Investigating the relationship between physical activity and cognition in children

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Abstract

Background

A positive relationship between physical activity (PA) and cognitive ability in children has been documented consistently over the last 50 years. Cross-sectional studies show a relationship between PA and cognition in many different groups, ages and in both sexes, and longitudinal studies give promising indications that PA has a positive influence on cognition. Despite that knowledge, experts are still trying to understand the complexities of the PA-cognition relationship [1, 2]. For example, are there other variables that have a stronger influence on cognition? Researchers no longer need to prove the relationship between PA and cognition but to explain the many specific interactions. Is the PA relationship with cognition and academic ability equal or independent? And most importantly: does PA have a causal effect on cognition? The overarching purpose of this thesis was to attempt to answer these questions via two related studies. The aim of the first study was to develop and test a conceptual model that explains the cross-sectional associations among PA, cognition, academic performance, and potential mediating factors in children. Expanding on the first study, the aim of the second study was to develop and test a longitudinal model that examines potential causal relationships between PA, cognition and academic performance in children.

Methods

This thesis represents secondary analyses of an existing dataset that comprised information collected from 675 New Zealand school children aged 6-11 years. The data included demographic details, body measures, weekly pedometer step readings, cognitive assessment from the CNS Vital Signs questionnaire, and formal school reading and maths assessment from on the New Zealand Ministry of Education electronic Assessment Tools for Teaching and Learning (e-asTTle). In Study 1, structured equation model (SEM) analyses was used to explain the cross-sectional relationship among three latent variables of PA, cognition, and academic performance. In Study 2, generalised linear mixed models were used to assess changes in PA, cognitive ability, and academic performance at baseline, two month, and six month time points, thereby examining potential causative pathways in the PA-cognition-academic performance relationships.

Results

In Study 1, the initial model identified a significant association between PA and academic performance (r = 0.225). The direct association weakened (r = 0.121) when cognition was included in the model, showing the partial mediating effect of cognition. While cognition was strongly associated with academic performance (r = 0.750), PA was also associated with cognition (r = 0.138). Subgroups showed similar patterns to the full sample, but the smaller group sizes limited the strength of the conclusions. Study 2 identified significant relationships between PA change at two months and executive functioning change at six months, reading proficiency change at six months, and maths proficiency change at two months ($P < 0.05$). No significant relationships were identified for the remaining cognitive domains. Results were adjusted for age, sex, and school socioeconomic decile.

Conclusion

The first study used SEM to characterise the direct cross-sectional association between PA and academic performance after controlling for cognition. That is important as it demonstrates PA has independent and cumulative relationships with cognition and academic performance. The second study showed that children who increased PA at two-months displayed small improvements in executive function and reading at six months, and maths proficiency. The findings support the theory that increased PA leads to improvements in cognitive function and academic performance. Future cross-sectional studies should include larger samples to assess patterns for groups of subject including sex, age and SES, and longitudinal studies consider time frames longer than six months to assess longer term effects and patterns.

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LIST OF ABBREVIATIONS

Term/symbol	***Definition***
BMI	Body Mass Index
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
CNSVS	CNS Vital Signs
EFA	Exploratory Factor Analysis
EM	Estimation Maximization
GLMM	General Linear Mixed Model
MAR	Missing at Random
MCAR	Missing Completely at Random
MNAR	Missing not at Random
MVA	Missing Values Analysis
NonNZEuro	Non-New Zealand European Ethnicity
NZEuro	New Zealand European ethnicity
PA	Physical Activity
PE	Physical Education
PNFI	Parsimonious Normed Fit Index
RMSEA	Root mean square error of approximation
SEM	Structured Equation Modelling
SES	Socio-ecomonic status
TLI	Tucker Lewis Index
WhTR	Weight to Height Ratio

NOMENCLATURE

Term/symbol	***Definition***
N	Total number of cases
No.	Number
p	*p*-value, statistical significance
r	Pearson correlation coefficient
M	Mean
SD	Standard Deviation
α	Cronbach's alpha
χ^2	Chi-square

Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Signed……………………………………………… Date………………….

Name………………………………………………….

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Overview

An exciting field of research has developed over the last 60 years investigating the relationships between physical activity (PA), cognition and academic achievement. In the face of declining activity levels in children, cross-sectional studies are showing PA has consistent positive links with both cognition and academic achievement. Furthermore, longitudