain, Sallis, Conway, Van Dyck, & Calhoon, 2013). Finally, causality could not be inferred from the present study due to the cross-sectional design.

4.2. End notes

In conclusion, this present study aimed to examine the independent associations between physical activity, sedentary time, aerobic fitness, and motor skills and executive functions and academic performance. The strongest independent associations were observed for motor skills to executive functions, thus, our findings give support to the motor-cognitive challenge hypotheses suggested by Best (2010). The role of physical activity level as a possible pathway to affect executive functions was partly supported, as independent associations were observed between aerobic fitness in boys, and not for MVPA, and executive functions and academic performance. Sex-specific associations were observed for aerobic fitness and motor skills, suggesting that the pathways are somewhat different for girls and boys. Thus, comprehensive physical activity targeted to increase both physical fitness and motor skills may have the potential to positively affect executive functions and academic performance.

Acknowledgements

The authors are grateful to the children and their families, principals and teachers from the 57 participating elementary schools who gave their time to the study. We would also like to acknowledge Professor Kolbjørn Brønnick for the preparation of the test battery for executive function. Thanks to all the master- and bachelor-students from Sogn og Fjordane University College participating in the data collection. Finally, we could not have completed our study without financial support from the Research Council of Norway, Sogn og Fjordane University College, the Norwegian School of Sport Sciences and the Gjensidige Foundation.

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PAPER II

Scandinavian Journal of Educational Research

ISSN: 0031-3831 (Print) 1470-1170 (Online) Journal homepage: http://www.tandfonline.com/loi/csje20

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To cite this article: Katrine Nyvoll Aadland , Yngvar Ommundsen , Sigmund Alfred Anderssen, Kolbjørn Selvåg Brønnick, Vegard Fusche Moe, Geir Kåre Resaland, Turid Skrede, Mette Stavnsbo & Eivind Aadland (2017): Effects of the Active Smarter Kids (ASK) Physical Activity School-based Intervention on Executive Functions: A Cluster-Randomized Controlled Trial, Scandinavian Journal of Educational Research, DOI: 10.1080/00313831.2017.1336477

To link to this article: http://dx.doi.org/10.1080/00313831.2017.1336477

Published online: 21 Jun 2017.

SCANDINAVIAN JOURNAL OF EDUCATIONAL RESEARCH, 2017
https://doi.org/10.1080/00313831.2017.1336477

Effects of the Active Smarter Kids (ASK) Physical Activity School-based Intervention on Executive Functions: A Cluster-Randomized Controlled Trial

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ABSTRACT
The purpose of this study was to examine the effects of a seven-month curriculum prescribed physical activity (PA) intervention (the Active Smarter Kids [ASK] intervention) on executive functions in 10-year-old Norwegian children. A linear mixed model was used to analyze data from 971–1,123 fifth grade children at 28 intervention schools and 29 control schools. The intervention constituted three PA elements: PA educational lessons, PA breaks, and PA homework, adding 165 minutes of PA to the mandatory 135 minutes of PA and physical education. There was no effect of the intervention on executive functions in the intention-to-treat analyses. Per protocol analyses ($n = 776–850$) revealed small effects of the intervention on the composite score of executive functions, cognitive flexibility, and motor skills. Cognitively engaging and coordinative demanding activities/games seem viable options to increase executive functions and possibly improve academic performance in children.

ARTICLE HISTORY
Received 8 July 2016
Accepted 12 May 2017

KEYWORDS
Children; aerobic fitness; motor skills; accelerometry

There is a growing body of evidence that physical activity (PA) has a positive influence on cognitive function and academic performance (Donnelly et al., 2016; Mura, Vellante, Nardi, Machado, & Carta, 2015; Singh, Uijtdewilligen, Twisk, van Mechelen, & Chinapaw, 2012; Vazou, Pesce, Lakes, & Smiley-Oyen, 2016), yet despite the opportunities afforded by school settings in terms of reach and the opportunity for early intervention (Diamond & Lee, 2011), few high quality studies have assessed the effects of PA interventions within school curricula on executive functions (Donnelly et al., 2016). This study aimed to investigate the effects of an intervention model incorporating 300 min/week of PA within the school curriculum on executive functions in a large sample of 10-year-old Norwegian children.

Executive functions, comprising inhibition, working memory, and cognitive flexibility (Miyake et al., 2000), play an important role in learning processes (Barenberg, Berse, & Dutke, 2011) and it is well documented that they are essential for academic performance (Bull & Scerif, 2001; St Clair-Thompson & Gathercole, 2006). Physical activity can affect executive functions through multiple pathways. Best (2010) proposed that: (1) PA causes general physiological responses in the brain; (2) participation in aerobic and novel games requires strategic and goal-directed behavior, and

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self-regulatory skills gained through involvement in these activities may transfer to executive function tasks; and (3) games requiring complex movement skills rely on prefrontal neural circuitry that supports executive functions. In order to test these hypotheses, different interventions examining the effect of PA on executive functions have been conducted in which quantitative features (i.e., intensity, duration, and frequency) (Ardoy et al., 2014; Chaddock-Heyman et al., 2013; Davis et al., 2011; Hillman et al., 2014; Kamijo et al., 2011; Krafft et al., 2014; Monti, Hillman, & Cohen, 2012; Schaeffer et al., 2014) or qualitative features (e.g., the type of PA, the complexity of movement and the variation in motor tasks) (Crova et al., 2014; Gallotta et al., 2015; Pesce et al., 2013; Pesce et al., 2016; Schmidt, Jager, Egger, Roebers, & Conzelmann, 2015; van der Niet et al., 2016) of PA have been manipulated.

In terms of studies focusing on quantitative features of PA, a number of randomized controlled trials of school-based PA interventions have revealed benefits of aerobic exercise on executive functions (Ardoy et al., 2014; Chaddock-Heyman et al., 2013; Davis et al., 2011; Hillman et al., 2014; Kamijo et al., 2011; Krafft et al., 2014; Monti et al., 2012; Schaeffer et al., 2014). Davis et al. (2011) examined the effects of a three-month after-school exercise program of 20 or 40 min/day (with the same intensity) compared to a control condition in 7- to 11-year-old overweight children. A dose-response benefit was observed, where the exercise program of 40 min had a significant effect on planning compared to the control condition. Overweight children participating in a similar after-school program with 40 minutes of aerobic exercise over an eight-month period have shown altered brain function supposed to reflect increased efficiency and greater flexible modulation of cognitive control (Krafft et al., 2014) and increased white matter integrity, which are related to improved cognitive function (Schaeffer et al., 2014). Likewise, several studies have shown beneficial effects from the nine-month FITKids after-school program (70 min/day of moderate-to-vigorous PA) in general sample of children on working memory (Kamijo et al., 2011), relational memory (Monti et al., 2012), and brain function coupled to executive function tasks (Chaddock-Heyman et al., 2013; Hillman et al., 2014). Supplementary to the after-school programs, Ardoy et al. (2014) examined the effect of two different four-month physical education interventions in general sample of adolescents. An effect on cognitive performance was observed for the intervention with increased time and intensity (4×55 min of high intensity) compared to both the intervention with increased time only (4×55 min) and the control condition (2×55 min).

Similar to studies manipulating the amount and intensity of aerobic exercise, changes to the coordinative and cognitive demands of the physical activities performed have been shown to affect executive functions (Crova et al., 2014; Gallotta et al., 2015; Pesce et al., 2013; Pesce et al., 2016; Schmidt et al., 2015; van der Niet et al., 2016). A cluster-randomized controlled study by Gallotta et al. (2015) compared the effect of two five-month interventions (a traditional and a coordinative PA intervention) to a control condition (no PA) on attention in normal weight and overweight/obese children. Children in both PA interventions showed higher levels of attention compared to the children in the control group, with superior improvement in children participating in the coordinative PA intervention. No differential effects were reported for weight status. Pesce et al. (2016) revealed larger effects of a six-month playful coordinative and cognitive enriched physical education that included tailored PA games that challenged motor skills and executive functions on motor coordination and inhibition, compared to traditional physical education in a general sample of preschool and elementary school children. Other studies that have revealed effects of increased cognitive demands in the physical education activities over six-months have shown superior effects on attention in typically developing children compared to children with motor impairment (Pesce et al., 2013) and greater effects on inhibition in overweight children compared to their lean peers (Crova et al., 2014). The quasi-experimental study by van der Niet et al. (2016), examined the effects of a five-month PA program during recess (30 min twice a week) that included both aerobic exercise and cognitively engaging physical activities (e.g., tag games and relay games with word spelling) on executive functions in a general sample of elementary school children. Children participating in the intervention showed greater improvements in both inhibition and working memory than was observed in the control group children, independent of gain in physical fitness. Schmidt et al. (2015) observed increased aerobic fitness in elementary school children following two different interventions that involved similar physical exertion, but with high (team games) or low cognitive engagement, compared to a control condition of low physical exertion. However, only the intervention with team games showed effects on executive functions, suggesting that cognitively engaging PA might have stronger effects than non-cognitively engaging PA on executive function. This has also been proposed by both Best (2010) and Diamond (2015).

These promising results suggest that children might benefit from physiologically demanding and/or mentally engaging PA during their school day. However, more evidence is needed to overcome limitations in the current literature concerning study designs, measurement of PA, small sample sizes, and large variations in sample characteristics (Donnelly et al., 2016; Howie & Pate, 2012; Mura et al., 2015; Singh et al., 2012). There is a lack of real-world trials of the effectiveness of PA interventions incorporated in the school curricula on executive function. To our knowledge, the cluster-randomized Learning, Cognition and Motion trial is the only controlled study investigating a teacher-led PA intervention on executive function that has been published. It was conducted with Danish adolescents and revealed no effects of a 20-week multi-faceted PA intervention on executive function (Tarp et al., 2016).

The present study aimed to determine the effects of a seven-month curriculum-prescribed PA intervention on executive functions in 10-year-old children. Meeting some of the current limitations, the trial was conducted in a real-world setting where the classroom teachers delivered the intervention. It comprises a large sample size (1,129 children), uses objective measurement of PA and assesses several key executive functions. We hypothesized that the Active Smarter Kids (ASK) intervention would result in improved inhibition, working memory, and cognitive flexibility. In light of the of Best's (2010) hypothesis we also tested for whether the intervention affected PA, aerobic fitness, and motor skills.

Materials and Methods

Design and Participants

The ASK study was a parallel group (intervention group vs control group, 1:1 ratio) cluster-randomized controlled trial conducted in Sogn og Fjordane county, Norway, between August 2014 and June 2015. The unit of randomization was the participating schools, with randomization performed by a neutral third party (Centre of Clinical Research, Haukeland University Hospital, Norway). The procedures and methods used in the ASK trial conformed to the ethical guidelines of the World Medical Association's Declaration of Helsinki and its subsequent revisions (WMA, 2013). The study protocol was approved by the Regional Committee for Medical Research Ethics South East. We obtained written informed consent from each child's parent(s) or guardian(s) prior to entry into the study.

We invited all 60 schools in the county that fulfilled the inclusion criteria of at least seven fifth-grade children enrolled. All schools, encompassing 1,202 fifth grade children, agreed to participate (Figure 1). Three schools (one control school and two intervention schools) from the same municipality dropped out of the study following randomization. In total, 1,145 of the 1,175 invited children from 57 schools agreed to participate, constituting 82.1% of the population of 10-year-olds in the county. At baseline, 30 children were not tested: 21 because they were absent from school, 5 because of medical conditions that precluded testing, 2 for refusing to perform the tests, and 2 because of language barriers. At follow-up, a total of 19 children were not assessed: 12 because of being absent, 5 because of medical conditions, and 2 through refusal. In addition, 7 children moved away from the area before follow-up. Furthermore, some children lack data on single tests (one or more tests). Reasons for missing these data were: children did not complete the test (63 tests), children were disturbed during testing (mainly due to noise) (30 tests), a test-leader mistake (23 tests), or 'other' (23 tests). Missing data were similarly distributed among intervention and control schools (intervention

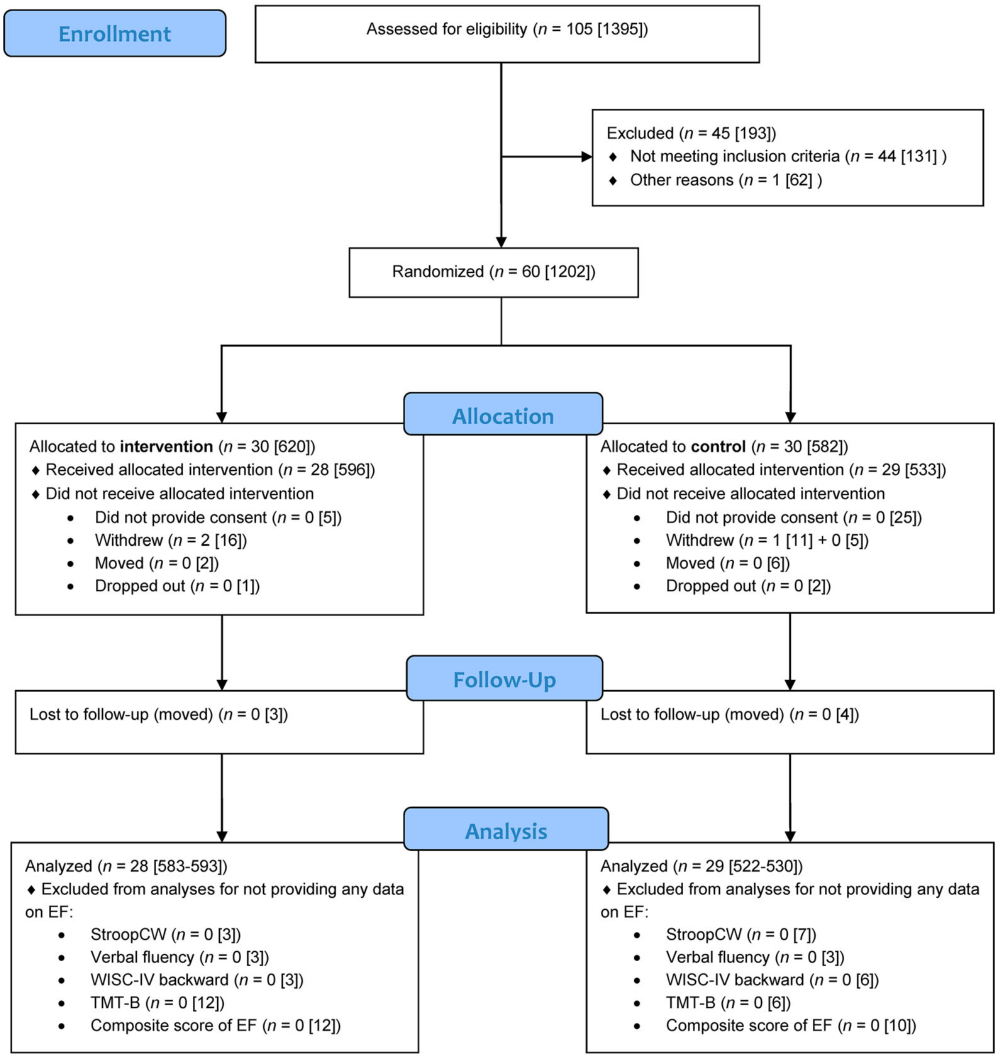

Figure 1. Flow-chart of recruitment, randomization, and participation of schools and children in the ASK study. All numbers are schools [children].

Note: StroopCW = Stroop Color Word; WISC-IV = Wechsler Intelligence Scale for Children fourth edition; TMT-B = Trail Making Test part B; EF = executive functions.

group/control group Stroop Color Word (StroopCW), $n = 35/37$; Verbal fluency, $n = 38/34$; WISC-IV backward, $n = 38/39$; Trail Making test part B (TMT-B), $n = 75/67$; composite score of executive function, $n = 74/78$). Only 18 children did not provide any data on any test of executive function, and were excluded from the analyses (Figure 1).

For a more thorough description of the sample and methods, see the previously published design paper (Resaland et al., 2015). The study was registered in the Clinicaltrials.gov registry [trial registration number: NCT02132494] prior to commencement.

Intervention

The ASK intervention was a part of the mandatory school curriculum for all children attending the intervention schools. It was led by classroom teachers and consisted of three components, generating an additional 165 min/week of PA: (1) physically active educational lessons (3 × 30 min/week) in the subjects Norwegian, mathematics, and English, (2) PA breaks during classroom lessons (5 min/school day), and (3) PA homework (10 min/school day). The research group developed the intervention in collaboration with teachers at the intervention schools. Our aim was to create a number of varied PA activities that could be carried out in small groups and which encouraged an inclusive and joyful learning environment (see www.askstudy.no for examples of PA activities). Two of the three intervention components, the PA educational lessons and the PA homework, incorporated academic learning tasks in the PA (e.g., rope jumping while spelling English vocabulary words), thus adding cognitive load to the activity. Approximately 25% of daily PA in the ASK intervention was intended to be of vigorous intensity. Intervention schools were provided with equipment for use in the intervention activities and the children received a skipping rope and a tennis ball for PA homework. To ensure that the teachers were empowered, supported, and qualified to the deliver the ASK intervention, we conducted three instructional seminars ahead of the start of the study for the teachers at the intervention schools. Further, we provided two regional refresher sessions during the intervention period. Finally, we provided teachers in intervention schools with email and telephone support, as well as a password-protected homepage (www.askstudy.no) that supplied teachers with information, videos, and PA lessons.

Children from both intervention schools and control schools participated in curriculum-prescribed 90 min/week of physical education and 45 min/week of PA (total 135 min/week). It was specified to the control schools that they should carry out the amount of PA and physical education that they would have done regardless of the ASK study.

Measures

Anthropometry, Pubertal Status, and Socioeconomic Status

Body mass (weight: 0.1 kg) was measured using an electronic scale (Seca 899, SECA GmbH, Hamburg, Germany) with children wearing light clothing. Stature (height: 0.1 cm) was measured with portable Seca 217 (SECA GmbH, Hamburg, Germany) stadiometers. We calculated body mass index (BMI) ($kg \cdot m^{-2}$) as weight (kg) divided by the height squared (m^2). Body fat was measured using four skinfold thickness sites (biceps, triceps, subscapular, and suprailiac) using a Harpenden skinfold caliper (Bull, British Indicators Ltd., West Sussex, England) according to the criteria described by Lohman, Roche, and Martorell (1991). The Harpenden skinfold caliper has been tested for validity and reliability in children (Yeung & Hui, 2010). Children self-assessed their pubertal stage with the Tanner method (Tanner, 1962) using a scale of colored images proposed by Carel and Leger (2008). We used breast and genital development for girls and boys, respectively. Socioeconomic status (defined as the highest education level obtained by the mother or father) (Sirin, 2005) was reported by the parents or guardians.

Outcome Measures

Executive Functions. We measured key executive functions identified by Miyake et al. (2000): inhibition, working memory, and cognitive flexibility, by using four pen-and-paper tests. We assessed inhibition with the StroopCW (Golden, 1978). To assess cognitive flexibility, we used a semantic Verbal fluency test (Spreen & Strauss, 1998), and the TMT (Lezak, Howieson, Bigler, & Tranel, 2012; Spreen & Strauss, 1998). Finally, we used a Digit Span test (Digits Forward and Backward) from the WISC-IV to assess working memory (Lezak et al., 2012). For tests containing several conditions, the conditions requiring the greatest demands on executive functions were used for the analyses: the color word condition of the StroopCW, the total score of Verbal fluency, the backward digit span of the WISC-IV, and the part B of the TMT. In addition, we applied a composite score of executive functions (mean of standardized scores) using these variables.

Before testing, a licensed neuropsychologist (author KSB) educated researchers and their assistants in the construction of the test battery, testing procedures, and the theoretical underpinnings of executive functions. Then, trained research assistants tested the children individually in a quiet room at their school during their usual school day. All research assistants followed the same training and test procedures. On average, the test battery was completed in 15–20 min. For a more thorough description of the executive functions test, see Aadland et al. (2017).

Exposure Measures

Physical Activity. Physical activity was measured by Actigraph accelerometers (ActiGraph GT3X+, LLC, Pensacola, Florida, USA). The children were instructed to wear the accelerometer on the right hip over seven consecutive days at all times, except during water-based activities or while sleeping. Our criterion for a valid day was a wear-time of ≥480 min/day accumulated between the hours of 06:00 and 24:00; a wear time of ≥180 min/day accumulated between hours 09:00 and 14:00 was the criterion for a valid school day. Periods of ≥20 min of zero counts were defined as non-wear time (Esliger, Copeland, Barnes, & Tremblay, 2005). A total of ≥4 (out of 7) days and ≥3 (out of 5) school days were applied as criteria for a valid measurement. The outcomes for PA were moderate-to-vigorous PA (cut-point 2296 counts per minute [cpm]) and sedentary time (0–100 cpm) (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008; Trost, Loprinzi, Moore, & Pfeiffer, 2011). All analyses were performed using data accumulated over 10-second epochs. We analyzed all accelerometry data using Kinesoft analytical software (http://kinesoft.org/).

Aerobic Fitness. Aerobic fitness was measured with the Andersen intermittent field running test (Aadland et al., 2014; Andersen, Andersen, Andersen, & Anderssen, 2008). The Andersen test was administered according to standard procedures. The children were tested indoor on a wooden or rubber floor in groups of 10–20 children. Children ran in a to-and-fro movement from one end line to another (20 m apart) in an intermittent manner having 15-s work periods and 15-s breaks (standing still) for a total duration of 10 min. We recorded the distance covered (meters) as the outcome for the analysis. To enable comparing of aerobic fitness levels across studies, VO_{2peak} was calculated using the equation suggested by Aadland et al. (2014).

Motor Skills. Motor skills were measured using a battery of three tests: (1) Catching with One Hand (Catching); (2) Throwing at a Wall Target (Aiming); and (3) Shuttle Run (10 × 5 meters). Tests 1 and 2 constitute the subgroup Aiming and Catching from the Movement Assessment Battery for Children 2 in age band 3 (11–16 years) (Henderson, Sugden, & Barnett, 2007) and Test 3 came from the Eurofit test battery (Council of Europe, 1993). We used a composite score (mean of standardized individual scores) of the three tests in the analyses.

Adherence to the Protocol. Teachers reported total activity for all three intervention components (PA educational lessons, PA breaks, and PA homework) and compulsory PA lessons and physical education using a pre-defined survey on a weekly basis.

Power Calculations

The study was designed to detect an effect size (Cohen's D) of 0.35 between the two groups for change in academic performance (main outcome). The effect size was based on findings from previous studies (Sibley & Etnier, 2003). An intraclass correlation (ICC) of 0.15 (observed clustering of academic performance during the previous school year [2013–2014]) was applied to account for the cluster-randomized design, leading to a design effect of 4.54. For further details, see Resaland et al. (2015).

Statistics

The children's characteristics are provided as frequencies, means, and standard deviations (SDs). We analyzed data in accordance with the statistical analysis plan (Resaland et al., 2015). Baseline group differences and the effects of the intervention were determined using a linear mixed model, including the random intercept of school to account for the multilevel structure of the data. The intervention effect was analyzed using an intention-to-treat analysis, thus including all children from whom we obtained baseline or final measures of executive functions. Missing data were imputed from relevant variables by means of multiple imputations using a Markov Chain Monte Carlo procedure. As an assumption for use of multiple imputation, we assumed data were missing at random (Little et al., 2012). We report results for imputed data as well as for completers only. We also performed secondary (per protocol) analyses with schools that demonstrated high compliance with the protocol (intervention schools performing ≥ 80% of prescribed PA and control schools performing < 120% of curriculum prescribed PA [135 min/week of PA and physical education]). Effect estimates were derived for change in executive functions as well as moderate-to-vigorous PA, sedentary time, aerobic fitness, and motor skills (dependent variables) while including group and baseline scores as independent variables. Thus, effects estimates are based on an ANCOVA model. Change in wear time was included as a covariate in the model for PA. All effect estimates are reported as regression coefficients (β) and 95% confidence intervals (95%CI), along with *p*-values and the ICC for the cluster effect of schools.

All analyses were performed using the SPSS software, version 23 (IBM SPSS Statistics for Windows, Armonk, NY: IBM Corp., USA). A *p*-value of < .05 was used as level of statistical significance.

Results

Children ($n = 1{,}129$; 541 [47.9%] girls) from 57 elementary schools participated in the study (Table 1). No differences between the intervention and control group were observed regarding BMI ($p = .750$), body fat ($p = .837$), pubertal status ($p = .676$), socioeconomic status ($p = .248$), PA levels ($p \geq .682$), aerobic fitness ($p = .822$), or motor skills ($p \geq .188$) at baseline. Furthermore, we found no statistical differences for any of the executive functions ($p \geq .180$, Table 2) or the composite score of executive functions ($p \geq .153$) at baseline.

Results did not reveal any effects of the ASK intervention on executive functions (mean group difference 0.2 –1.2%, 0.01–0.06 SD units, $p = .191$–.893 [imputed file]) (Table 3).

Exposure Measures

Physical Activity, Aerobic Fitness, and Motor Skills

From the total sample of 1,129 children, 939 children had valid accelerometry data for both the pre- and post- intervention measurements during school hours; 911 children had valid data during the whole day. There were no significant differences between groups for change in PA during school hours ($p \geq .303$) or during the whole day ($p \geq .440$) (Table 4). Similarly, no significant differences were observed for aerobic fitness (mean difference [95% CI] 6.9 [−8.9 to 22.6], $p = .387$, $n = 962$) or motor skills (.12 [−.01 to .25], $p = .071$, $n = 863$).

Self-Reported Adherence to the Protocol

Total PA reported by the intervention and control schools over the intervention period was 288 (21) and 157 (35) min/week, respectively. Thus, the reported difference between schools (131 min/week) was 20% less than prescribed (165 min/week), mainly due to children in the control schools being more physically active than had been anticipated. Results from the per protocol analyses are presented in Table 5, including intervention schools that completed ≥ 80% of the prescribed PA (27 schools, 574 children included; 1 school, 22 children excluded) and control schools that reported

Table 1. Baseline characteristics for the included children.

	Intervention ($n = 596$)		Control ($n = 533$)	
Variable	*N*	*M* (SD) or frequencies	*N*	*M* (SD) or frequencies
Age (years)	596	10.2 (0.3)	533	10.2 (0.3)
Sex: Girls/boys (%)	596	47.3/52.7	533	48.6/51.4
BMI	578	18.0 (2.3)	517	18.1 (3.0)
Normal weight (%)	453	76.0	402	75.4
Overweight (%)	104	17.4	95	17.8
Obese (%)	21	3.5	20	.8
Body fat (mm)	571	49.7 (26.4)	513	50.5 (26.8)
Pubertal stage (Tanner) (%)	569		512	
Stage 1	170	29.9	139	27.1
Stage 2	330	58.0	318	62.1
Stages ≥ 3	69	12.1	55	10.8
Socioeconomic status (%)	578		491	
≤ Upper-secondary school	178	30.8	171	34.8
< 4 years of university/college	178	30.8	142	28.9
≥ 4 years of university/college	222	38.4	178	36.3
PA-levels (full day)	542		464	
cpm		745 (299)		723 (257)
SED (min all day)		468.3 (56.9)		467.5 (59.7)
MVPA (min all day)		77.4 (27.7)		73.6 (23.6)
% Meeting PA guidelines		71.4		70.0
Aerobic fitness (m)	550	893.6 (102.6)	495	891.9 (103.7)
Estimated VO_{2peak} (ml/kg/min)	549	52.3 (7.3)	495	52.0 (7.5)
Motor skills				
Shuttle run (s)	575	23.1 (2.5)	511	23.2 (2.5)
Aiming (*n*)	577	3.9 (1.9)	516	4.1 (1.9)
Catching (*n*)	519	4.2 (3.2)	514	4.0 (3.1)

Note: BMI = body mass index; PA = physical activity; cpm = counts per minute; SED = sedentary time; MVPA = moderate-to-vigorous physical activity.

Table 2. Mean (SD) for baseline and post-intervention values for the intervention and the control groups on tests of executive functions.

	Intervention			Control		
Variable	*N*	Before	After	*N*	Before	After
Stroop CW (*n*)	564	25.8 (5.8)	29.8 (6.2)	503	26.0 (6.2)	29.7 (6.7)
Verbal fluency (*n*)	561	16.0 (4.5)	17.8(5.0)	502	16.0 (4.8)	17.7 (4.6)
WISC-IV backward (*n*)	562	6.1 (1.3)	6.5 (1.4)	499	6.2 (1.3)	6.5 (1.5)
TMT-B (s)	533	123.0 (48.9)	98.0 (33.0)	472	118.8 (46.4)	97.5 (34.9)

Note: StroopCW = Stroop Color Word; WISC-IV = Wechsler Intelligence Scale for Children fourth edition; TMT-B = Trail Making Test part B.

≤ 120% of recommended PA (16 schools, 324 children included; 13 schools, 209 children excluded). Per protocol analyses revealed statistically significant effects of the intervention for the composite score of executive functions (.14 SDs), the TMT-B (−.13 SDs) and motor skills (.15 SDs).

Discussion

Intention-to-treat analyses revealed no significant effect of the ASK intervention on executive functions. However, teachers in almost one-half of the control schools reported more PA than prescribed, leading us to also consider the results of the per protocol analyses. Here, we observed statistically significant intervention effects on the composite score of executive functions and cognitive flexibility.

Our null-finding relying on the intention-to-treat analyses contrasts with previous randomized controlled trials in which PA interventions (Pesce et al., 2013; van der Niet et al., 2016), physical education interventions (Ardoy et al., 2014; Crova et al., 2014; Gallotta et al., 2015; Pesce et al., 2016; Schmidt et al., 2015) and after-school programs (Chaddock-Heyman et al., 2013;

Table 3. Effects of the intervention (intention-to-treat analyses).

Variable	*N*	*β* (95%CI)	*P*	ICC
StroopCW (*n*)				
Imputed file	1,119	.31 (−.32 to .95)	.333	.02
Completers only	1,067	.30 (−.35 to .95)	.356	.02
Verbal fluency (*n*)				
Imputed file	1,123	.17 (−.31 to .64)	.491	.00
Completers only	1,063	.17 (−.31 to .65)	.484	.00
WISC-IV backward (*n*)				
Imputed file	1,120	.01 (−.18 to .21)	.893	.02
Completers only	1,061	.02 (−.18 to .21)	.871	.02
TMT-B (sec)				
Imputed file	1,111	−.63 (−4.26 to 3.01)	.736	.00
Completers only	1,005	−1.27 (−5.00–2.46)	.492	.01
Executive functions (composite score)				
Imputed file	1,107	.06 (−.03 to .16)	.191	.02
Completers only	971	.11 (−.04 to .27)	.157	.04

Note: *β* = regression coefficient; CI = 95% confidence interval; ICC = intraclass correlation; StroopCW = Stroop Color Word; WISC-IV = Wechsler Intelligence Scale for Children fourth edition; TMT-B = Trail Making Test part B.

Table 4. Mean baseline, post-intervention, and group (intervention-control) differences (95%CI) in change in physical activity during school hours (A) and during full days (B).

	Intervention group ($n = 506$)		Control group ($n = 433$)			
PA measure	Before	After	Before	After	Group difference	*P*
(A)						
Overall PA (cpm)	655 (639–671)	660 (643–677)	644 (626–661)	624 (606–642)	14.0 (−36.6 to 64.6)	.582
SED (min/day)	178 (177–180)	179 (177–180)	179 (177–181)	182 (180–184)	−1.0 (−5.2 to 3.1)	.613
MVPA (min/day)	30 (29–30)	30 (29–31)	28 (28–29)	29 (27–30)	0.2 (−3.0 to 3.3)	.922
	Intervention group ($n = 494$)		Control group ($n = 407$)			
PA measure	Before	After	Before	After	Group difference	*P*
(B)						
Overall PA (cpm)	752 (725–779)	626 (609–644)	734 (709–759)	611 (592–630)	−3.0 (−49.1 to 43.0)	.896
SED (min/day)	469 (464–474)	496 (491–500)	465 (459–471)	495 (490–501)	2.8 (−4.3 to 9.8)	.440
MVPA (min/day)	78 (75–80)	68 (66–70)	75 (72–77)	66 (64–68)	−1.3 (−6.3 to 3.8)	.620

Note: PA = physical activity; SED = sedentary time; MVPA = moderate-to-vigorous physical activity; cpm = counts per minute.

Davis et al., 2011; Hillman et al., 2014; Kamijo et al., 2011; Monti et al., 2012) have shown enhanced performance in executive function tasks in both normal weight and overweight/obese children.

There are major differences between studies examining the effect of PA on executive functions, both regarding their measurement of exposure (i.e., subjective or objective measurement of PA) or outcome (i.e., various test batteries of executive functions), and the prescribed type and dose of PA. Thus, irrespective of variation in findings using intention-to-treat versus per protocol analyses, comparing results from the present large curriculum-prescribed PA intervention study with results from smaller studies manipulating PA or physical education in a school setting or after-school programs is problematic due to the large heterogeneity of the studies. First, the possibility of strongly keeping record with intervention versus control group conditions, typically seen in smaller studies and after-school programs, was unattainable for this large-scale curriculum-based PA intervention involving many schools. Second, the mode of intervention delivery differs. Small-scale studies and after-school programs have relied on specialized physical education teachers to deliver the intervention using only a single site, whereas this study included several intervention schools with classroom teachers in charge of delivery. Hence, many previous studies investigating after-school programs and small-scale studies are delivered under more optimal conditions in which researchers can strictly monitor the implementation process (i.e., efficacy trials). Indeed, the high internal validity of such

Table 5. Effects of the intervention (per protocol analyses).

Variable	*N*	*β* (95%CI)	*P*	ICC
StroopCW (*n*)	850	.44 (−.33 to 1.21)	.255	.02
Verbal fluency (*n*)	847	.29 (−.27 to .85)	.317	.00
WISC-IV backward (*n*)	843	.09 (−.15 to .32)	.459	.02
TMT-B (sec)	804	−4.60 (−8.44 to −.76)	.019	.00
Composite score of executive functions (1 SD)	776	.14 (.02–.26)	.023	.02
MVPA (school hours) (min)	819	1.19 (−2.43 to 4.82)	.510	.30
SED (school hours) (min)	819	3.84 (−9.23 to 1.55)	.157	.23
MVPA (full day) (min)	819	−.42 (−6.03 to 5.19)	.880	.14
SED (full day)(min)	819	5.71 (−2.49 to 13.91)	.166	.04
Aerobic fitness (m)	769	−.05 (−17.71 to 17.62)	.996	.14
Motor skills (1 SD)	755	.15 (.01–.29)	.034	.04

Note: *β* = regression coefficient; CI = 95% Confidence Interval; ICC = Intraclass Correlation; StroopCW = Stroop Color Word; WISC-IV = Wechsler Intelligence Scale for Children fourth edition; TMT-B = Trail Making Test part B; SED = sedentary time; MVPA = moderate-to-vigorous physical activity.

studies lends credibility to the causal relationship between the intervention and executive functions (Shadish, Cook, & Campbell, 2002). Nevertheless, the external validity of the present study is strong in terms of providing evidence of the generalizability of the intervention model to the school system in Norway and possibly worldwide (Flay et al., 2005; Gottfredson et al., 2015; Price, Hillyer, & van der Molen, 2013).

According to Best (2010), there are three pathways that might explain the influence of PA on executive functions. The first pathway is through physiological changes: group activities might for example, result in neurogenesis in the hippocampus; and repetitive aerobic exercise in angiogenesis, increased cerebral blood volume, and up-regulation of growth factors and neurothrophins. These physiological changes could be linked to the total amount of PA (duration, intensity, and frequency). Compared to studies that have revealed significant effects of PA on executive functions (Chaddock-Heyman et al., 2013; Davis et al., 2011; Hillman et al., 2014; Kamijo et al., 2011), the dose of the present study is clearly less. Our intervention group added 165 min/week of PA to the 135 minutes mandatory school curriculum PA over a seven-month period, which equals ~60 minutes of PA per school day. However, this only differs by ~33 min/day for the children in the intervention schools compared to their peers in the control schools. This is substantially less than in other studies, such as the FITKids study, where children exercised at moderate-to-vigorous intensity for 70 min/day (in addition to any PA during the school day) on an average of 150 of the 170 annual academic calendar school days. Considering their ability to strictly control the intervention conditions, including monitoring of compliance using heart rate measurements during exercise sessions (Hillman et al., 2014, supplementary material), it is also very likely that the difference in moderate-to-vigorous PA is even greater. Since previous studies have shown a dose-response relation between PA and executive functions (Ardoy et al., 2014; Davis et al., 2011; Hillman et al., 2014), one probable explanation for our findings is a lack of sufficient PA prescribed and performed. Furthermore, a certain intensity level might be needed to alter the executive functions through the physiological mechanisms (Barenberg et al., 2011). In support for this, mean time above the target heart zone has been shown to be a predictor of performance on both the StroopCW and TMT-B in pre-adolescent children (Castelli, Hillman, Hirsch, Hirsch, & Drollette, 2011). Further, the study by Ardoy et al. (2014) revealed that an increase of two physical education sessions per week resulted in better cognitive performance only in the high intensity physical education group. Our accelerometer measurement indicated no significant group differences in PA outcomes, either during school hours or during the whole day. Thus, as expected, but contrary to Hillman et al. (2014), who found a ~4% increase in VO_{2peak}, we did not obtain any significant change in aerobic fitness. This finding indicates that the ASK intervention probably did not succeed in significantly influencing children's executive functions by means of change in their physiological state, as would have been expected according to the first of Best's hypothesis (the physiological hypothesis). Yet, the group differences found when relying on the teacher-reported and objectively measured PA differ substantially. A significant (desirability) reporting bias seems evident for the teacher reports, consistent with general agreement regarding the limitations of subjective PA reporting (Prince et al., 2008). An alternative explanation might be that the two measures capture different aspects of PA. It is well known that accelerometers have severe limitations in obtaining accurate movement estimates in circumstances such as cycling, being in water-based activities, and performing upper-body movements in general. The per protocol analysis showed effects of the intervention on both executive functions and motor skills. Thus, the discrepant findings might indicate that the children were engaged in PA activities tapping qualitative characteristics of PA for which accelerometers are insensitive.

The ASK intervention (as well as other interventions) comprised group-based PA activities and games, which requires using complex cognitive resources to be able to simultaneously cooperate with classmates, employing strategies, and adapting to changing task demands (Best, 2010). According to Best (2010), group games can affect executive functions through physiological changes (Hypothesis 1: neurogenesis in the hippocampus) and the cognitive demands inherent in engaging games (Hypothesis 2). In support for the effects of the distinctiveness of group activities and cognitively engaging games on executive functions (irrespective of quantitative characteristics), Chang, Tsai, Chen, and Hung (2013) revealed similar effects from soccer exercises of low- and moderate- intensity on executive functions in kindergarten children. Furthermore, intervention studies enriching physical education by cognitive and social interaction challenges have found improved inhibition (Crova et al., 2014; Pesce et al., 2016; van der Niet et al., 2016), working memory (van der Niet et al., 2016), and cognitive flexibility (Schmidt et al., 2015), some independent of gain in aerobic fitness (Crova et al., 2014; van der Niet et al., 2016).

Regarding effects on motor skills in the per protocol analysis, it is reasonable to conclude that the intervention was challenging in terms of motor tasks. Because all children received a tennis ball for homework, we can speculate that they practiced aiming and catching; activities that are challenging in terms of co-ordination and unlikely to be detected by the accelerometer. In the study by Pesce et al. (2016) ball skills such as aiming and catching were found to be a mediator for the relationship between the physical education intervention and inhibition. They suggest that ball skills are a mechanism that partially explains why enriched physical education benefits executive functions. This is in line with the third pathway of Best (2010), which suggests that cognitive demands inherent in coordination of complex motor tasks may affect executive functions. Furthermore, the study by Gallotta et al. (2015) revealed that a coordinative PA intervention was more effective compared to traditional PA at improving attention in both normal weight and overweight/obese children.

The ASK study lacks direct measurements/observations of aspects pertaining to level of mental engagement and coordinative challenges during the intervention, as seen in the studies by Pesce et al. (2016), Schmidt et al. (2015), and Crova et al. (2014), which makes it impossible to specify their effects on executive functions. Furthermore, the considerable freedom teachers had in their choice of activities might have resulted in variation pertaining to level of mental engagement and coordinative challenges embedded in the intervention activities across schools, although this might be considered a strength as it enabled teachers to adapt the intervention activities to their children's levels. The importance of adjusting the task complexity in PA to match the optimal challenge point was underlined in the study by Pesce et al. (2013), where the optimal level of challenge afforded by different activities was dependent on the children's motor development. Furthermore, the review by Diamond and Lee (2011) concluded that interventions that had not matched task difficulty with children's skill level into account had failed to improve executive functions. Given the improvement in executive function (per protocol analysis) identified in this study, it seems that the teachers kept the activities challenging throughout the intervention period.

Strengths and Limitations

A major strength of this study was the strong implementation of the intervention among the intervention schools in accord with the intervention protocol (according to the teacher reports). Moreover, given that the intervention was developed and delivered as a field-based randomized controlled study, we argue that the study exhibits good external validity. However, we did not manage to keep up solid contrasts between the intervention and control condition. Many control schools carried out more PA than prescribed, which may have led to an underestimation of observed intervention effects in the intention-to-treat analyses. Effects from the intervention were only identified in our per-protocol analysis. This might be interpreted as a weakness, but it was overwhelmingly control schools that were excluded in the per protocol analysis ($n = 13$), rather than intervention schools ($n = 1$). This contrasts with several other previous intervention studies, and demonstrates that the intervention prescribed was feasible for the schools, but it was not possible to restrict the control schools to only the mandatory PA and physical education during a school day.

Another strength of the study is the inclusion of several exposure measurements, enabling investigations of both quantitative and qualitative characteristics of the PA in the intervention. However, we were not in a position to be able directly to trace the mental and coordinative challenge that the children met during the intervention activities. Hence, the composite score of motor skills functioned as a measure of exposure, such as qualitative characteristics of the PA intervention activities. The composite score of motor skills comprised only three single tests (Catching, Aiming, and Shuttle Run) selected from two standardized and validated test batteries, and was therefore not a comprehensive measure of motor skills. However, as the ASK study comprised a large variety of measurements, a selection of motor skills tests was necessary, both for ethical reasons and to meet logistical challenges. Thus, the results of the present study, with its strengths and limitations, support the need for future studies to test effects of interventions comprising a broader repertoire of both quantitative and qualitative aspects of PA to extend our knowledge about their contributions on executive functions. This knowledge will be important in designing sustainable PA models with positive effects on children's executive functions and thus their academic performance.

Conclusion

Intention-to-treat analysis in the present study did not reveal an effect of the ASK intervention on executive functions. However, by conducting supplementary per protocol analyses, we were able to obtain small significant effects of the intervention on the composite score of executive functions and cognitive flexibility. The effects that were identified may by qualitative characteristics of PA, as indicated by an effect of the intervention on motor skills.

Acknowledgements

The authors are grateful to the children and their families, principals, and teachers from the 57 participating elementary schools who gave their time to the study. Many thanks also to all the master and bachelor students from Sogn og Fjordane University College who supported the data collection.

Disclosure Statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Research Council of Norway [grant number 221047/F40]; Sogn og Fjordane University College; the Norwegian School of Sport Sciences, and the Gjensidige Foundation [grant number 1042294].

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PAPER III

Preventive Medicine 91 (2016) 322–328

Contents lists available at ScienceDirect

Preventive Medicine

journal homepage: www.elsevier.com/locate/ypmed

Effects of physical activity on schoolchildren's academic performance: The Active Smarter Kids (ASK) cluster-randomized controlled trial☆

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ARTICLE INFO

Article history:
Received 14 May 2016
Received in revised form 2 September 2016
Accepted 4 September 2016
Available online 7 September 2016

Keywords:
Physical activity
Elementary school
Children
Academic performance
Physically active educational lessons
Cluster RCT

ABSTRACT

Objective. To investigate the effect of a seven-month, school-based cluster-randomized controlled trial on academic performance in 10-year-old children.

Methods. In total, 1129 fifth-grade children from 57 elementary schools in Sogn og Fjordane County, Norway, were cluster-randomized by school either to the intervention group or to the control group. The children in the 28 intervention schools participated in a physical activity intervention between November 2014 and June 2015 consisting of three components: 1) 90 min/week of physically active educational lessons mainly carried out in the school playground; 2) 5 min/day of physical activity breaks during classroom lessons; 3) 10 min/day physical activity homework. Academic performance in numeracy, reading and English was measured using standardized Norwegian national tests. Physical activity was measured objectively by accelerometry.

Results. We found no effect of the intervention on academic performance in primary analyses (standardized difference 0.01–0.06, $p > 0.358$). Subgroup analyses, however, revealed a favorable intervention effect for those who performed the poorest at baseline (lowest tertile) for numeracy ($p = 0.005$ for the subgroup * group interaction), compared to controls (standardized difference 0.62, 95% CI 0.19–1.07).

Conclusions. This large, rigorously conducted cluster RCT in 10-year-old children supports the notion that there is still inadequate evidence to conclude that increased physical activity in school enhances academic achievement in all children. Still, combining physical activity and learning seems a viable model to stimulate learning in those academically weakest schoolchildren.

1. Introduction

Exploring new teaching and learning methods to improve children's academic performance is important. Physical activity (PA) may be an effective strategy affecting positively academic performance, and school-based studies investigating the effect of increased PA on academic performance have steadily increased in number the last decade. It is suggested that beneficial effects of PA on academic performance are due to improved cognitive functions, such as attention, concentration and working memory (Trudeau and Shephard, 2008; Tomporowski et al., 2008; Bailey et al., 2009; Rasberry et al., 2011; Fedewa and Ahn, 2011; Singh et al., 2012; Norris et al., 2015; Mura et al., 2015; Donnelly et al.,

☆ Trial registration number: Clinicaltrials.gov ID nr: NCT02132494.
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http://dx.doi.org/10.1016/j.ypmed.2016.09.005

2016). Results are mixed and range from a positive effect to none on academic performance. Most consistent is the observation that increases in school-time PA apparently do not affect pupils' academic performance negatively. However, most previous studies are hampered by several limiting factors, including a lack of randomization, low statistical power and subjective measurement of PA. Therefore, the evidence base regarding whether increases in school-time PA affect academic performance is limited. Extending this knowledge is important for curricula developments and to inform future interventions. We therefore assessed the effect of a seven-month, school-based PA intervention (i.e., Active Smarter Kids, ASK) on academic performance on a large sample of 10-year-old children in Norwegian elementary schools. In addition, we determined the effects of sex, socioeconomic position, and baseline level of academic performance on the relation between participation in the intervention and academic performance.

2. Methods

The intervention was conducted within a socio-ecological conceptual framework that recognizes that PA behaviors have multiple levels of influence (McLeroy et al., 1988). Our procedures and methods conform to ethical guidelines defined by the World Medical Association's Declaration of Helsinki and subsequent revisions (WMA, 1964). The Regional Committee for Medical Research Ethics approved the study protocol. We obtained written consent from each child's parents or legal guardian and from school authorities prior to all testing. The study is registered in Clinicaltrials.gov ID nr: NCT02132494. We previously published a detailed description of the study (Resaland et al., 2015), but provide a brief overview below.

2.1. Design and participants

ASK was a seven-month cluster-randomized controlled trial (cluster RCT) with a random allocation at the school level using a 1:1 ratio. Such randomization eliminated the possibility of contamination between pupils in the same school. Sixty schools were approached and 57 schools (1129 children) agreed to participate (recruitment success of 95% of schools, 94% of children) (Fig. 1). Inclusion criteria were: i) schools had ≥7 pupils in fifth grade; ii) pupils were able to participate in daily PA and physical education (PE); and iii) pupils were able to complete

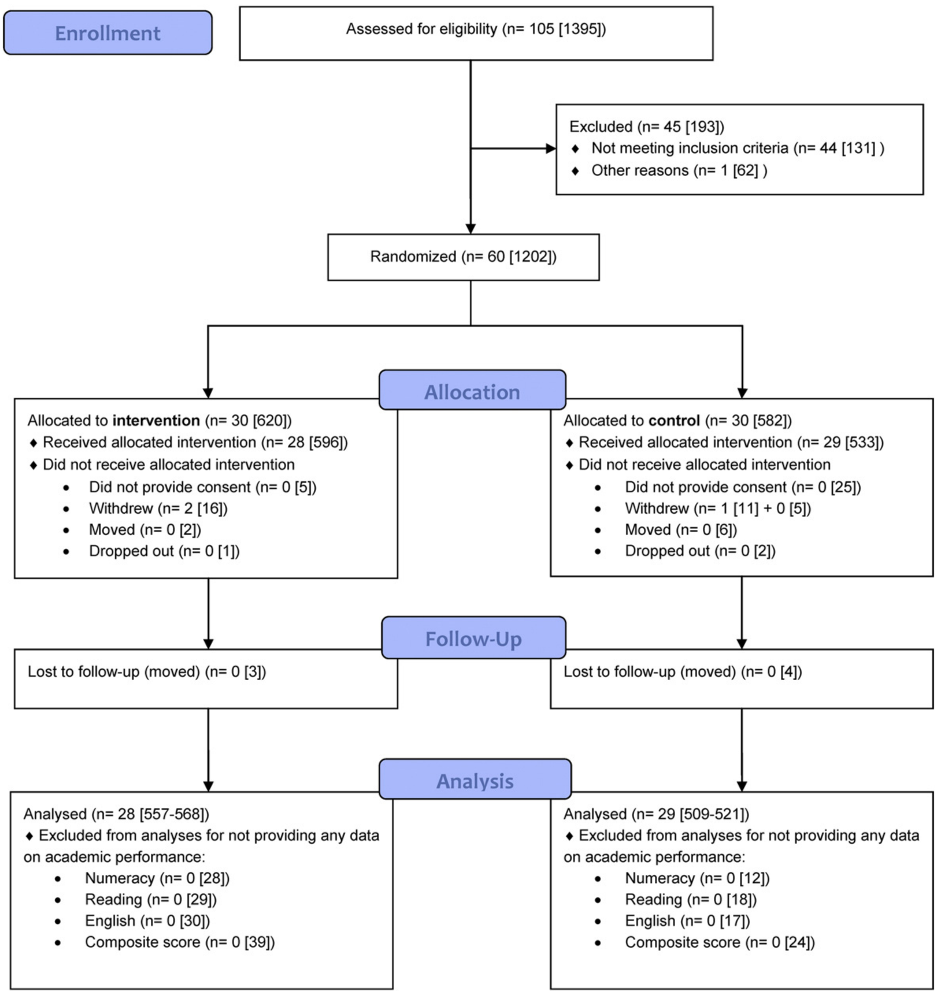

Fig. 1. The consort flow diagram. Flow of schools and children through the study. All numbers are schools [children].

academic performance tests. Children were 10.2 years old (standard deviation ± 0.3) and attending fifth-grade classes in Sogn og Fjordane County, Norway. The ASK study was designed to detect an effect size of 0.35 between two groups for change in academic performance (Resaland et al., 2015).

2.2. Teacher training

Fifth-grade classroom teachers in the intervention schools (I-schools) delivered the intervention. To support and qualify teachers to conduct the intervention, we arranged three comprehensive pre-intervention seminars and two regional refreshing sessions during the intervention period. We also gave support via email and telephone to teachers in I-schools. A password-protected homepage (http://www.askstudy.no) further provided teachers in I-schools with information, videos and content for approximately 100 PA lessons. All lessons on the homepage were developed in collaboration with I-schools in Sogn og Fjordane County. Finally, we provided all I-schools with equipment (e.g., laminating machines and accessories, mathematics bingo tiles, cones) necessary to support the intervention.

2.3. The intervention

The intervention comprised three components aimed at providing children with the opportunity to engage in 165 min of PA/week more than the control group did: i) physically active lessons for 90 min/week, conducted in the playground; physically active educational lessons were delivered in three core subjects – Norwegian (30 min/week), mathematics (30 min/week) and English (30 min/week); ii) PA physical activity breaks (5 min/day) implemented in the classroom during academic lessons; and iii) PA homework (10 min/day) prepared by teachers. In addition, pupils attending I-schools participated in the curriculum-prescribed 90 min/week of PE and the curriculum-prescribed 45 min/week of PA. Thus, PA (165 min/week) and PE/PA (135 min/week) components provided children opportunities to engage in school-based physical activities 300 min/week. The intervention was established as part of the mandatory school curriculum for all pupils attending I-schools. Control schools (C-schools) were asked to provide the “normal practice” school curriculum, including usual amounts of PA/PE, being approximately 135 min/week.

The intervention was designed so activities could be varied and enjoyable for the children. We emphasized to I-school teachers that activities were intended for all children, including those neither particularly fit nor enthusiastic about PA. Teachers were encouraged to motivate children during active lessons, in order to stimulate their positive feelings and attitudes towards PA. We adopted a self-determination perspective, providing teachers with choices and options, and ASK teachers could draw upon a pool of physical activities, developed pre-intervention by the teachers themselves in co-operation with ASK's study group. The intervention was designed so approximately 25% of daily PA was of vigorous intensity, defined as “children sweating and being out of breath.” Teachers achieved the vigorous-PA-intensity component through selecting a variety of high-intensity activities such as running, relay racing, obstacle courses and various forms of high-activity play.

2.4. Outcome measures

Children were assessed at baseline (Time (T)1) and follow-up (T2, after 7 months) as described below.

2.4.1. Academic performance

Academic performance in numeracy (often referred to as mathematics in the literature), reading and English was measured using standardized Norwegian national tests designed and administered by The Norwegian Directorate for Education and Training (NDET) (The Norwegian Directorate for Education and Training, 2015). Most (~95%) fifth-grade pupils in Norway completed these tests during autumn 2014. The numeracy test measured pupils' ability to understand numbers and measurements, and measured their skills in statistics. The reading test measured pupils' ability in basic Norwegian reading skills such as finding information in a text, interpreting and understanding the text, and reflecting on and considering its form and content. The English test measured pupils' ability to find information and understand the main content and some details in simple texts (The Norwegian Directorate for Education and Training, 2015). The three academic performance tests were conducted to map whether a pupil's achievements were in accordance with national curricular goals. The score was standardized to a mean of 50 scale points, with a standard deviation of 10 (Norwegian Ministry of Education, 2013). The three different tests were administered on three different days at both baseline and follow-up. The numeracy test was computer-based, while the other two were paper and pencil tests. Pupils had 60 min to complete the English test and 90 min to complete the other two. These tests are extensively verified for validity and reliability by NDET (The Norwegian Directorate for Education and Training, n.d.) and aligned with competencies demanded from all schools by the national curriculum. Numeracy, reading and English tests were analyzed individually and individual scores were used to derive a composite score, being the total score of the three test scores.

2.4.2. Physical activity

Physical activity was measured using triaxial accelerometry (ActiGraph GT3X+, LLC, Pensacola, Florida, USA). Children were instructed to wear the accelerometer on the right hip throughout seven consecutive days, except during water-based activities or while sleeping. Our criterion for a valid day was a wear time of ≥480 min/day accumulated between 06:00 and 24:00; a wear time of ≥180 min/day accumulated between 09:00 and 14:00 was a criterion for a valid school day. Periods of ≥20 min of zero counts were defined as non-wear time (Esliger et al., 2005). Totals of ≥4 (out of 7) days and ≥3 (out of 5) school days were applied as valid measurements. All analyses were based on accumulated data using a 10-s epoch. Outcomes for PA levels were i) total PA (counts/min), ii) sedentary time (SED), iii) light-intensity PA (LPA) and iv) moderate-to-vigorous intensity PA (MVPA)(min/day). Additionally, we reported the proportion of children who achieved the guideline PA level (a minimum mean of 60 min/day of MVPA). We adopted previously applied and established cut points (Evenson et al., 2008; Trost et al., 2011). We analyzed all accelerometry data using Kinesoft analytical software (“http://kinesoft.org/”). The collection of baseline accelerometer data (April–June 2014) was conducted before the intervention started. The post-test collection of accelerometer data (April–June 2015) took place before the post-test collection of academic performance data.

2.4.3. Adherence to protocol

Schools received a questionnaire every month to assess adherence to the intervention protocol, where teachers reported duration (min/week) and intensity of pupils' PA.

Intensity was reported on a scale from 1 to 3 where 1 = low-intensity activity, 2 = moderate-intensity activity and 3 = vigorous-intensity activity for all three intervention components (PA educational lessons, PA break and PA homework) and for compulsory PE and PA lessons.

2.4.4. Anthropometry

Body mass (weight; 0.1 kg) was measured using an electronic scale (Seca 899, SECA GmbH, Hamburg, Germany). Stature (height; 0.1 cm) was measured with a portable Seca 217 (SECA GmbH, Hamburg, Germany).

2.4.5. Demographic characteristics

We obtained self-reported educational level from parents/guardians to assess socio-economic status. Parental education was categorized into three levels using the highest educational level obtained by the mother or father: i) upper or lower secondary school, ii) university < four years and iii) university ≥ four years.

2.5. Statistics

We report descriptive statistics as means and standard deviations (SD). We tested differences between groups on categorical baseline variables using generalized estimating equations with school as a cluster variable. All other analyses were performed using a mixed-effect model with school as a random effect. The intervention effect was analyzed using an intention-to-treat analysis. We included all children from whom we obtained baseline or final measures of academic performance. Missing data were imputed from relevant variables by means of multiple imputations using a Markov Chain Monte Carlo procedure with 20 iterations; we assumed data were missing at random. To analyze the effect of the prescribed contrast between groups, we also performed secondary (per protocol) analyses comparing I-schools that reported performing ≥80% of prescribed PA with C-schools performing ≤120% of curriculum-prescribed PA (i.e. ≤162 min PA and PE/week) (efficacy). Effect estimates were derived from testing the main effect of group on change in academic performance (dependent variable), while including baseline scores for independent variables as covariates. We tested the between-group difference in change in PA (T2-T1) using minutes per day spent in SED, LPA and MVPA, including baseline scores and change in wear time as covariates. All effect estimates are reported as regression coefficients (β) and 95% confidence intervals (95% CI), along with *p*-values and the intraclass correlation coefficient (ICC) for the cluster effect of schools.

To further explore PA's effect on change in academic performance, we conducted association analyses across all 57 schools without respect to group allocation. Independent variables were PA reports from teachers and change in all accelerometry-derived PA outcomes (individual and aggregated data, i.e., mean change in PA over time for each school).

We performed subgroup analyses to assess the moderating effect of several variables on the intervention's effect on academic performance. Moderating effects for change in academic performance (dependent variable) were determined by testing a categorical subgroup ∗ group interaction, after controlling for main effects of group and subgroup. Variables in the model were academic performance (at T1; tertiles), sex, socioeconomic status and baseline school-time PA and total PA level (total PA (counts/min; tertiles), SED (%) and MVPA (%)). For moderators other than academic performance, baseline academic performance was a covariate in the model.

Outcomes and analyses were determined a priori (Resaland et al., 2015). All analyses were performed using IBM SPSS v. 23 (IBM SPSS Statistics for Windows, Armonk, NY: IBM Corp., USA) or later versions. A two-sided p-value ≤ 0.05 is considered statistically significant.

3. Results

We could not acquire academic performance data from some children and therefore excluded them from analyses for numeracy (n = 40), for reading and English (n = 47), and the composite score (n = 63) (~4% of total; see Fig. 1). Seven children dropped out during follow-up.

Table 1 shows children's baseline characteristics by group. There were no differences between I-schools and C-schools for any variables.

Table 1
Children's demographic and anthropometric characteristics, physical activity levels and academic performance at baseline. Mean (SD). Children not providing valid data did not differ between the intervention and the control group.

	n	Intervention	n	Control
Demographics				
Age (years)	596	10.2 (0.3)	533	10.2 (0.3)
Sex (% girls/boys)	596	47/53	533	49/51
Parents' education level (%)	578		491	
Upper secondary school		30.8		34.8
University <4 years		30.8		28.9
University ≥4 years		38.4		36.3
Anthropometry	578		517	
Body mass (kg)		36.9 (8.0)		37.2 (8.1)
Height (cm)		142.6 (6.8)		142.8 (6.8)
BMI (kg/m^2)		18.0 (3.0)		18.1 (3.0)
Overweight/obese (%)		17.4/3.5		17.8/3.8
Physical activity full day	564		496	
Total PA (cpm)		740 (300)		721 (263)
SED (min/day)		468 (57)		465 (62)
MVPA (min/day)		77 (28)		73 (24)
Achieving guideline PA level (%)		67		64
Physical activity at school	566		497	
Total PA (cpm)		650 (184)		639 (192)
SED (min/day)		178 (19)		179 (20)
MVPA (min/day)		29 (11)		28 (10)
Academic performance				
Numeracy (points)	564	51.1 (9.8)	516	51.4 (9.2)
Reading Norwegian (points)	560	49.2 (10.0)	506	49.7 (9.4)
English (points)	555	49.0 (9.6)	507	49.8 (10.0)
Composite score (z-score)	545	-0.02 (1.02)	502	0.02 (0.98)

BMI = body mass index; SED = sedentary time; MVPA = moderate-to-vigorous intensity physical activity.

During school hours, 946 children had valid accelerometry data for T2-T1; 908 children had valid data during the full day. There were no significant differences between groups for change in PA either during school hours (p ≥ 0.399) or during the full day (p ≥ 0.370) (Table 2). The same findings extend to the subgroup that achieved a significant intervention effect on numeracy (p ≥ 0.142, n = 288–309).

Total PA levels reported by I-schools and C-schools over the intervention period were 288 (21) and 157 (35) min/week, respectively. Thus, differences between schools (131 min/week), according to teacher reports, were 20% less than prescribed, but clearly greater than those differences indicated by accelerometry. Sensitivity analyses using stricter wear time criteria did not change any findings.

We found no significant effect of the intervention on any academic performance measure in the intention-to-treat analyses (Fig. 2). Effect sizes were very small across all outcomes (0.01–0.06 SD units).

To test for possible moderating effects of changes in academic performance, we tested group ∗ subgroup interactions for academic performance at T1, sex, socioeconomic position and PA at T1. We found a significant effect of the intervention on numeracy by tertile (subgroup ∗ group p = 0.005). The specific subgroup effects were 2.39 (95% CI 0.72–4.06) points for the lowest tertile, −0.04 (−1.54–1.47) points for the middle tertile, and −0.23 (−1.63–1.17) points for the highest tertile. The standardized effect size was 0.25 (95% CI 0.08–0.43) SDs when considering the whole group SD (9.5 points), and 0.63 (0.19–1.07) SDs when I-school children in the lowest tertile were compared to their C-school counterparts (SD 3.8 points). No other interactions for baseline values reached statistical significance (p = 0.298 for Reading, p = 0.087 for English and p = 0.115 for the composite score).

Sex was the only moderator that reached statistical significance for the change in academic performance. Boys demonstrated a positive trend (mean difference [95% CI] 0.44 [−1.00–1.87] points) and girls a negative trend (−1.33 [−2.78–0.10] points) in Reading (p for interaction = 0.032). We observed the same trend for numeracy (boys: 0.97 [−0.33–2.26]; girls −0.01 [−1.31–1.29]). However the group ∗ sex interaction for numeracy was not statistically significant (p = 0.096). Sex-

Table 2
Mean baseline, follow-up and group (intervention–control) differences (95% confidence intervals) in change in PA during school hours and during full days.

	Intervention group		Control group		Group difference
	Baseline	Follow-up	Baseline	Follow-up	
School hours					
n	508		438		
Total PA (cpm)	654 (638–670)	658 (641–676)	647 (629–664)	626 (608–644)	13.5 (−36.9–64.0)
SED (min/day)	178 (177–180)	179 (177–180)	179 (177–181)	182 (180–183)	−1.0 (−5.2–3.2)
LPA (min/day)	85 (84–86)	82 (81–83)	83 (82–85)	82 (80–83)	0.9 (−1.2–3.0)
MVPA (min/day)	30 (29–30)	30 (29–31)	29 (28–30)	29 (28–30)	0.1 (−3.0–3.2)
Full day					
n	497		411		
Total PA (cpm)	750 (723–776)	628 (610–645)	732 (707–758)	612 (593–630)	−2.1 (−47.5–43.2)
SED (min/day)	469 (464–474)	496 (491–500)	466 (461–472)	495 (490–501)	3.4 (−4.2–11.0)
LPA (min/day)	236 (233–240)	220 (217–223)	233 (229–236)	222 (219–225)	−1.1 (−5.2–2.8)
MVPA (min/day)	78 (75–80)	68 (66–70)	74 (72–77)	66 (64–68)	−1.1 (−6.1–4.0)

PA = physical activity; cpm = counts per minute; SED = sedentary time; LPA = light physical activity; MVPA = moderate-to-vigorous intensity physical activity.

specific patterns were less pronounced for English ($p = 0.477$) and for the composite score ($p = 0.192$).

We provide results from the per protocol analyses (Table 3), comparing I-schools that according to self-reports completed ≥80% of the prescribed PA (27 schools, 574 children included; 1 school, 22 children excluded) with C-schools that reported ≤120% of recommended PA (16 schools, 324 children included; 13 schools, 209 children excluded). Compared to the intention-to-treat analyses, the per protocol analyses showed that the intervention's effect decreased for all measures, except for English, where the effect became statistically significant (mean difference 0.13 [0.01–0.26] SDs).

Post hoc analyses across groups showed no significant associations between reported PA levels from each school and change in any academic performance variable ($p > 0.116$). These results agree with the non-significant associations observed between change in academic performance and change in PA (accelerometry; whole day and during school time) according to individual ($p > 0.058$) and aggregated data (mean change in PA for each school; $p > 0.129$) (sample sizes: PA during the whole day: $n = 793–865$ children across the outcome variables; school-time PA: $n = 821–899$ children across the outcome variables).

4. Discussion

We did not detect any significant effect of the intervention on numeracy, reading, English or the academic composite score. However, the intervention significantly affected numeracy in children in the lowest tertile of the numeracy score at baseline.

We observed no significant difference between I-schools and C-schools in pupils' PA or SED measured objectively using accelerometers. An important reason for this seems to be high levels of PA in the control group, something which is not uncommon in PA intervention trials (Waters et al., 2012). As our premise was that PA would cause a change in academic performance, this is likely to be the main reason we were unable to detect measurable benefits between I-schools and C-schools in pupils' academic performance. Yet, teacher-reports of PA indicated high adherence to the intervention and a clear contrast between the groups. These contrasting results between subjective and objective measures of PA might be partly expected as over reporting of PA is common by self-report measures. In addition, some of the activities performed by the I-schools (e.g., activities focusing on motor skills as throwing, catching, balance or muscular strength) might be underestimated by the objective measurement. Still, the present study can be viewed as a study of the effect of PA without academic content vs. PA with academic content. The issue regarding PA type with or without academic content has yet to be addressed, and is of great interest to the field.

The observed significant effect on numeracy for children in the lowest tertile of numeracy performance at baseline may be more a result of how PA was integrated into the curriculum rather than a result of the amount of PA (i.e., the dose). The "physically active educational lessons" were a cornerstone and a novel part of the intervention, where curricular content that involved solving problems or addressing questions was embedded within physical activities. This approach to learning may have affected those who were less literate in numeracy. Although this

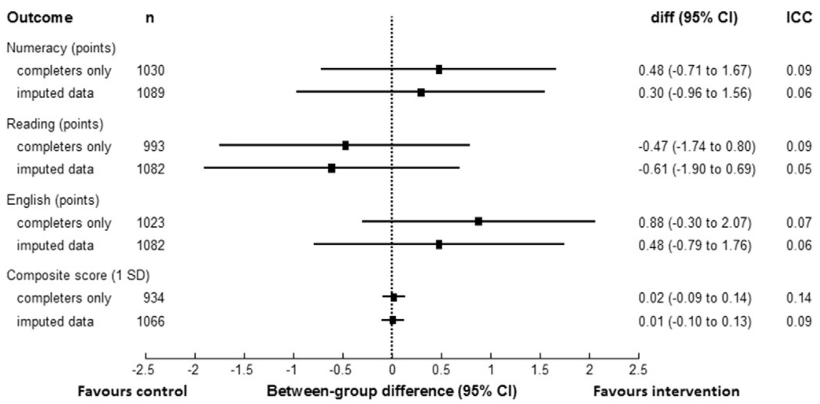

Fig. 2. The intervention's effect (intention-to-treat analyses): completers only vs. imputed data (all children with pre- or post-data for a given variable). The composite score is expressed as the standardized mean of standardized individual scores. 95% CI = 95% confidence interval; ICC = intraclass correlation coefficient; SD = standard deviation.

Table 3
The intervention's effect (per protocol analyses).

	n	Group difference (95% CI)	p	ICC
Numeracy	822	0.18 (−1.09–1.45)	0.777	0.07
Reading Norwegian	805	−0.30 (−1.54–0.94)	0.626	0.04
English	821	1.39 (0.08–2.70)	0.039	0.05
Composite score	767	0.05 (−0.07–0.16)	0.415	0.09

is speculation, it may be that those children who performed most poorly at baseline in numeracy responded best to this combined approach – rather than simply to an increased amount of PA. This approach to learning may be more appealing to those children who performed most poorly at baseline in numeracy. It also allows teachers to use different didactic methods, which may be important because of pupils' different learning strategies (Dunn and Dunn, 1993; Gardner, 2011). In addition, it seems that the perception that PA "steals" time away from traditional subjects in school can be overcome by using an approach that effectively combines PA and academic learning.

Mullender-Wijnsma et al. (2016) carried out a two-year cluster RCT including 499 s- and third-graders from the Netherlands, investigating the effects of an innovative physically active academic intervention called Fit & Vaardig op School (F&V) on academic achievement of children. Their multilevel analysis showed that children in the intervention group had significantly greater gains in mathematics and spelling scores after two years. However, the results revealed that the intervention had no significant effect on a number of variables after only one school year. The non-significant intervention effect observed in our study and the two-year length of the F&V study suggest that the ASK intervention may have been of insufficient length to yield benefits in academic performance in students at the group level similar to those in Mullender-Wijnsma et al. (2016). This notion is supported by the Physical Activity Across the Curriculum (PAAC) (Donnelly et al., 2009), a three-year cluster RCT that found that mathematics, spelling and reading improved significantly in the intervention group as compared to the control group after three years.

Our objectively measured PA data suggested that participants, in both I-schools and C-schools, were on average more active than a population-based national sample of Norwegian 10-year-olds (Anon., 2012) and European and US counterparts (Cooper et al., 2015). Therefore, the high level of PA at baseline for our group of pupils may have resulted in a limited potential to intervene, and ceiling effects may have influenced our results. Yet, contrary to this hypothesis, we found no interaction effect of baseline PA for change in academic performance.

Is there a negative trade-off between having active, healthy students and having better academic performance? The mounting evidence suggests there is not. Several studies have demonstrated that increased time allocated to school-time PA did not detract from academic performance (Singh et al., 2012; Norris et al., 2015; Ahamed et al., 2007). Given the documented health benefits children derive from increased PA levels (Strong et al., 2005; Janssen and LeBlanc, 2010; Dobbins et al., 2013) and the number of hours that children spend in school, educating "healthier" children seems a justifiable use of valuable school time. There is little evidence that eliminating subjects (such as PE) to allow for more classroom-based "academic" learning is associated with better academic performance (Hillman et al., 2008). Furthermore, increasing time allocated to theoretical subjects (without more effective methods or better-quality teaching) does not translate into better test scores (Committee et al., 2013). Thus, given the varied nature of how children learn, it is reasonable that practical didactical approaches that incorporate physically active educational lessons and short physical activity breaks during classroom lessons for children may be a feasible and simple approach to improving academic performance for some, if not all, children.

Study strengths included the cluster RCT design, large sample size and high attrition, and objective measurements of PA. Regarding limitations, our objectively measured PA data suggested that within our sample the amount of PA was high across intervention and control groups at baseline and follow-up, indicating the existence of ceiling effects.

The present study was carried out in one Norwegian county, and one should therefore be careful when generalizing the results.

5. Conclusion

We designed a multi-component model of school-based PA that teachers were able to deliver effectively and we conducted a rigorous seven-month cluster RCT on the effects of this school-based PA program on an academic performance, with the largest sample to date of 10-year-old elementary schoolchildren.

We found no significant overall effect of the intervention on academic performance. However, there was a significant effect on numeracy among the children who initially performed the poorest (in the lower-third tertile of numeracy). Our study therefore adds to a growing body of evidence that PA may be one way of improving academic performance in numeracy in some children (i.e., in those whose performance in numeracy is lowest). Thus, integrating PA and numeracy seems a viable model to stimulate learning in some schoolchildren. However, this study also supports the notion that there is still inadequate evidence to conclude that increased time in school PA or PE enhances academic achievement in children throughout the population (Keeley and Fox, 2009; Howie and Pate, 2012).

Competing interests

WvM is director-shareholder of VU University Medical Center spin-off company Evalua Nederland B.V. ("http://www.evalua.nl") and non-executive board member of ArboUnie B.V. (www.arbounie.nl). Both companies are active in the Dutch occupational healthcare market.

Abbreviations

ASK	active smarter kids
cluster RCT	cluster randomized controlled trial
cm	centimeter
C-schools	control schools
CV	coefficient of variation
ICC	intraclass correlation coefficient
I-schools	intervention schools
kg	kilogram
LPA	light-intensity physical activity
MVPA	moderate-to-vigorous intensity physical activity
PA	physical activity
PE	physical education
SED	sedentary time

Transparency document

The Transparency document associated with this article can be found, in online version.

Acknowledgments

We are grateful to the children and their parents/guardians from the 57 participating elementary schools for their time and effort. Their generosity allowed us to complete the study. We thank the I-school teachers who delivered the daily PA intervention for their commitment to the study and to their pupils, and for their talent as educators. We also thank the principals from the I-schools and C-schools for allowing us to be part of their world. All authors would like to acknowledge and thank master- and bachelor-level students from Sogn og Fjordane University College who participated in data collection. We are grateful to the

Norwegian Directorate for Education and Training for providing the national test we used to assess academic performance. Finally, we could not have completed our study without generous financial support from the Research Council of Norway (grant number 221047/F40), Sogn og Fjordane University College, the Norwegian School of Sports Science and the Gjensidige Foundation (grant number 1042294).

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PAPER IV

frontiers in Psychology

ORIGINAL RESEARCH
published: 29 June 2017
doi: 10.3389/fpsyg.2017.01088

Executive Functions Do Not Mediate Prospective Relations between Indices of Physical Activity and Academic Performance: The Active Smarter Kids (ASK) Study

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Edited by:
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Specialty section:
This article was submitted to Educational Psychology, a section of the journal Frontiers in Psychology

Received: 11 April 2017
Accepted: 13 June 2017
Published: 29 June 2017

Citation:
Aadland KN, Ommundsen Y, Aadland E, Brønnick KS, Lervåg A, Resaland GK and Moe VF (2017) Executive Functions Do Not Mediate Prospective Relations between Indices of Physical Activity and Academic Performance: The Active Smarter Kids (ASK) Study. Front. Psychol. 8:1088. doi: 10.3389/fpsyg.2017.01088

Changes in cognitive function induced by physical activity have been proposed as a mechanism for the link between physical activity and academic performance. The aim of this study was to investigate if executive function mediated the prospective relations between indices of physical activity and academic performance in a sample of 10-year-old Norwegian children. The study included 1,129 children participating in the Active Smarter Kids (ASK) trial, followed over 7 months. Structural equation modeling (SEM) with a latent variable of executive function (measuring inhibition, working memory, and cognitive flexibility) was used in the analyses. Predictors were objectively measured physical activity, time spent sedentary, aerobic fitness, and motor skills. Outcomes were performance on national tests of numeracy, reading, and English (as a second language). Generally, indices of physical activity did not predict executive function and academic performance. A modest mediation effect of executive function was observed for the relation between motor skills and academic performance.

Trial registration: Clinicaltrials.gov registry, trial registration number: NCT02132494.

Keywords: objectively measured physical activity, aerobic fitness, motor skills, structural equation modeling, elementary school, cognition

INTRODUCTION

There is a growing body of evidence to suggest that children derive cognitive benefits from participating in physical activity, with changes in cognitive function induced by physical activity proposed as a mechanism for improved academic performance (Howie and Pate, 2012; Tomporowski et al., 2015; Donnelly et al., 2016). For example, Howie and Pate (2012) hypothesized a model for the causal links in their systematic review, where cognitive function acts as a mediator in the relation between physical activity (as well as physical fitness, and sports participation) and academic performance. Across the range of cognitive functions it is the higher-level executive functions that are shown to benefit the most from physical activity (Hillman et al., 2009).

Executive functions encompass inhibition, working memory, and cognitive flexibility, functions that are distinguishable, but moderately correlated with each other (Miyake et al., 2000). Despite a rapid growth in studies investigating relations between physical activity and executive function and/or academic performance, most evidence is cross-sectional and only investigates single links. To our knowledge, only the studies by Rigoli et al. (2012) and Roebers et al. (2014) have tested the mediation effects of executive function. Rigoli et al. (2012) showed that working memory mediated the relation between motor coordination and academic performance in an adolescent sample. A major limitation in their study, however, was the cross-sectional design. In order to claim mediation, evidence of change would need to be demonstrated (Little, 2013). Roebers et al. (2014) examined the predictive value of fine motor skills, intelligence, and executive function on academic performance 2 years later in preschool children. They showed that executive function plays a role in the link between motor skills and academic performance, as the prediction of academic performance from fine motor skills and intelligence was no longer significant when executive function was added in the model. Furthermore, no significant effect was evident for a link between fine motor skills and executive function. Fine motor skills, intelligence, and executive function covaried, suggesting that executive function processes are shared mechanisms involved in both fine motor tasks and intelligence tests.

Concerning this limited evidence for the executive function hypothesis, this study examined whether executive function mediated a possible prospective relation between indices of physical activity and academic performance in a cohort of 1,129 Norwegian elementary schoolchildren. The term "indices of physical activity" includes accelerometer measures [overall physical activity (counts per minute, cpm), moderate-to-vigorous physical activity (MVPA), and sedentary time], aerobic fitness, and motor skills. Our hypothesized model is illustrated in **Figure 1**.

The evidence for a direct link between physical activity and academic performance is mixed. A position paper published in 2016 concluded that physical activity has a neutral to positive effect on academic performance (Donnelly et al., 2016). The evidence base for this conclusion, however, is sparse and has important limitations, as randomized controlled studies of high quality are lacking (Singh et al., 2012; Mura et al., 2015; Donnelly et al., 2016). A recent intervention study by Mullender-Wijnsma et al. (2016) found improved performance in mathematics and spelling after 2 years of physically active mathematics and language lessons. However, neither the 5-month Learning, Cognition, and motion (LCoMotion) trial (Tarp et al., 2016), nor the 7-month ASK trial (Resaland et al., 2016), found evidence for an effect of physical activity interventions on academic performance.

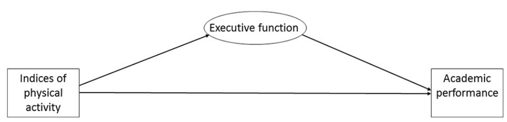

FIGURE 1 | The hypothesized model.

There is stronger evidence for a positive relation between physical activity and executive function, than between physical activity and academic performance (Donnelly et al., 2016; Vazou et al., 2016). Laboratory research has reported both superior brain function and structure in more fit compared to less fit children (see Chaddock et al., 2011; Khan and Hillman, 2014 for reviews). However, the majority of these studies are cross-sectional and are thus unable to demonstrate a causal link.

Three pathways have been suggested by which physical activity could affect executive function (Best, 2010). First, participation in aerobic physical activity may induce physiological changes in the brain. Second, the cognitive demands inherent in goal-directed physical activities (e.g., group games) may also develop cognitive skills that can transfer to executive function tasks, and finally, the cognitive demands in executing complex motor tasks may induce physiological changes in the brain (Best, 2010). Hence, research has focused on both the quantitative (dose) and qualitative (type) characteristics of physical activity. These studies have reported both a dose-response relation between physical activity and executive functions (Davis et al., 2011; Hillman et al., 2014), and evidence for the importance of the cognitive demands inherent in physical activity through social interaction and complex motor skill tasks on executive functions (Crova et al., 2013; Schmidt et al., 2015; Pesce et al., 2016). Recently, Schmidt et al. (2015) demonstrated that although both an intervention with group-games and an intervention with individual aerobic exercise increased aerobic fitness, only the group-game intervention improved cognitive flexibility. Moreover, Pesce et al. (2016) showed the effects of an enriched physical education intervention consisting of both cognitively challenging activities and motor coordination compared to traditional physical education on inhibition. Despite the promising evidence of several pathways by which physical activity may affect executive functions, the effects of different kinds of physical activities (aerobic, coordinative, and cognitively engaging) on executive function is still unknown due to the large heterogeneity in the existing intervention studies investigating these questions (Vazou et al., 2016). The present study used objectively measured physical activity levels, aerobic fitness, and motor skills as predictors in separate mediation models, to investigate their possible different relations to executive function.

There is a clear link between executive functioning and academic performance (Bull and Scerif, 2001; St Clair-Thompson and Gathercole, 2006; Best et al., 2011; Bull and Lee, 2014; Cantin et al., 2016). Mathematics and reading are complex skills that reflect executive function skills such as selecting and coordinating different executive function components (Best et al., 2011). Even though the content in mathematics and reading are very different, their patterns of correlations to executive functions across age are similar (Best et al., 2011). This similarity indicates that the same cognitive processes are important to both reading and mathematics. The present study examines the relation between executive function and performance on national tests of numeracy, reading, and English (as a second language).

Against this evidence for the hypothesized links of indices of physical activity to executive function and academic performance, the present study extends previous research aiming to investigate whether executive function is a mediator in a prospective relation between indices of physical activity (objectively measured physical activity, aerobic fitness, and motor skill) and academic performance in numeracy, reading, and English. Since MVPA and sedentary time are separate dimensions of activity (Sedentary Behaviour Research Network, 2012), their possible different predictions of executive function and academic performance were examined. Furthermore, as sex-specific associations were observed between aerobic fitness and motor skills, and executive function and academic performance, in a previous study (Aadland et al., 2017a), we also examined if the mediation of executive function was different in girls and boys.

METHODS

The present study used data from the ASK study—a cluster-randomized controlled trial conducted in the county of Sogn og Fjordane, Norway, between August 2014 and June 2015. Sixty schools, encompassing 1,202 fifth-grade children, fulfilled the inclusion criterion of at least seven fifth-grade children enrolled, and agreed to participate. In total, 1,145 (82.1% of the population of 10-year-olds in the county) of the 1,175 invited children from 57 school agreed to participate. Valid data were provided from 1,129 children (Supplemental Figure 1). As there were no differences in physical activity levels (Resaland et al., 2016), aerobic fitness, and motor skills (Aadland et al., 2017b) between children in the intervention- and control group during the trial, both groups were included in the present study. We only provide a brief overview of relevant methods below as a detailed description of the study is given elsewhere (Resaland et al., 2015).

Assessments

All assessments were conducted during school hours (between 08:30 a.m. and 2:30 p.m.), unless otherwise stated.

Physical Activity and Sedentary Time

Physical activity and sedentary time were measured by ActiGraph accelerometers (ActiGraph GT3X+, LLC, Pensacola, Florida, USA), which is being widely applied and extensively tested for validity and reliability in children and youth (De Vries et al., 2009). Children were instructed to wear the accelerometer on the right hip at all time over seven consecutive days, except during water-based activities or while sleeping. A wear-time of $\geq$480 min/day for $\geq$4 days was applied as a criterion for a valid measurement. Periods of $\geq$20 min of zero counts were defined as non-wear time (Esliger et al., 2005). The outcomes for physical activity were overall physical activity (counts per minute, cpm), percent all day in MVPA (cut-point 2,296 cpm), and percent all day sedentary (0–100 cpm; Evenson et al., 2008; Trost et al., 2011). Files were analyzed at 10-s epochs using the KineSoft analytical software version 3.3.80 (KineSoft, Loughborough, UK).

Aerobic Fitness

Aerobic fitness was measured with an intermittent practical running field test (the Andersen-test; Andersen et al., 2008; Aadland et al., 2014). The Andersen-test was administered according to standard procedures: Children ran from one end line to another (20 m apart) in an intermittent to-and-fro movement, with 15-s work periods and 15-s breaks (standing still), for a total duration of 10 min. Children were tested indoors on a wooden or rubber floor in groups of 10–20 children. We recorded the distance covered as the outcome for the analysis. To enable comparing of aerobic fitness level across studies, VO_{2peak} was calculated using the equation suggested by Aadland et al. (2014).

Motor Skills

Motor skills were measured using a battery of three tests: (1) Catching with One Hand (Catching), (2) Throwing at a Wall Target (Aiming), and (3) Shuttle Run, 10 × 5 m. Tests 1 and 2 constitute the subgroup Aiming and Catching from the Movement Assessment Battery for Children 2 (Movement ABC-2), ageband 3 (11–16 years; Henderson et al., 2007), and test 3 is from the Eurofit test battery (Council of Europe, 1993). In accordance with the standard testing procedure for the Movement ABC-2, children performed five practice attempts in each task (1 and 2) before testing. No practice was given prior to the Shuttle Run test (3).

Executive Functions

We measured key executive functions identified by Miyake et al. (2000); inhibition, working memory, and cognitive flexibility, by using four pen and paper tests. We assessed inhibition with the Stroop Color and Word Test (Golden, 1978). To assess cognitive flexibility, we used a semantic Verbal Fluency test (Spreen and Strauss, 1998), and The Trail Making Test (Spreen and Strauss, 1998; Lezak et al., 2012). Finally, we used a digit span test (digits forward and backward) from the Wechsler Intelligence Scale for Children, fourth edition (WISC-IV) to assess working memory (Lezak et al., 2012). All tests of executive functions are validated for use in children, and have been shown to be appropriate for measuring executive functions in 10-year-old children [Stroop (Peru et al., 2006), Verbal Fluency (Riva et al., 2000; Ardila et al., 2006), WISC-IV (Wechsler, 2003), and the Trail Making Test (Reitan and Wolfson, 2004)].

Trained research assistants tested the children individually in a quiet room at the child's school. All research assistants followed the same training and test procedures. On average, the test battery was completed in 15–20 min. For a more thorough description of the executive function tests, see Aadland et al. (2017a).

Although, the three-factor model of executive functions identified in young adults by Miyake et al. (2000) has also been confirmed in children (Lehto et al., 2003), age related differences in model solutions have been demonstrated (Brocki and Bohlin, 2004; Huizinga et al., 2006; St Clair-Thompson and Gathercole, 2006; Lee et al., 2013). This may indicate that executive function become more differentiated during childhood (Best and Miller, 2010). From the apparent interrelation of the executive functions in childhood, and the known impurity problems in executive function tasks (Best and Miller, 2010; Cassidy, 2016) we treated executive function as a single latent factor. Furthermore, a latent factor has increased reliability, as measurement errors are excluded (Cole and Maxwell, 2003). Variables included in the latent factor were the Color-Word task of the Stroop Test (Stroop CW), Verbal Fluency total, the Digit Backward of WISC-IV (WISC-IV backward), and the Trail Making Test part B (TMT-b).

Academic Performance

Academic performance in numeracy, reading, and English was measured using specific standardized Norwegian National tests designed and administered by the Norwegian Directorate for Education and Training (NDET). The three different tests were administered on three different days. The tests have shown evidence of good validity and reliability by NDET and are aligned with the competencies demanded from all schools by the national curriculum (Resaland et al., 2015). The scores are reported as standardized points, with a mean of 50 and a standard deviation (SD) of 10.

Potential Covariates

Several covariates were controlled for in the analyses as they have been shown to affect the dependent and independent variables in the present study; age (Best and Miller, 2010; Kolle et al., 2010; Esteban-Cornejo et al., 2015), sex (Aadland et al., 2017a), body fat (Kolle et al., 2010; Davis and Cooper, 2011), pubertal status (Kalkut et al., 2009), and socio economic status (London and Castrechini, 2011). Body fat was measured using four skinfold thickness sites (biceps, triceps, subscapular, and suprailiac) using a Harpenden skinfold caliper (Bull; British Indicators Ltd., West Sussex, England) according to the criteria described by Lohman et al. (1991). The Harpenden skinfold caliper has been tested for validity and reliability in children (Yeung and Hui, 2010). Children self-assessed their pubertal stage with the Tanner method (Tanner, 1962) using a scale of colored images proposed by Carel and Leger (2008). We used breast and genital development for girls and boys, respectively. Socio economic status (the highest education level obtained by the mother and father) was reported by the parents or guardians. Furthermore, as we merged children from an intervention- and a control group into one cohort, we also controlled for group allocation in our mediation analyses. A more detailed description of the methods is provided in the design paper (Resaland et al., 2015).

Ethics Statement

The procedures and methods used in the ASK study conform to the ethical guidelines defined by the World Medical Association's Declaration of Helsinki and its subsequent revisions (WMA, 2013). The study protocol was approved by the Regional Committee for Medical and Health Research Ethics South East (REC South East). We obtained written consent from a parent or guardian of each child prior to all testing.

Statistical Methods

All study variables were examined for distributional properties. TMT-b was transformed (1/x) while other variables were left in their original form. We excluded all values exceeding five standard deviations from the mean. Children's characteristics are provided as means and standard deviations (SD), or frequencies.

A linear mixed model including school as a random effect was used to examine differences between sexes. A chi-square test was used to test for differences between sexes in pubertal status and socio economic status. The descriptive analyses were conducted with SPSS software, version 23.0 (IBM SPSS Statistics for Windows, Armonk, NY: IBM Corp., USA).

Structural equation modeling (SEM), with full information maximum likelihood estimation (FIML) was used to examine the mediation models and the bivariate correlations. The analyses were implemented through Mplus, version 7.4 (Muthén and Muthén, Los Angeles, USA). Because we only had two time points of measurement, we used a half-longitudinal mediation approach as explained in Cole and Maxwell (2003) and Little (2013). As it is possible for a predictor to have an indirect effect on academic performance through executive function, without a direct effect between the two, we tested the full mediation models and did not use the causal steps approach by Baron and Kenny (1986) and Hayes (2009). We used seven predictor variables (cpm, MVPA, sedentary time, aerobic fitness, Shuttle Run, Aiming, and Catching) and three outcome variables (numeracy, reading, and English), resulting in 21 different mediation models. Each mediation model was conducted in two steps, advancing in complexity; (1) mediation models including covariates, by adding a regression from each covariate to all dependent and independent variables, and (2) mediation models examining sex-differences, by conducting a multi-group analysis (covariates included). As it is not possible to take into account the cluster effect while using the bootstrap command, each model was furthermore performed twice; once including cluster (MLR estimator) and once with bias corrected bootstrap (10,000 bootstrap samples). We used bootstrapping to construct asymmetric confidence interval for the indirect effects (ab). With bootstrapping, the confidence intervals are based on an empirical generated representation of the sampling distribution of ab that respect the fact that indirect effects can be extremely non-normally distributed.

Due to the large sample size, multiple indices in addition to the chi-square test statistic were used to assess model fit; the Comparative Fit Index (CFI), the Root Mean Squared Error of Approximation (RMSEA), and the Standardized Root Mean Square Residual (SRMR). We used a non-significant χ^2 and the cutoff recommendations of CFI > 0.95, and RMSEA and SRMR < 0.05 as indications of good model fit to the data (Geiser, 2013).

Measurement invariance was tested for the latent factor of executive function both across time and across sex. A $p \leq 0.05$ was used to indicate statistical significance in all analyses.

RESULTS

The children's characteristics are shown in **Table 1**. Girls performed better on all but one test of executive function, while

TABLE 1 | Baseline characteristics of the children as means and standard deviations (SD) or frequencies.

	Girls		Boys		Total	
Variable	***n***	***M (SD)/%***	***n***	***M (SD)/%***	***n***	***M (SD)/%***
Age (years)	541	10.2 (0.3)	588	10.2 (0.3)	1,129	10.2 (0.3)
BMI	531	18.1 (3.0)	564	18.0 (3.0)	1,095	18.1 (3.0)
Body fat (mm)	527	58.4 (29.3)	557	42.2 (20.9)***	1,084	50.1 (26.6)
Pubertal stage (Tanner) (%)	526		555		1,081	
Stage 1	116	21.4	193	32.8***	309	27.4
Stage 2	345	63.8	303	51.5	648	57.4
Stage 3, 4, and 5	65	12.2	59	10.0	124	11.0
Socio economic status (%)	511		558		1,049	
≤ Upper secondary school	156	28.8	193	32.8	349	30.9
<4 years of university/college	156	28.8	164	27.9	320	28.3
≥4 years of university/college	199	36.8	201	34.2	400	35.4
PA-levels (full day)						
Counts per minute (cpm)	484	691 (236)	521	773 (299)***	1,005	733 (274)
SED (% all day)	484	60.2 (5.9)	522	59.5 (6.5)	1,006	59.8 (6.2)
MVPA (% all day)	484	8.9 (2.7)	522	10.5 (3.5)***	1,006	9.7 (3.3)
Aerobic fitness (m)	511	868.6 (85.8)	534	915.9 (112.6)***	1,045	893.8 (103.1)
Estimated VO_{2peak} (ml/kg/min)	510	48.9 (6.9)	534	55.2 (7.3)	1,044	52.3 (8.0)
Motor skills						
Shuttle Run (s)	527	23.6 (2.2)	556	22.7 (2.3)***	1,083	23.1 (2.5)
Aiming (n)	532	3.8 (1.9)	561	4.2 (1.9)***	1,093	4.0 (1.9)
Catching (n)	507	3.3 (2.9)	526	4.8 (3.1)***	1,033	4.1 (3.1)
Executive function						
Stroop CW (n)	525	26.6 (5.8)	563	25.1 (6.0)***	1,088	25.8 (5.9)
Verbal Fluency (n)	528	16.0 (4.6)	567	16.0 (4.7)	1,095	16.0 (4.6)
WISC-IV backward (n)	526	6.3 (1.4)	567	6.1 (1.3)**	1,093	6.2 (1.3)
TMT-b (s)	512	114.9 (40.8)	529	128.6 (53.3)***	1,051	121.9 (48.1)
Academic performance						
Numeracy	518	50.3 (8.9)	562	52.1 (9.9)***	1,080	51.3 (9.5)
Reading	513	49.7 (9.4)	553	49.2 (10.0)	1,066	49.4 (9.7)
English	515	48.6 (9.0)	547	50.1 (10.5)*	1,062	49.4 (9.8)

*BMI, body mass index; PA, physical activity; SED, sedentary time; MVPA, moderate-to-vigorous physical activity; Stroop CW, Stroop Color Word; WISC-IV, Wechsler Intelligence Scale for Children fourth edition; TMT-b, Trail Making Test part B. *p ≤ 0.05 for the difference between girls and boys; **p ≤ 0.010 for the difference between girls and boys; ***p ≤ 0.001 for the difference between girls and boys.*

boys did better on the tests of numeracy and English. Boys had higher physical activity levels, better aerobic fitness, and better motor skills than girls, whereas girls had higher skinfold thickness and more advanced pubertal status than boys. A correlation matrix for the included independent and dependent variables is provided in **Table 2**.

The Latent Executive Function Factor

As the score on the Verbal Fluency test made a small contribution to the latent executive function factor (baseline: $R^2 = 0.095$ vs. $R^2 = 0.206–0.481$ for other variables; follow-up: $R^2 = 0.085$ vs. $R^2 = 0.205–0.402$ for other variables), it was excluded. The latent factor of executive function showed metric and partial scalar invariance over time, with ΔCFI, ΔRMSEA, and ΔSRMR below suggested criteria (Putnick and Bornstein, 2016), as well as a non-significant Sartorra-Bentler scaled Chi-square. Comparing the metric model against the configural model gave $\Delta\ \chi^2\ (\Delta df = 2) = 1.436$, ΔCFI <0.001, ΔRMSEA <0.001, and ΔSRMR = 0.005, and comparing the partial scalar model against the metric model gave $\Delta\ \chi^2\ (\Delta df = 1) = 0.096$, ΔCFI < 0.001, ΔRMSEA < 0.001, and ΔSRMR = 0.006. The intercept of the WISC-IV backward was varied over time.

The Mediation Models

As shown in **Table 3**, all models had good fit. When comparing each model adjusted for cluster against the same models with bootstrapping the results were nearly identical. Generally, the indices of physical activity did not predict either executive function or academic performance when controlling for covariates, hence no mediation effect of executive function was observed. Yet, executive function partially mediated the relation between the performance on the Shuttle Run test and numeracy (**Figure 2**). Both direct and indirect effects were statistically significant with small estimates. Direct paths from the Shuttle Run test to reading and from sedentary time to English were also observed. Additionally,

TABLE 2 | Estimated correlation matrix for the independent and dependent variables at baseline (above the diagonal line) and at follow-up (below the diagonal line).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.cpm	–	**0.88**	**–0.67**	**0.23**	**–0.20**	**0.10**	**0.25**	–0.01	0.05	0.01	0.02	0.10	–0.01	0.00
2.MVPA	**0.90**	–	**–0.75**	**0.35**	**–0.27**	**–0.11**	**0.29**	–0.00	0.04	0.02	0.01	**0.12**	0.00	–0.00
3.SED	**–0.68**	**–0.72**	–	**–0.18**	**0.13**	–0.05	**–0.14**	0.04	–0.05	0.04	0.01	–0.05	0.04	**0.11**
4.Aerobic fitness	**0.37**	**0.47**	**–0.25**	–	**–0.58**	**0.23**	**0.38**	**0.17**	**0.09**	**0.14**	**0.16**	**0.23**	**0.10**	**0.08**
5.Shuttle Run	**–0.23**	**–0.30**	**0.17**	**–0.66**	–	**–0.24**	**–0.39**	**–0.20**	**–0.13**	**–0.13**	**–0.16**	**–0.28**	**–0.19**	**–0.16**
6.Aiming	**0.17**	**0.22**	**–0.14**	**0.31**	**–0.29**	–	**0.36**	**0.15**	**0.09**	**0.07**	**0.10**	**0.13**	0.05	0.04
7.Catching	**0.25**	**0.31**	**–0.14**	**0.42**	**–0.41**	**0.36**	–	**0.18**	**0.08**	**0.12**	**0.17**	**0.19**	**0.10**	**0.09**
8.Stroop CW	–0.05	–0.03	**0.08**	**0.17**	**–0.19**	**0.16**	**0.15**	–	**0.14**	**0.28**	**0.41**	**0.33**	**0.32**	**0.31**
9.Verbal Fluency	–0.04	–0.02	0.01	**0.07**	**–0.09**	0.05	–0.02	**0.18**	–	**0.17**	**0.23**	**0.24**	**0.25**	**0.19**
10. WISC–IV backward	–0.01	0.02	0.04	0.05	**–0.07**	**0.09**	**0.08**	**0.29**	**0.13**	–	**0.30**	**0.33**	**0.32**	**0.30**
11.TMT–b	–02	0.02	–0.00	**0.12**	**–0.16**	**0.13**	**0.13**	**0.40**	**0.20**	**0.28**	–	**0.44**	**0.36**	**0.32**
12.Numeracy	0.05	**0.09**	0.04	**0.27**	**–0.31**	**0.18**	**0.20**	**0.38**	**0.20**	**0.34**	**0.42**	–	**0.67**	**0.60**
13.Reading	–0.02	–0.02	**0.11**	**0.17**	**–0.20**	**0.13**	**0.13**	**0.41**	**0.26**	**0.35**	**0.37**	**0.64**	–	**0.69**
14.English	–0.04	–0.03	**0.18**	**0.09**	**–0.11**	**0.05**	**0.06**	**0.32**	**0.17**	**0.28**	**0.25**	**0.51**	**0.64**	–

Significant regression coefficients are in boldface. Cpm, counts per minute; SED, sedentary time; MVPA, moderate-to-vigorous physical activity; Stroop CW, Stroop Color Word; WISC-IV backward, Wechsler Intelligence Scale for children backward; TMT-b, the Trail Making test part B. R.

executive function significantly predicted numeracy and reading.

Scalar invariance was found across sex for the latent factor of executive function when comparing the scalar model against the configural model ($p = 0.409$). None of the mediation models was statistically different for girls and boys.

DISCUSSION

The main finding from the present study was that executive function generally did not mediate the prospective relations between indices of physical activity and academic performance. Supplementing a direct link between motor skills and numeracy, we observed a small partial mediation effect through executive function. Executive function predicted numeracy and reading 7 months later.

Our findings generally do not support a hypothesized model in which executive function mediates the relations between indices of physical activity and academic performance (Howie and Pate, 2012; Tomporowski et al., 2015; Donnelly et al., 2016). Our predictors were associated with neither executive function nor academic performance, and our findings contrast with the conclusions drawn in recent systematic reviews, based on a small number of high-quality studies (Singh et al., 2012; Donnelly et al., 2016), that identified a positive relation between indices of physical activity, academic performance and even more so executive function. To our knowledge, only Roebers et al. (2014) have previously examined whether executive function mediates the relation between fine motor skills and academic performance in children using a longitudinal design. As the present study measured multiple predictors, it adds knowledge about the genuine prospective role of different indices of physical activity to executive function and academic performance.

Neither physical activity, sedentary time, nor aerobic fitness predicted executive function or academic performance 7 months later indicate a consistent pattern of findings. Aerobic fitness is frequently used as a proxy of physical activity, as it is partly determined by the physical strain induced by MVPA, and also due to its superior measurement precision compared to physical activity. It has been hypothesized that the effect of physical activity on executive function and academic performance operates through aerobic fitness (Tomporowski et al., 2011), as physical activity increasing aerobic fitness causes physiological changes in the brain that influence cognitive functioning. This hypothesis is partly supported by the cross-sectional study by Lambourne et al. (2013) in which aerobic fitness mediated the relation between physical activity and performance in mathematics, but not in reading and spelling. However, their indirect estimate was very low (0.003). Our longitudinal study does not provide support for this hypothesis, as no link was observed between aerobic fitness and executive function at follow-up. However, previous longitudinal studies have revealed positive relation between aerobic fitness and both executive function (Niederer et al., 2011; Chaddock et al., 2012) and academic performance (London and Castrechini, 2011; Wittberg et al., 2012; Bezold et al., 2014). In contrast to the present study, Booth et al. (2014) observed that the proportion of time spent in MVPA predicted performance in English and mathematics. Aggio et al. (2016) observed that higher levels of sedentary time were associated with improved cognitive performance 3 years later. In the present study, higher levels of sedentary time were associated with increased performance in English, but not in numeracy or reading. An explanation for this finding might be that children partly learn their English from screen-based, and thus sedentary, forms of entertainment (Cliff et al., 2016).

A considerable heterogeneity exists across the studies examining relations between indices of physical activity and cognitive outcomes, opening up for inconsistent findings in the literature. We cannot exclude the possibility that we failed adequately to identify expected links as a result of measurement error or methodological problems. Although, all assessments used in the present study have been shown to be appropriate and

TABLE 3 | Standardized coefficients for the paths and goodness of fit indices for the half-longitudinal mediation models controlled for covariates.

Model	a	b	axb	c′	χ^2	CFI	RMSEA	SRMR
	β	β	β	β	(*df*)		(95% CI)	
NUMERACY								
cpm	−0.081	0.245***	−0.020	0.027	47.386 (45)	0.999	0.007 (0.000–0.022)	0.017
MVPA	0.003	0.244***	0.001	0.035	46.553 (45)	0.999	0.006 (0.000–0.022)	0.017
SED	−0.048	0.246***	−0.012	−0.022	48.433 (45)	0.999	0.009 (0.000–0.023)	0.017
Aerobic fitness	−0.023	0.241***	0.010	−0.006	41.430 (45)	0.998	0.012 (0.000-0.025)	0.017
Shuttle Run	−0.072*	0.226***	−0.016*	−0.098	57.946 (45)	0.996	0.017 (0.000–0.028)	0.017
Aiming	0.000	0.245***	0.000	−0.004	52.645 (45)	0.997	0.013 (0.000–0.026)	0.017
Catching	−0.033	0.233***	−0.008	0.026	47.712 (45)	0.999	0.008 (0.000–0.023)	0.017
READING								
cpm	−0.005	0.187***	0.001	−0.004	47.126 (45)	0.999	0.007 (0.000–0.022)	0.017
MVPA	0.002	0.187***	0.000	−0.004	46.451 (45)	0.999	0.006 (0.000–0.022)	0.017
SED	−0.050	0.187***	−0.009	0.018	48.513 (45)	0.999	0.009 (0.000–0.023)	0.017
Aerobic fitness	−0.026	0.166***	−0.004	0.055	49.091 (45)	0.999	0.009 (0.000–0.024)	0.017
Shuttle Run	−0.066	0.169***	−0.011	−0.069*	53.192 (45)	0.997	0.013 (0.000–0.026)	0.018
Aiming	−0.006	0.190***	−0.001	−0.012	50.791 (45)	0.998	0.011 (0.000–0.025)	0.017
Catching	−0.040	0.183***	−0.007	0.012	45.726 (45)	1.000	0.004 (0.000–0.024)	0.017
ENGLISH								
cpm	−0.005	0.046	−0.000	−0.006	48.111 (45)	0.999	0.008 (0.000–0.023)	0.017
MVPA	0.002	0.047	0.000	−0.009	47.456 (45)	0.999	0.007 (0.000–0.023)	0.017
SED	−0.049	0.047	−0.002	0.056*	49.008 (45)	0.999	0.009 (0.000–0.023)	0.017
Aerobic fitness	−0.028	0.056	−0.002	−0.030	49.396 (45)	0.999	0.010 (0.000–0.024)	0.017
Shuttle Run	−0.065	0.046	−0.003	−0.002	53.242 (45)	0.997	0.013 (0.000–0.026)	0.018
Aiming	−0.005	0.046	−0.000	0.000	51.329 (45)	0.998	0.012 (0.000–0.025)	0.017
Catching	−0.041	0.048	−0.002	−0.005	46.347 (45)	1.000	0.005 (0.000–0.022)	0.017

*a, the path between the predictor and executive function at timepoint 2; b, the path between the executive function at baseline to the outcome at follow-up; axb, the indirect effect; c', the path between the predictor and the outcome; cpm, counts per minute; MVPA, moderate-to-vigorous physical activity; SED, sedentary time; *p ≤ 0.05; ***p ≤ 0.001.*

valid for the included age group (Council of Europe, 1993; Riva et al., 2000; Wechsler, 2003; Reitan and Wolfson, 2004; Ardila et al., 2006; Peru et al., 2006; Henderson et al., 2007; Andersen et al., 2008; De Vries et al., 2009; Utdanningsdirektoratet, 2013; Aadland et al., 2014), our null-findings might be a type 2 error as a result of measurement errors. Although, accelerometer-determined physical activity is more reliable than self-report, it does nevertheless have well-known limitations (Ekelund et al., 2007; Corder et al., 2008). For example, our measure of physical activity levels over 4–7 days might be an insufficient snapshot of a child's complex physical activity behavior (Ekelund et al., 2007), despite reliability (intra-class correlation) of accelerometry of ∼0.70–0.80 for monitoring in children over 3–7 days (Aadland and Johannessen, 2015). As

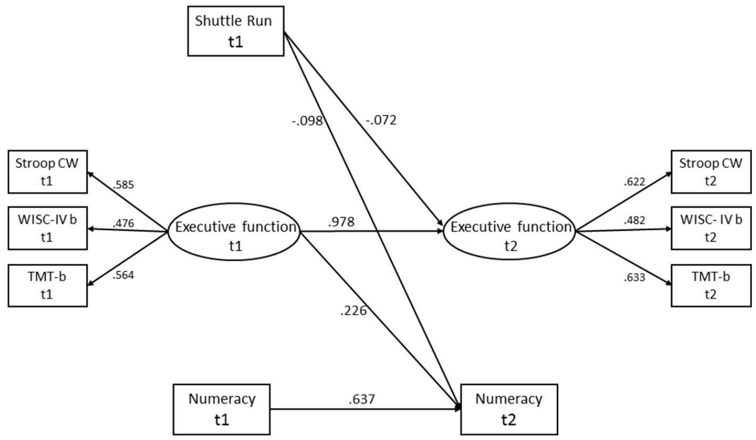

FIGURE 2 | The half-longitudinal mediation model for executive function in the relation between Shuttle Run and numeracy. All path coefficients are significant and reported as standardized β-estimates. The covariates age, sex, tanner, body fat, socio economic status, and group allocation are adjusted for in the model, but not shown. t1, baseline; t2, follow-up; Stroop CW, Stroop Color Word; WISC-IV backward, Wechsler Intelligence Scale for children fourth edition backward; TMT-b, the Trail Making test part B.

is well known, measurement error in predictors can lead to regression dilution bias, which underestimates the paths between the predictors and the mediator (Cole and Maxwell, 2003). Nonetheless, the lack of a prospective link between MVPA and executive function has also been shown by others (Booth et al., 2013; Aggio et al., 2016). Underestimation of the link between the mediator and the outcome may also be present in our models, as a result of measurement errors in the academic performance scores we used.

Our failure to identify links between predictors and executive function, in contrast with the existing literature (Donnelly et al., 2016), might also be explained by the use of different statistical approaches to examine these relations. To our knowledge, only the study by Roebers et al. (2014) have previously used structural equation modeling, treating executive function as a latent factor. Our rationale for using a latent factor was two-fold; first, to take into account the known impurity issues observed in executive function tasks (Cassidy, 2016) as we only had one measure of each domain, and second, to avoid measurement errors. The exclusion of measurement errors in our mediator enhances reliability, and avoids underestimation of both the a and b path and an overestimation of the direct link which is the case for observational mediator variables (Cole and Maxwell, 2003). Possibly, using latent variables of each dimension of executive function might have yielded other results, as randomized controlled trials have reported effects of indices of physical activity on only one aspect of executive functions and not the others (Schmidt et al., 2015; Pesce et al., 2016). However, such an approach would have required a more comprehensive test battery, which was not feasible for the present study. The selection of executive function tasks might also explain our null findings, as we did not include tasks measuring reaction time or accuracy, which would have allowed more fine-grained analysis. For example, Syvaoja et al. (2014) observed cross-sectional associations between objectively measured physical activity and both reaction time and rapid visual information processing, but not with other tests of executive function.

The longitudinal design of the present study differs from the majority of existing evidence stemming from cross-sectional studies. Indeed, a cross-sectional examination of our mediation models supports the executive function hypothesis proposed in previous studies (Howie and Pate, 2012; Rigoli et al., 2012; Tomporowski et al., 2015; Donnelly et al., 2016). More specifically, indirect effects through executive function were present for the cross-sectional relations between both aerobic fitness and all tests of motor skills and academic performance in numeracy, reading, and English (results not shown). Yet, cross-sectional studies lack a temporal relation between the exposure and outcome, and are unable to demonstrate causation. Thus, the half-longitudinal approach applied in the present study is a significant improvement compared to cross-sectional testing of mediation, as we were able to control for prior levels of the mediator and the outcome, and thus examining the influence of their change (Little, 2013). The use of only two measurement time points however, poses a limitation to the present study, as the path between the predictor and the mediator, and the path between the mediator and the outcome, are measured at the same time point. An assumption therefore is that these paths would have had time-ordered relations if more than two occasions of measurement were obtained (Little, 2013). Hence, studies replicating our analysis with more than two time points of measurement are warranted.

Another explanation for our null findings may be the short duration of our follow-up period. 7 months might have been an insufficient duration to cause a change in executive function and academic performance. Assuming that change in executive function will result from structural changes in the brain, sufficient time for the predictor to affect structural changes in the brain is necessary. In order to observe changes in academic performance, it is possible that a longer time is necessary. For example, the study by Mullender-Wijnsma et al. (2016) found effects on academic performance after 2 years but not after 1 year of physically active mathematics and language lessons. Other studies using shorter physical activity intervention length (5–7 months) have not revealed effects on academic performance or executive functions (Resaland et al., 2016; Tarp et al., 2016).

On the other side, a 7-month follow-up period also impose noise. As a prerequisite for our prospective examinations, our indices of physical activity measured at baseline represents the child's supposed physical activity level, aerobic fitness, and motor skills during the follow-up period. However, we cannot rule out the possibility of fluctuations from the baseline measures. Levels of physical activity may have been less stable over the follow-up period (Jones et al., 2013), compared to aerobic fitness and motor skills, as it represents a behavior and not a personal trait. Following this line of reasoning, our observed significant prediction for the Shuttle Run test on both executive function and academic performance, might be explained by the stability of this trait over time. Furthermore, Pesce and Ben-Soussan (2016) suggest that motor skills have a longer-lasting predictive value of cognitive efficiency compared to aerobic fitness. A prospective association for motor skills with executive function has also been observed in previous studies (Niederer et al., 2011; Roebers et al., 2014).

Following up on the prediction of motor skills to executive function and academic performance, executive function mediated the relation between the Shuttle Run and academic performance in numeracy. These findings may be explained by the close parallelism of development and interaction between neural substrates of motor coordination (the cerebellum) and executive function the (prefrontal cortex; Diamond, 2000; Koziol et al., 2012; Rigoli et al., 2012). Likewise, the concept of embodied cognition directly links movements to thought, where executive functions are seen as an extension of the motor control system (Koziol et al., 2012). The review by Best (2010) suggests that engaging in activities that are complex in terms of motor coordination may transfer executive function skills to other contexts. Nevertheless, the magnitude of both the direct and indirect links between motor skills and academic performance in the present study was small (standardized coefficient of −0.016), emphasizing the need for more research examining this relation. Furthermore, taken into account the large number of mediation models analyzed, which potentially may increase the type 1 error rate, it could be a chance finding that should be interpreted carefully (Ioannidis, 2005). The lack of mediation for the two other measures of motor skills, Aiming and Catching, may support this line of reasoning. However, we found a low pre-to-post correlation for Aiming ($r = 0.27$), indicating poor reliability. On the contrary, pre-to-posttest correlations for Catching and Shuttle Run were 0.66 and 0.70, respectively. In contrast to the present study's findings, both the study by Rigoli et al. (2012) (cross-sectional) and Pesce et al. (2016) (RCT) highlight that the subgroup Aiming and Catching from the Movement ABC is linked to executive function and academic achievement.

Finally, our contrasting findings to the present literature might be attributable to publication bias in the literature, as also considered by Howie and Pate (2012). It is possible that positive findings have been highlighted despite mixed findings, or that the variables reported were selected on the basis of positive findings (Ioannidis, 2005; Howland, 2011; Howie and Pate, 2012).

We found that executive function predicts numeracy and reading, which is in line with previous research (St Clair-Thompson and Gathercole, 2006; Best et al., 2011; Cantin et al., 2016; Samuels et al., 2016). A close link between numeracy and reading has been demonstrated previously (Bull et al., 2008; Best et al., 2011), and a study by Cantin et al. (2016) revealed that reading mediated the influence of executive function on mathematics. The Norwegian national tests of both numeracy and reading reflect integrated tasks across several subjects, and require both problem solving and metacognition, with high demands on executive functions. The test in English, however, focuses on grammar and vocabulary. It is possible that these tasks put less demand on executive functions, explaining the lack of relation between executive functions and English. Randomized controlled trials have revealed that the effect of indices of physical activity to cognition are selective to aspects of cognition that required extensive amounts of executive functions (Kamijo et al., 2011; Hillman et al., 2014).

Strengths and Limitations

The main strengths of the present study were the longitudinal design with inclusion of a large sample of 10-year-old children. We furthermore adjusted for the effect of clustering of observations within schools, as well as several covariates in our analyses. However, we cannot rule out that factors being important for the relations examined were not taken into consideration; for example, the child's motivation, other academic activities, quality of life, home environment, nutritional habits, or sleep (Tomporowski et al., 2011). Another, strength is the use of structural equation modeling including a latent variable of executive function. This approach excludes measurement errors in our executive function factor, thus increasing its reliability and validity. However, the latent variable comprising executive function obtained only partial invariance which might have conceptual implications (Putnick and Bornstein, 2016). Yet, partial invariance across time for executive functions might be expected in this case. Executive functions in these fifth-grade children typically undergo developmental changes giving rise to changes in how such functions are conceptualized. Moreover, through learning and experience children might acquire skills that reorganize and expands their cognitive abilities which as well have implications for how executive functions are cognitively processed (Putnick and Bornstein, 2016). Furthermore, the analyses of several predictors, gives the opportunity to investigate different indices of physical activity to both executive function and academic performance. However, this also increases the chance of performing Type

1 errors, meaning that our results should be interpreted cautiously.

CONCLUSION

The results from the present study revealed that executive function generally does not mediate the prospective relation between indices of physical activity and academic performance in 10-year-old Norwegian children over a period of 7 months. The modest mediation effect of executive function observed in the relation between motor skills and academic performance, as well as the direct link of the two, suggests that promoting physical activity that includes novel and complex motor tasks could be a useful approach for improving academic performance in children of this age group. Although, this finding should be interpreted carefully.

AUTHOR CONTRIBUTIONS

KA conceived the idea for the paper together with YO, performed the data collection, analyzed the data, and wrote the manuscript draft. YO helped out in interpretation of the results and drafting the manuscript. EA contributed in data analyses and drafting the manuscript. KB composed the test battery concerning executive function. AL contributed in data analyses. GR obtained funding for the study. VM contributed in data collection and drafting the manuscript. All authors read, commented on, and approved the final manuscript.

FUNDING

The study was funded by the Research Council of Norway under grant number 221047/F40 and the Gjensidige Foundation under grant number 1042294. None of the funding agencies had any role in the study design, data collection, analyzing or interpreting of data, or in writing the manuscript.

ACKNOWLEDGMENTS

The authors are grateful to the children and their families, principals, and teachers from the 57 participating elementary schools who gave their time to the study. Finally, thanks to all the master and bachelor students from Sogn og Fjordane University College participating in the data collection.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fpsyg.2017.01088/full#supplementary-material

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

PAPER V

RESEARCH ARTICLE

Does self-regulation mediate the relationship between school-based physical activity and academic performance in numeracy in ten-year-old children? The Active Smarter Kids (ASK) study

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The research was conducted at: the former Sogn og Fjordane University College, Faculty of Teacher Education and Sport, now a part of the Western Norway University of Applied Sciences.

Funding: This work was supported by the Research Council of Norway under grant number 221047/F40; Sogn og Fjordane University College; the Norwegian School of Sport Sciences, and the Gjensidige Foundation under grant number 1042294.

Running head: Physical activity, self-regulation, and academic performance

Date of submission: 17.08.2017

Word count excluding figure, tables, and references: 5309

Word count abstract: 217

Abstract

Background: Inconsistent findings exists for the effect of school-based physical activity interventions on academic performance. The Active Smarter Kids (ASK) study revealed a favorable intervention effect of school-based physical activity on academic performance in numeracy in a subsample of 10-year-old elementary schoolchildren performing poorer at baseline in numeracy. Aiming to explain this finding, we investigated the mediating effects of executive function, behavioral self-regulation, and school related well-being in the relation between the physical activity intervention and child's performance in numeracy.

Methods: An ANCOVA model with latent variable structural equation modeling was estimated using data from 360 children (the lower third in academic performance in numeracy at baseline). The model consisted of the three latent factors as mediators; executive function, behavioral self-regulation, and school related well-being.

Results: We found no mediating effects of executive function, behavioral self-regulation or school related well-being in the relationship between the ASK intervention and academic performance in numeracy ($p \geq .256$).

Conclusion: Our results suggests that the effect of the intervention on performance in numeracy in the present subsample is not explained by change in executive function, behavioral self-regulation, or school related well-being. We suggest this finding mainly could be explained by the lack of effect of the intervention on the mediators, which might be due to an insufficient dose of physical activity.

Keywords: executive function, behavioral self-regulation, school related well-being, elementary school children, structural equation modeling

Trial registration: Clinicaltrials.gov registry, trial registration number: NCT02132494.

BACKGROUND

Cluster randomized controlled studies (c-RCT) have shown inconsistent findings regarding the effect of physical activity interventions incorporated in the school curriculum on children's academic performance (Beck et al., 2016; Donnelly et al., 2009; Donnelly et al., 2017; Donnelly & Lambourne, 2011; Mullender-Wijnsma et al., 2016; Resaland et al., 2016; Riley, Lubans, Holmes, & Morgan, 2016; Tarp et al., 2016). Our group conducted The Active Smarter Kids (ASK) study (Resaland et al., 2015) and found no effect of a seven-month physical activity intervention on academic performance in numeracy, reading, or English (second language) in the overall sample (Resaland et al., 2016). Yet, a favorable effect of the intervention on numeracy was found in children who performed the poorest in numeracy at baseline (the lowest tertile). Because this effect was most likely not a result of an increased physical activity dose, the effect might stem from how physical activity was integrated in the learning activities. This hypothesis is consistent with studies showing a favorable effect of physical activity integrated in academic lessons (Bartholomew & Jowers, 2011; Beck et al., 2016; Donnelly et al., 2009; Donnelly & Lambourne, 2011; Mullender-Wijnsma et al., 2016; Norris, Shelton, Dunsmuir, Duke-Williams, & Stamatakis, 2015). A closer examination of possible mediators of this effect may increase our understanding of how physical activity at school can improve academic performance in those children most in need. Due to the importance of self-regulation for academic performance (McClelland & Cameron, 2011), we aimed to investigate the possible mediating role of cognitive, behavioral and emotional assets of self-regulation related to the effect of the ASK intervention on academic performance in numeracy. Self-regulation is a comprehensive construct and involve the ability to regulate cognition, behaviors, and emotions (McClelland, Ponitz, Messersmith & Tominey, 2010) (von Suchodoletz et al., 2013). Hence, we explored the mediating role of core executive functions, behavioral self-regulation, and school related well-being.

The relationship between self-regulation as an overarching concept and executive functions is intricate (Audiffren & André, 2015) and described as bidirectional, where executive functions are psychological abilities that contribute to self-regulation, and where the executive functions are dependent on self-regulation through its control of attention and arousal (Blair, 2016). Executive function can be defined as "the cognitive processes necessary for goal-directed cognition and behavior" (Best, 2010, p. 331). Core executive functions involve inhibition and interference control, working memory, and cognitive flexibility (Diamond, 2013; Miyake et al., 2000). The importance of executive function for academic performance is well documented (Best, Miller, & Naglieri, 2011; Cantin, Gnaedinger, Gallaway, Hesson-McInnis, & Hund, 2016; St Clair-Thompson & Gathercole, 2006). Furthermore, promising evidence exists for a positive effect of physical activity on executive function (Donnelly et al., 2016; Vazou, Pesce, Lakes, & Smiley-Oyen, 2016). Possible pathways in which physical activity can affect executive function are through physiological responses in the brain, and through cognitive and motor challenging activities that improve cognitive skills that can be transferred to executive function tasks (Best, 2010). Supporting these pathways, studies have shown favorable effects of physical activity on both brain function and structure in children (Chaddock, Pontifex, Hillman, & Kramer, 2011; Khan & Hillman, 2014). Furthermore, physical activity interventions with increased cognitive engagement, through either enhanced cognitive demands and/or execution of complex motor skills, have shown superior effects on executive functions compared to physical activity without this enhancement (Crova et al., 2014; Jager, Schmidt, Conzelmann, & Roebers, 2014; Koutsandreou, Wegner, Niemann, & Budde, 2016; Pesce et al., 2013; Schmidt, Jager, Egger, Roebers, & Conzelmann, 2015). In a school setting, incorporating physical activity in academic lessons may prove a particularly appealing way of enhancing the cognitive demands of physical activity, as it preserves the scheduled time to academic teaching. In support of this approach, Vazou & Smiley-Oyen (2014) revealed larger improvements in response time in a task emphasizing inhibition control following an acute 10 min bout of physical activity integrated with math practice, compared to seated math practice.

Besides the important contribution of executive functions to academic performance, behavioral self-regulation skills are important as they enables children to adapt successfully to classroom demands and engage in learning opportunities (McClelland & Cameron, 2012). Behavioral self-regulation requires coordination of executive functions along with motor and verbal functions, and includes behavioral skills such as paying attention, following instructions, and inhibiting inappropriate actions (McClelland et al., 2007). Hence, measures of context specific behavioral self-regulation in the classroom through teacher self-reports add ecological validity to tests of executive function.

Behavioral self-regulation is important for academic performance (McClelland & Cameron, 2012), and several studies have revealed predictive effects of behavioral self-regulation on academic performance (Bryce, Whitebread, & Szucs, 2015; Gestsdottir et al., 2014; Schmitt, Pratt, & McClelland, 2014; von Suchodoletz et al., 2013). Few studies, however, have investigated the effect of physical activity on behavioral self-regulation in elementary school children (Lubans et al., 2016). Some studies have investigated the effect of incorporating physical activity during the school day on attention and on-task behavior (Bartholomew & Jowers, 2011; Carlson et al., 2015; Kibbe et al., 2011; Matthew T. Mahar, 2011; M. T. Mahar et al., 2006; Riley et al., 2016). Carlson et al. (2015) found that teacher implemented classroom physical activity breaks of 10 minutes was positively related to better on-task and attentive behavior in the classroom. Riley et al. (2016) revealed a positive effect of an intervention incorporating physical activity in the pre-existing mathematics program (3x60 min/week) over 6 weeks on on-task behavior (observation) during the mathematics lessons. Other studies, have observed increased time on-task behavior after combining physical activity and academic lessons (Bartholomew & Jowers, 2011; Matthew T. Mahar, 2011; M. T. Mahar et al., 2006) with greatest effect in those children exhibiting least on-task behavior before the intervention (Mahar et al., 2006).

The effect of a physical activity intervention on academic performance in numeracy might also be affected through a psychosocial mechanism in which school related well-being is triggered (Bailey, 2016). Physical activity provides a natural settings for development of friendship and peer relationships, social identities, and belonging, all of which are important nutrient's for children's social engagement or well-being at school (Bailey, 2016). Supporting this link, Haapala et al. (2014) found that physical activity during recess was positively associated with peer relationships at school, relatedness to school, and school climate (Haapala et al., 2014). In turn, research has consistently shown that social belonging and peer acceptance relate positively to pursuit of goals to learn, interest in school, and perceived academic competence and academic accomplishments (Wentzel, 2017). Furthermore, academic peer popularity is observed to mediate the relationship between self-regulation (attentional control) and academic performance in mathematics in elementary schoolchildren (Sanchez-Perez, Fuentesu, Pine, Lopez-Lopez, & Gonzalez-Salinas, 2015). As examples of activities used in the ASK intervention, socially reinforcing co-operative group based physical activities have been shown to stimulate peer relations and satisfaction of the need for social relatedness, which might enhance well-being at school and intrinsic regulation of school motivation (Ryan & Moller, 2017).

Against this background, we aimed to investigate if improved executive function, behavioral self-regulation, and school related well-being mediated the observed effect of the ASK intervention on performance in numeracy for those performing poorest in numeracy at baseline. We hypothesized that the effect of the intervention on performance in numeracy, worked through improvement in executive functions, behavioral self-regulation, and school related well-being (figure 1).

METHODS

Design and participants

The ASK study is a parallel group (intervention group vs control group, 1:1 ratio) cluster-randomized controlled trial conducted in Sogn og Fjordane county, Norway, between August 2014 and June 2015 (Resaland et al., 2015). Randomization was performed by a neutral third part (Centre of Clinical Research, Haukeland University Hospital, Norway) and the unit of randomization was the participating schools. The procedures and methods used in the ASK trial conform to the ethical guidelines defined by the World Medical Association´s Declaration of Helsinki and its subsequent revisions (WMA, 2013). The study protocol was approved by The Regional Committee for Medical Research Ethics (REC southeast). We obtained written informed consent from each child´s parent(s)/guardian(s) prior to all testing.

We invited all sixty schools in the county that fulfilled the inclusion criteria of at least seven fifth-grade children enrolled. All schools, encompassing 1202 fifth grade children, agreed to participate (figure 2). Three schools (one control school and two intervention schools) from the same municipality resigned after randomization. In total, 1145 (82.1 % of the population of 10-year-olds in the county) of the 1175 invited children from 57 schools agreed to participate. The present study includes children in the lowest tertile of academic performance in numeracy at baseline. The study was registered in the Clinicaltrials.gov registry [trial registration number: NCT02132494] prior to commencement.

Intervention

The ASK intervention was a part of the mandatory school curriculum for all children attending the intervention schools. It was led by the classroom teachers and consisted of three components (165 min/week); 1) physically active educational lessons, mostly performed outdoor in the school yard (3 x 30 min/week) in the subjects Norwegian, mathematics and English, 2) physical activity breaks during classroom lessons (5 min/school-day) and 3) physical activity homework (10 min/school-day). The research group developed the intervention in collaboration with teachers at the intervention schools. Our mutual aim was to create a number of varied physical activity activities that should be carried out in small groups and which encouraged an inclusive and joyful learning environment (see www.askstudy.no for examples of physical activity activities). Two of the three intervention components, that is, the physical activity educational lessons and the physical activity homework, incorporated academic learning tasks in the physical activity (e.g., rope jumping while spelling English vocabulary words), thus adding cognitive load to the activity. Approximately 25 % of the daily physical activity in the ASK intervention was intended to be of vigorous intensity. This was defined as “children would be sweating and out of breath”. Intervention schools were provided with equipment for use in the intervention activities and the children received a skipping rope and a tennis ball for physical activity homework. To ensure that the teachers were empowered, supported, and qualified to deliver the ASK intervention, we conducted three instructional seminars ahead of the intervention start for the teachers at the intervention schools. Further, we provided two regional refresher sessions during the intervention period. Finally, we provided teachers in intervention school with e-mail- and telephone-support, as well as password-protected homepage (www.askstudy.no) that supplied teachers with information, videos, and physical activity lessons.

Children from both intervention schools and control schools participated in curriculum-prescribed 90 min/week of physical education and 45 min/week of physical activity (total 135 min/week). It was specified to the control schools that they should carry out the amount of physical activity and physical education that they would have done regardless of the ASK study.

Measures

Anthropometry, pubertal status, and socio economic status

Body mass (weight; 0.1 kg) was measured using an electronic scale (Seca 899, SECA GmbH, Hamburg, Germany) with children wearing light clothing. Stature (height; 0.1 cm) was measured with portable Seca 217 (SECA GmbH, Hamburg, Germany). We calculated body mass index ($kg \cdot m^{-2}$) as weight (kg) divided by the height squared (m^2). Body fat was measured using four skinfold thickness sites (biceps, triceps, subscapular, and suprailiac) using a Harpenden skinfold caliper (Bull; British Indicators Ltd., West Sussex, England) according to the criteria described by Lohman, Roche and Martorell (1991). The Harpenden skinfold caliper has been tested for validity and reliability in children (Yeung & Hui, 2010). Children self-assessed their pubertal stage with the Tanner method (Tanner, 1962) using a scale of colored images proposed by Carel and Leger (2008). We used pubic hair for both sexes and breast and genital development for girls and boys, respectively. Socio economic status (the highest education level obtained by the mother or father) (Sirin, 2005) was reported by the parents or guardians.

Mediators

Executive functions. We measured key executive functions identified by Miyake et al. (2000); inhibition, working memory, and cognitive flexibility, by using four pen and paper tests. We assessed inhibition with the Stroop Color and Word Test (Stroop CW) (Golden, 1978). To assess cognitive flexibility, we used a semantic Verbal Fluency test (Spreen & Strauss, 1998), and The Trail Making Test (TMT) (Lezak, Howieson, Bigler, & Tranel, 2012; Spreen & Strauss, 1998). Finally, we used a Digit Span test (Digits Forward and Backward) from the Wechsler Intelligence Scale for Children, fourth ed. (WISC-IV) to assess working memory (Lezak et al., 2012). For a more thorough description of the executive functions tests, see Aadland and Moe et al. (2017). We treated executive function as one latent factor including the Color-Word task of the Stroop Test (Stroop CW), Verbal Fluency total, the Digit Backward of WISC-IV (WISC-IV backward), and the Trail Making Test part B (TMT-b).

Behavioral self-regulation. We assessed behavioral self-regulation with the 10 items from the Child Behavior Rating Scale (CBRS) (Bronson, Goodson, Layzer, & Love, 1990), identified to describe child behavioral self-regulation in a classroom setting (Gestsdottir et al., 2014). Teachers were asked to rate children's classroom behavior on a five point Likert scale ranging from 1 (never) to 5 (always) to indicate how frequently a given behavior occurred. The CBRS is a reliable and valid tool that has been used in multiple studies in Western countries (Lim, Rodger, & Brown, 2010; von Suchodoletz et al., 2013). A mean score of the CBRS was used for descriptive statistics, and a latent behavioral self-regulation factor was used in the mediation analysis.

School related well-being. Quality of life was assessed by self-reporting using the Kidscreen-27 questionnaire (Ravens-Sieberer et al., 2007), which consists of 27 items covering the following five quality of life dimensions: 1) physical well-being (5 items); 2) psychological well-being (7 items); 3) parent/guardians relations & autonomy (7 items); 4) social support & peers (4 items); and 5) school environment (5 items). The Kidscreen-27 questionnaire has been validated in Norwegian children (Andersen et al., 2015; Haraldstad, Christophersen, Eide, Nativg, & Helseth, 2011). For descriptive statistics, T-scores were obtained according to the developer's manual, where a mean of 50 and a standard deviation (SD) of 10 define normality for children in Europe. Higher score indicate better school related well-being. For the mediation analysis, we composed a latent school related well-being factor from the four items concerning school environment (Questions: 1. “Have you been happy at school?” 2. “Have you got on well at school?” 3. “Have you been able to pay attention?” 4. “Have you got along well with your teachers?”).

Outcome measure

Academic performance in numeracy. We measured academic performance in numeracy using a specific standardized Norwegian National test designed and administered by the Norwegian Directorate for Education and Training (NDET). The test have shown evidence of good validity and reliability by NDET and are aligned with the competencies demanded from all schools by the national curriculum (Resaland et al., 2015). The score is reported as standardized points, with a mean of 50 and a standard deviation of 10.

Power calculations

The ASK study was designed to detect an effect size (Cohen´s D) of 0.35 between the two groups for change in academic performance (main outcome). The effect size was based on findings from previous studies (Sibley & Etnier, 2003). An intra-class correlation (ICC) of 0.15 (observed clustering of academic performance during the previous school year (2013–2014)) was applied to account for the cluster-randomized design, leading to a design effect of 4.54. For further details, see Resaland et al. (2015).

Statistics

All study variables were examined for distributional properties, of which TMT-b was transformed and other variables kept in theirs original form. We excluded all values exceeding five standard deviations from the mean.

Children’s characteristics are provided as means and standard deviations (SD) or frequencies. A linear mixed model including school as a random effect was used to examine differences between children in tertiles of numeracy. The descriptive analyses were conducted with SPSS software, version 23.0 (IBM SPSS Statistics for Windows, Armonk, NY: IBM Corp., USA).

Structural equation modeling (SEM), with full information maximum likelihood estimation (FIML) was used to examine bivariate correlations and the mediation model. The analyses were implemented through the Mplus program, version 7.4 (Muthén & Muthén, 1998-2015). To estimate the mediating effects in our pretest-posttest control group design, we used the ANCOVA model as recommended and explained by Valente and MacKinnon (2017). To account for children nested within schools, the complex method with robust maximum likelihood (MLR) estimator was used in all analyses. To reduce the complexity of the mediation model, we made five parcels from the 10 items in the CBRS. The parcels were composed by a balanced approach described in Little (2013), and as we had two measurement time points we used the average loading across the time points to rank the items.

Multiple fit indices in addition to the chi-square test statistic were used to assess model fit; the Comparative Fit Index (CFI), the Root Mean Squared Error of Approximation (RMSEA), and the Standardized Root Mean Square Residual (SRMR). We used a non-significant χ^2 and the cutoff recommendations of CFI >.95, and RMSEA and SRMR <.05 as indications of good model fit to the data (Geiser, 2013).

Measurement invariance (metric and scalar) was tested across time and group for the latent factors of executive function, behavioral self-regulation, and school related well-being. Criteria used to test differences between nested models (configural, metric, and scalar) were ΔCFI of -.010, ΔRMSEA of .015 , and ΔSRMR of .010 (for scalar) as recommended by Chen (2007) for sample size N > 300. A p-value $\leq$ .05 was used to indicate statistical significance in all analyses.

RESULTS

The characteristics of the included (tertile 1) and excluded children (tertile 2 and 3) are shown in table 1. The included children had significant higher skinfold thickness compared to tertile 3 (p =.008), but no statistical differences was observed between the included and excluded children for BMI, pubertal status, or socioeconomic status (p >.127). The included children performed significantly poorer on all tests of executive functions and academic performance in numeracy, and had significantly lower score on measures of behavioral self-regulation (CBRS) and school related well-being (Kidscreen, school dimension) compared to both tertile 2 and 3. Bivariate correlations between the mediators and the outcome are shown in table 2.

The confirmatory factor analysis (CFA) for the three latent variables showed scalar invariance across time and group with ΔCFI, ΔRMSEA, and ΔSRMR below suggested criteria comparing the scalar against the configural model ($\Delta\chi^2(\Delta df)$ = 28.04 *(18)* (p = .245), ΔCFI = -.001, ΔRMSEA = .001, ΔSRMR = .009, and $\Delta\chi^2(\Delta df)$ = 61.02 *(36)* (p =.006), ΔCFI = -.006, ΔRMSEA =.002 ΔSRMR = .011 across time and group, respectively).

The mediation model

Our results revealed that neither executive functions, behavioral self-regulation, nor school related well-being mediated the effect of the intervention on academic performance in numeracy (figure 3). Standardized β-coefficients (unstandardized p-values) for the indirect effects were .035 (p=.479) for executive function, .020 (p=.256) for behavioral self-regulation, and .002 (p=.714) for school related well-being. The mediation model had good fit ($\chi^2(df)$ = 433.178 *(307)* (p < .001), RMSEA = .034 (90% CI, .026, .041), CFI = .976, and SRMR = .049).

DISCUSSION

In the present study, we aimed to investigate mediators for the effect of the ASK school-based physical activity intervention on academic performance in numeracy for the poorest performing children in numeracy at baseline. Contrary to our hypothesis, we found that neither executive functions, behavioral self-regulation, nor school related well-being mediated the effect.

Compared to their peers, the children included in the present study scored significantly lower on all mediators at baseline. Hence, the potential for the intervention to affect these mediators may have been larger for this group of children. In support of this hypothesis, we found an effect of the intervention on executive functions in the present study, while this was not evident in a previous study including the total ASK study sample (Aadland, Ommundsen, et al., 2017). The present finding is in line with previous studies, where children most behind on executive functions are shown to benefit the most from any interventions to increase executive functions (Diamond, 2013). However, the intervention did not affect behavioral self-regulation or school related well-being.

The role of executive function

The effect of the intervention on executive functions despite no difference in objectively measured physical activity between the intervention and control schoolchildren, suggests that the content of the intervention was of importance. The prevailing literature support the value of the cognitive demands inherent in the physical activities in order to affect executive functions (Best, 2010; Diamond, 2015; Pesce, 2012; Tomporowski, McCullick, Pendleton, & Pesce, 2015). The ASK intervention might have enhanced the cognitive demands of the physical activity in several ways. First, the integration of academic learning tasks while being physically active likely increased the challenge on executive functions, as these functions are important for solving for example academic problem-solving tasks in mathematics (Bull & Scerif, 2001; Cantin et al., 2016). To our knowledge, no previous study have investigated the effect on executive functions using physical activity integrated in mathematics lessons in a sample of children performing lower in numeracy. In general samples of elementary schoolchildren, no effects of physical activity integrated in academic lessons on executive functions have been observed (Beck et al., 2016; de Greeff et al., 2016). This might indicate that children with lower math competence take unique advantage of getting involved in academic learning tasks while being physically active.

Second, the greater part of the intervention activities was organized as group activities, which require use of strategic and goal-directed behavior through social interactions in an environment that constantly change (Best, 2010). Executive function skills acquired in these activities may transfer to other executive function tasks. Supporting this line of reasoning, Schmidt et al. (2015) observed only intervention effects on executive function following a team-game intervention, and not following an aerobic exercise intervention, although both interventions increased aerobic fitness equally.

There is also a possibility that challenging features of the activities in terms of motor coordination helped make the activities more cognitively demanding. For example, all children in the intervention group received a tennis ball for the homework, which may have resulted in enhanced practice of aiming and catching skills that previously have been shown to act as a mediator in the effect of a physical activity intervention on executive function (Pesce et al., 2016). Furthermore, the daily five minute physical activity breaks during the academic lessons in the classroom were often coordinative demanding dancing activities (e.g., Just Dance), possibly targeting the same mechanisms as studied by Budde et al. (2008), where coordinative exercise affected attention and concentration. Supporting evidence for the relevance of coordinative demands of chronic physical activity on executive functions have been observed previously (Crova et al., 2014; Koutsandreou et al., 2016).

The observed effect on executive functions only in this subsample of the ASK study, could well also be attributed to the fact that the intervention optimally challenged these children in terms of the motor capabilities, as addressed by Pesce et al. (2013). Finally, the effect of the intervention on executive functions might also be owing to the fact that the included children had higher body fat than the other children (however, only significantly higher than the best performing children in numeracy). Studies have suggested that overweight children benefit more from physical activity to improve executive functions (Crova et al., 2014; Davis et al., 2011).

Contrary to the literature showing a consistent relationship between executive functions and academic performance (Best et al., 2011; Cantin et al., 2016; St Clair-Thompson & Gathercole, 2006), we found no relationship between change in executive functions and change in academic performance. However, it represent a conservative design to investigate change in the mediator on change in the outcome, as in the current case. In order to capture the effects of change in the executive functions on change in numeracy, a longer follow-up period might be necessary. For example, we have previously observed a significant relation between executive function at baseline and change in numeracy (Aadland et al., 2017)

The role of behavioral self-regulation

We found no effect of the intervention on behavioral self-regulation. This stands in contrast to the effect on executive functions and results from previous studies that have observed increased time on-task during of following physically active academic lessons (Bartholomew & Jowers, 2011; Riley et al., 2016) and short physical activity bouts during academic lessons with or without academic instruction (Carlson et al., 2015; Kibbe et al., 2011; Mahar et al., 2006). An explanation for this discrepant finding might be that these previous studies also increased physical activity levels, likely reflecting the importance of the physical activity dose on behavioral self-regulation. More specifically, our physical activity breaks of five minutes during academic lessons were shorter than previous studies reporting effects on on-task resulting from ten minutes bouts of physical activity (Carlson et al., 2015; Kibbe et al., 2011; Mahar et al., 2006). Studies that have revealed effects acute physical activity on arousal and attention have also used bouts of longer durations (Budde, Voelcker-Rehage, Pietrassyk-Kendziorra, Ribeiro, & Tidow, 2008; M. Janssen et al., 2014; Janssen, Toussaint, van Mechelen, & Verhagen, 2014). Hence, it is possible that our intervention did not reach the physical activity dose necessary to achieve beneficial effects on arousal and attention.

Other explanations for the discrepant findings might be the measurement used for behavioral self-regulation and the timing of the measurement. For example, Riley et al. (2016) reported increased time on-task during their physically active academic lessons based on observational data. Our measure, in contrast focused on behavior in the classroom, reported by the teachers at baseline and at follow-up. Hence, our measure expressed the behavior in the classroom over a long period in which, the majority of the academic lessons did not follow or include physical activity. Thus, it is possible that our intervention children were more on-task during the intervention activities compared to their control peers, as in Riley et al. (2017), but this was not captured by our way of measurement. Furthermore, the variance in the behavioral self-regulation factor observed across the intervention and control group teachers may have delimited the construct validity thus explaining the lack of intervention effect on this mediator. The use of teacher rated behavioral self-regulation is furthermore a subject to observer bias (McClelland & Cameron, 2012). Direct observation of behavioral self-regulation was out of scope for the present study.

The relation between the change in behavioral self-regulation and change in academic performance in numeracy is an important finding, emphasizing the significant role of behavioral self-regulation for academic performance also in an older age group than previously shown (Gestsdottir et al., 2014; Schmitt et al., 2014; von Suchodoletz et al., 2013).

The role of school related well-being

Our intervention did not improve school related well-being. Moreover, change in school related well-being was not related to change in numeracy. This is in line with the quasi-experimental study by Kall, Malmgren, Olsson, Linden, & Nilsson (2015), who did not observe any effects of a curricular physical activity intervention on any of the Kidscreen dimensions in elementary school children. An important limitation in the Kall et al. (2015) study however, was that they did not include objectively measurement of physical activity. Hence, it is possible that both their findings and ours revealing lack of effect on school related well-being are attributable to an insufficient dose. As observed by Norris et al. (1992), duration and intensity of physical activity may be of importance to affect emotions.

Furthermore, it could also well be that our intervention activities and the mode of delivery did not stimulate positive peer-relationships, social identity, and belonging, which all are important for well-being (Bailey, 2016; Orkibi & Ronen, 2017). Indeed, both type of activities and mode of delivery influence intervention effects (Morgan, Young, Smith, & Lubans, 2016). In terms of delivery, the ASK study pre-intervention workshops for teachers emphasized a mastery- and autonomy supportive learning environment which has been shown to facilitate need satisfaction, quality of motivation, and psychological well-being (Ryan & Moller, 2017). However, our study included a large number of intervention teachers with variability of experience and expertise in organizing and facilitating physical activity. Hence, it is possible that the settings for the implementation of the intervention activities were different across schools with some teachers not being able to implement the physical activities such that children's well-being were facilitated. For example, although group activities creates opportunities for cooperation, and facilitates belonging and mastery (Ryan & Moller, 2017), the different emphasis on the competition element potentially initiated by some intervention teachers may have led to various experiences of the activities among the children of which some then may have experienced reduced rather than enhanced their well-being. Indeed, teachers' ability to create a safe learning environment, as well as promoting good social relationship and acceptance of peers, has previously been shown to be of major importance for well-being in the classroom (Holfve-Sabel, 2014). Intervention teachers may not have been able to put this into effect outside the classroom.

In terms of intervention activities, the children are different in terms of social and physical-motor competence to participate. This requires tailored activities. It is possible that the group of children in the present study joined the physical activities with less social and physical competencies to their disposal for involvement in and mastery of the group activities. Hence, the possible benefits of these activities for school related well-being might have been counteracted. Indeed, according to self-determination theory, psychological well-being rests upon satisfaction of basic needs, including not only social relatedness, but satisfaction of the need for competence as well (Orkibi & Ronen, 2017; Ryan & Moller, 2017). Future studies would do well to examine the role of these psychological prerequisites when examining well-being as a psychosocial mediating mechanism. At this point then we cannot rule out the possibility that, consistent with previous findings (Bergh et al., 2012), our intervention generated unintended effects on this special group of children.

Strengths and limitations

The cluster randomized controlled design and the large sample size, together with the statistical approach used to examine our hypotheses, are strengths of the present study. In line with the recommendations by Valente and MacKinnon (2017), we estimated the mediating effect in our RCT with an ANCOVA model, which increases the precision of the treatment effect through the adjustment for baseline scores. We furthermore ran the ANCOVA model with a latent variable SEM approach, which enabled testing of the full ANCOVA model with three latent mediating factors simultaneously. The use of latent mediating factors exclude measurement error which enhance reliability and avoids underestimation of both the path between the predictor and mediator and the mediator and the outcome, and an overestimation of the direct link between the predictor and the outcome (Cole & Maxwell, 2003). A further strength is the inclusion of three different aspects of self-regulation (cognitive, behavioral, and emotional) measured by different data sources (executive function tests, self-report by the children, and teacher reports).

The main aim of the ASK study was to determine the effect of physical activity on academic performance. The present study is based on a secondary analysis using a subsample of children, and was not a priori defined. Thus, our results should be interpreted with this limitation in mind.

CONCLUSION

In conclusion, neither change in executive function, behavioral self-regulation, nor school related well-being mediated the effect of the ASK intervention on performance in numeracy in these children performing lowest in numeracy. This might primarily be attributed to the lack of effect of the intervention on the mediators generated by lack of sufficient physical activity dose. Future studies should investigate mediators between physical activity and academic performance using interventions with a sufficient physical activity, over a longer time-span, using several measurement time points. Such research will be critical to augment our understanding of mechanisms for the suggested effect of physical activity on schoolchildren’s academic performance.

DECLARATIONS

Ethics approval and consent to participate

The procedures and methods used in the ASK trial conform to the ethical guidelines defined by the World Medical Association´s Declaration of Helsinki and its subsequent revisions (WMA, 2013). The study protocol was approved by The Regional Committee for Medical Research Ethics (REC southeast). We obtained written informed consent from each child´s parent(s)/guardian(s) prior to all testing.

Consent for publication

Not applicable.

Availability of data and material

The dataset used and analyzed during the current study is available from the corresponding author in reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

This work was supported by the Research Council of Norway under grant number 221047/F40; Sogn og Fjordane University College; the Norwegian School of Sport Sciences, and the Gjensidige Foundation under grant number 1042294.

Authors' contributions

KNAA conceived the idea for the paper together with YO, performed the data collection, analyzed the data, and wrote the manuscript draft. EAA contributed in data analyses and drafting the manuscript. JRA contributed in data collection and interpretation of results. AOL contributed in data analyses. GKR obtained funding for the study. VFM contributed in data collection and drafting the manuscript. YO helped out in interpretation of the results and drafting the manuscript. All authors read, commented on, and approved the final manuscript.

Acknowledgements

The authors are grateful to the children and their families, principals and teachers from the 57 participating elementary schools who gave their time to the study. Finally, thanks to all the master and bachelor students from the former Sogn og Fjordane University College, now a part of the Western University of Applied Sciences, for participating in the data collection.

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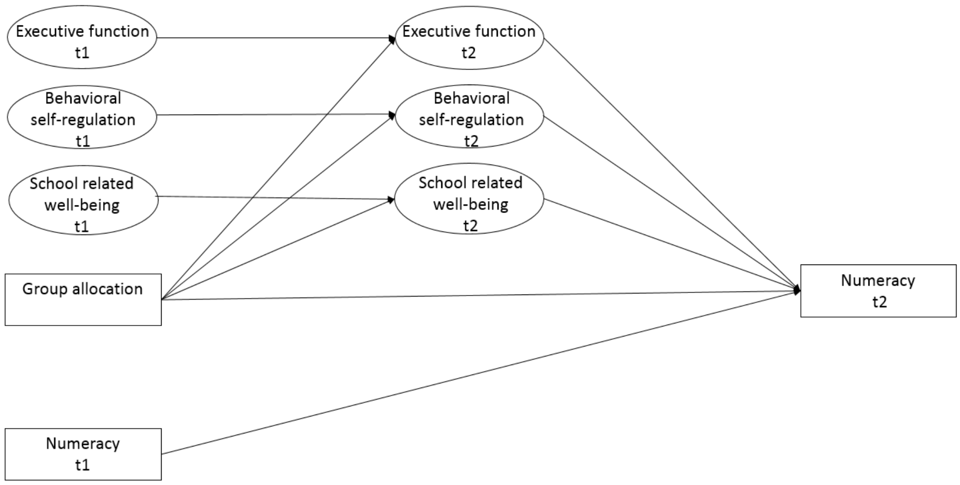

Figure 1. The hypothesized model. t1 = pre intervention; t2 = post intervention; group allocation = intervention/control.

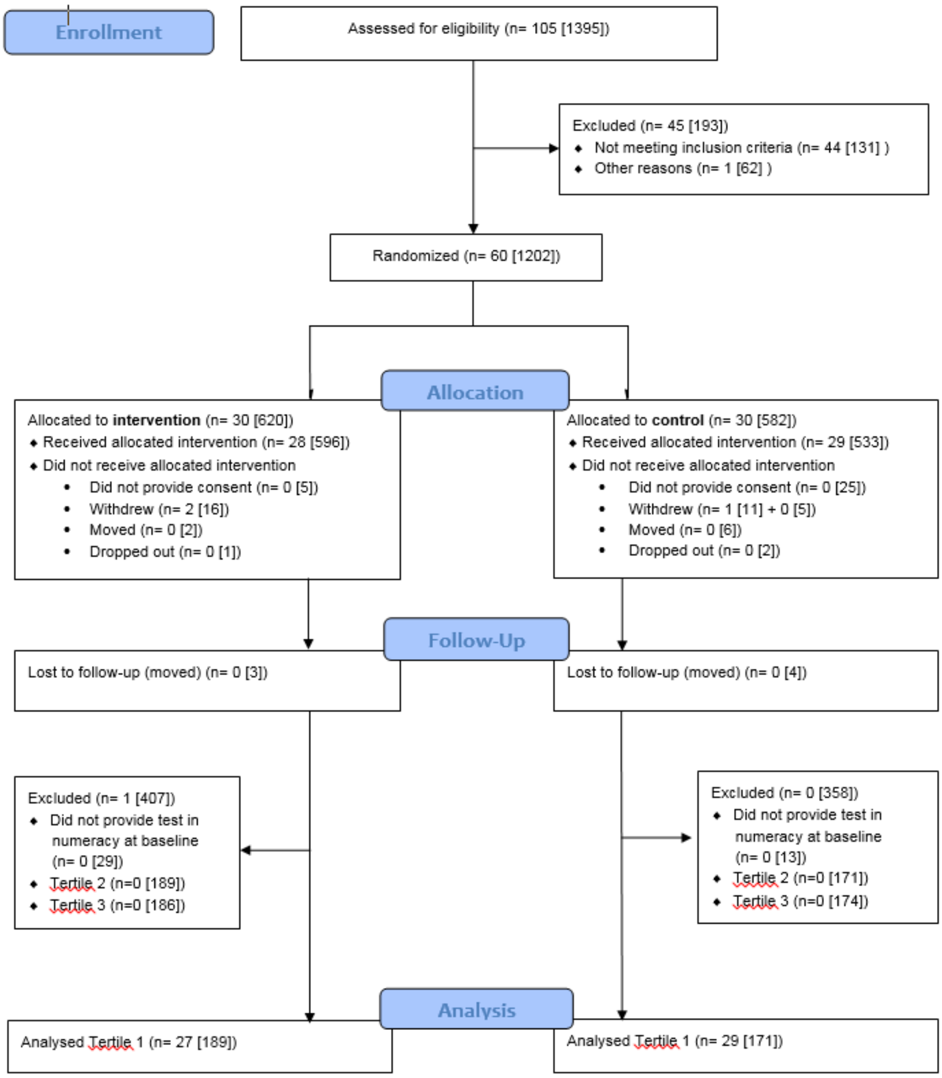

Figure 2. Flow diagram of the included children (n = schools [children]).

Table 1. Baseline characteristics of the children as means (standard deviations (SD)) or frequencies of included (tertile 1 = lowest performance in numeracy) vs. excluded children.

	Tertile 1		Tertile 2		Tertile 3	
Variable	***n***	***M (SD)/ %***	***n***	***M (SD)/ %***	***n***	***M (SD)/ %***
Age (yrs)	360	10.2 (.31)	360	10.2 (.28)	360	10.2 (.27)
Sex (%)						
Girls	177	49.2	194	53.9	147	40.8
Boys	183	50.8	166	50.8	213	59.2
BMI	355	18.3 (3.3)	348	18.1 (3.15)	348	17.7 (2.4)
Skinfold thickness (mm)	352	52.4 (28.5)	347	51.6 (27.6)	345	46.1 (23.1)**
Pubertal stage (Tanner) (%)						
Stage 1	98	27.2	103	28.6	94	26.1
Stage 2	210	58.3	201	55.8	216	60.0
Stage 3, 4 and 5	43	12.0	42	11.7	35	9.7
Socio economic status (%)						
≤ Upper secondary school	117	32.5	105	29.2	119	33.1
< 4 yrs of university	104	29.9	98	27.2	136	37.8
≥ 4 yrs of university	112	31.1	100	27.8	130	36.1
Executive function						
Stroop CW (n)	352	23.6 (5.2)	355	26.1 (5.5)***	346	28.1 (6.1)***
Verbal Fluency (n)	353	14.8 (4.3)	357	16.4 (4.4)***	348	17.2 (4.7)***
WISC-IV b (n)	353	5.7 (1.1)	355	6.3 (1.2)***	350	6.7 (1.4)***
TMT-b (s)	331	147(59)	345	115 (34)***	351	102 (33)***
Behavioral self-regulation	334	3.4 (.8)	333	4.0 (.7)***	317	4.2 (.6)***
School related well-being (T-score)	298	51.9 (10.2)	314	54.0 (9.6)*	325	54.9 (9.1)***
Academic performance						
Numeracy	360	40.7 (3.9)	360	51.1 (2.6)***	360	62.0 (4.7)***

Note. BMI = body mass index; Stroop CW; Stroop Color Word; WISC-IV b = Wechsler Intelligence Scale for Children, fourth edition, backward digit span; TMT-b = Trail Making Test part B; * $p < .05$ compared to tertile 1; ** $p < .01$; *** $p <.001$ compared to tertile 1.

Table 2. Estimated correlation matrix for the mediators and the outcome at baseline (above the diagonal line) and at follow-up (below the diagonal line).

	Executive function	Behavioral self-regulation	School related well-being	Numeracy
Executive function	—	**.40**	.10	**.34**
Behavioral self-regulation	**.37**	—	**.24**	**.20**
School related well-being	.09	**.25**	—	**.21**
Numeracy	**.40**	**.19**	.06	—

Note. Significant correlations (p < .005) are shown in bold.

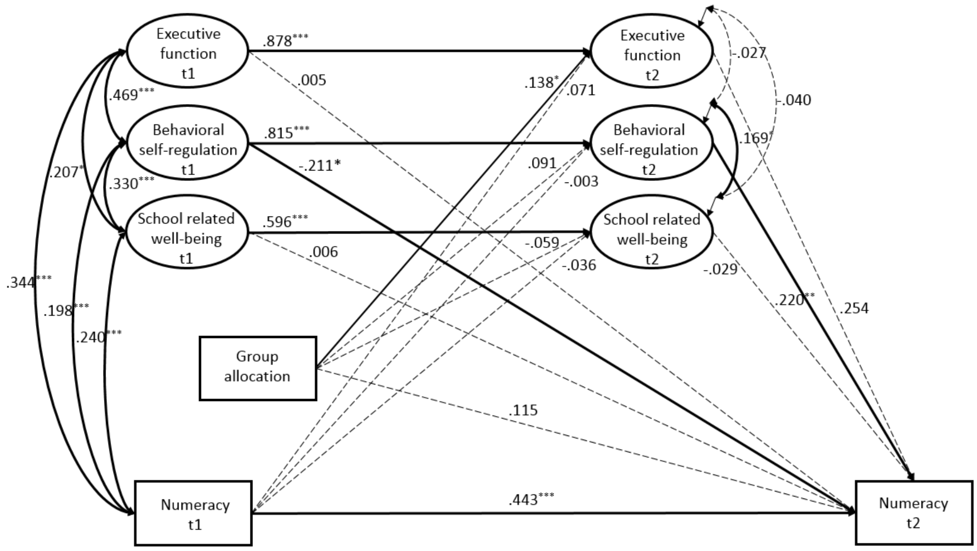

Figure 3. The mediation model. All path coefficients are reported as standardized β-estimates. Significant paths are in bold lines. t1 = baseline, t2 = follow-up. * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$.

APPENDIX

Approval letter from the Regional Committees for Medical and Health Research Ethics

REK
REGIONALE KOMITEER FOR MEDISINSK OG HELSEFAGLIG FORSKNINGSETIKK

Region:	Saksbehandler:	Telefon:	Vår dato:	Vår referanse:
REK sør-øst	Anette Solli Karlsen	22845522	04.03.2014	2013/1893/REK sør-øst A
			Deres dato:	Deres referanse:
			28.01.2014	

Vår referanse må oppgis ved alle henvendelser

Sigmund Anderssen
Høgskulen i Sogn og Fjordane

2013/1893 ASK - Active Smarter Kids

Forskningsansvarlig: Høgskulen i Sogn og Fjordane
Prosjektleder: Sigmund Anderssen

Vi viser til søknad om forhåndsgodkjenning av ovennevnte forskningsprosjekt. Søknaden ble behandlet av Regional komité for medisinsk og helsefaglig forskningsetikk (REK sør-øst) i møtet 13.02.2014. Vurderingen er gjort med hjemmel i helseforskningsloven (hfl.) § 10, jf. forskningsetikklovens § 4.

Opprinnelig prosjektbeskrivelse
Målsettingen i dette prosjektet er å undersøke effekten av en time daglig fysisk aktivitet i skolehverdagen for elever i femte klasse.
En eventuell effekt skal måles på skoleprestasjoner i matematikk, lesing og engelsk, på kognitive prestasjoner og på helsevariabler som lipider og hjernederivert nevrotrofisk faktor (Brain Derived Neurotrophic Factor, BDNF), som påvirker hjernecellers utvikling og funksjon.
Prosjektet har et klynge randomisert design. Skolen er enheten med to grupper, en intervensjons- og en kontrollgruppe. Forsøket har en varighet på åtte måneder. I alt 1196 barn som går i femte klasse i ulike skoler i Sogn og Fjordane skal spørres om deltakelse. Halvparten av skoleklassene vil bli randomisert til intervensjonsgruppen med daglig fysisk aktivitet, mens den andre halvdelen vil komme i kontrollgruppen og får fysisk aktivitet som vanlig i skolen, dvs. to timer per uke. Den fysiske aktiviteten, som intervensjonsgruppen tilbys er variert, og etter endt forsøk, vil kontrollgruppen bli tilbudt den sammen intervensjonen dvs. når de går i 6. klasse. Med et slikt design vil alle få det samme tilbudet.
Hele utvalget vil undersøkes ved baseline og etter åtte måneder med en rekke fysiske tester, med antropometriske mål, høyde, vekt midjemål og hudtykkelse, med blodtrykk, flere kognitive tester, spørreskjema om livskvalitet, kosthold, samt vil det bli tatt blodprøver for å måle lipidmønster i blod, glukose og BDNF.
Det er utarbeidet et informasjonsskriv med samtykkeerklæring som er adressert både til foreldrene og til barna. Noen av deltakerne, dvs. barn og lærere, vil bli spurt om å delta i en kvalitativ studie, hvor intervju skal tas opp på bånd, transskriberes og analyses. I denne kvalitative delen av studien vil man også benytte seg av fotografi, dvs. man ønsker å ta bilder i de fysiske aktivitetene i prosjektet, og disse vil bli forelagt deltakerne og brukt i intervjusituasjonen.

Saksbehandling
Søknaden ble behandlet i møte 24.10.2013, og det ble fattet et utsettende vedtak. Komiteen ba om tilbakemelding på følgende punkter:

1. Datamaterialet vil bli anonymisert for forskerne i prosjektet 31.12 2016, men en navneliste vil bli

oppbevart hos en tredje person, dvs. hos NSD. Man opplyser også i informasjonsskrivet at man planlegger å be barna nå de er fylt 16 år om deres samtykke til å anvende data for senere forskning. Hva denne forskningen vil medføre står det ingenting om, og det går heller ikke klart fra prosjektprotokollen hva som planlegges. Prosjektbeskrivelsen omtaler ikke en slik eventuell oppfølging.

2. I informasjonsskrivet ber man om at data fra undersøkelsen kan kobles mot nasjonalt helseregister, medisinsk fødselsregister og mor/barn-registeret. Denne koblingen er ikke begrunnet noe sted, og man kan heller ikke i prosjektbeskrivelsen finne noen omtale av en slik kobling som man ber deltakerne samtykke til i informasjonsskrivet.
3. Det fins ingen opplysninger i informasjonsskrivet om den kvalitative delen av studien og heller ingen informasjon til lærerne som vil bli bedt om å delta i den delen av studien er vedlagt.
4. Prosjektledelsen har på side 8 i søknadsskjemaet diskutert ulike mulig ulemper som prosjektet kan ha på barna og argumentere for at prosjektet ikke kan ha slike ulemper som de diskuterer. En mulig ulempe er muligens uteglemt i diskusjonen og det er relatert til gruppepress. Hva med elever som ikke vil delta, for eksempel en elev i en klasse på 20 som ikke vil være med. Om hele klassen er randomisert til 1 times fysisk aktivitet hver dag, hva skjer med den ene elevens undervisningstilbud og hva kan han/hun eventuelt utsette for av mobbing/gruppepress? Det savnes en diskusjon av dette aspektet og hvordan man skal ivareta «ikke-deltakere».
5. Komiteen ber om en nærmere redegjørelse om behovet for en beredskap i forbindelse med informasjon som kan komme opp som resultat av prosjektet. Kan det tenkes uventede funn i analysene av blodprøver? Kan det tenkes svar på spørsmål i spørreskjemaet som kan tyde på det trenges en eller annen form for oppfølging?
6. Norsk versjon engelsk spørreskjema må ettersendes.

Prosjektleder har sendt tilbakemelding, denne ble mottatt 28.01.2014.

Om komiteens merknader fremkommer det av tilbakemeldingen:

1. Det kan i fremtiden være aktuelt å se på langtidseffektene av intervensjonen. Kontrolldeltakerne vil bli tilbudt samme intervensjon som studiegruppen, noe som i første omgang vil vanskeliggjøre en sammenligning mellom gruppene. Av denne grunn omfatter ikke protokollen en oppfølging på det nåværende tidspunkt. I midlertid vil en oppfølging av deltakerne i et longitudinelt design muliggjøre en evaluering av langtidseffekter, og for å sikre at man kan be barna om deltakelse i et slikt eventuelt oppfølgingsstudie ønsker man nå å legge dette inn i informasjonsskrivet. Formuleringene i informasjonsskrivet er endret slik at dersom barnet planlegges undersøkt på nytt eller dersom data vil bli benyttet etter barna er fylt 16 år, så vil man be om et nytt samtykke for dette.
2. Det skal innhentes data fra medisinsk fødselsregister og MoBa-registeret, og disse koblingene er nå spesifisert i informasjonsskrivet.
3. Det foreligger nå en beskrivelse av den kvalitative delen av prosjektet, og det er utformet separate informasjonsskriv for deltakerne i denne delen.
4. Randomiseringen til intervensjon eller kontroll vil foregå på skolenivå, og ved intervensjonsskolene vil den ekstra timen med fysisk aktivitet inngå som en ordinær del av det pedagogiske tilbudet. Det vil derfor ikke oppleves som press på enkeltelever i forhold til deltakelse i prosjektet eller ikke. For de elever som av ulike årsaker søker fritak fra fysisk aktivitet, vil skolen på ordinær måte finne andre undervisningstilbud.
5. Eventuelle funn som måtte avdekkes ved deltakelse i prosjektet vil håndteres gjennom den enkeltes skolehelsetjeneste på ordinær måte.
6. Tidligere engelske skjema foreligger nå i norsk oversettelse, dette gjelder deler av MSLQ skjemaet (management strategies, learning self-efficacy) og CCC-instrumentet (cross-curricular competencies).

Prosjektleders tilbakemelding er å anse som tilfredsstillende i forhold til komiteens merknader.

Vedtak
Komiteen godkjenner at prosjektet gjennomføres i samsvar med det som fremgår av søknaden.

Godkjenningen gjelder til 31.12.2017.

Av dokumentasjonshensyn skal opplysningene oppbevares i 5 år etter prosjektslutt. Forskningsfilen skal oppbevares avidentifisert, dvs. atskilt i en nøkkel- og en datafil. Opplysningene skal deretter slettes eller anonymiseres, senest innen et halvt år fra denne dato. Forskningsprosjektets data skal oppbevares forsvarlig, se personopplysningsforskriften kapittel 2, og Helsedirektoratets veileder for «Personvern og informasjonssikkerhet i forskningsprosjekter innenfor helse- og omsorgssektoren».

Prosjektet skal sende sluttmelding på eget skjema, se helseforskningsloven § 12, senest et halvt år etter prosjektslutt.

Dersom det skal gjøres endringer i prosjektet i forhold til de opplysninger som er gitt i søknaden, må prosjektleder sende endringsmelding til REK.

Komiteens vedtak kan påklages til Den nasjonale forskningsetiske komité for medisin og helsefag, jf. helseforskningsloven § 10 tredje og forvaltningsloven § 28. En eventuell klage sendes til REK sør-øst A. Klagefristen er tre uker fra mottak av dette brevet, jf. forvaltningsloven § 29.

Med vennlig hilsen

Knut Engedal
Professor dr. med.
Leder

Anette Solli Karlsen
Komitesekretær

Kopi til: erik.kyrkjebo@hisf.no; post@hisf.no

Katrine Nyvoll Aadland // Physical activity, executive function, and academic performance among 10-year-old schoolchildren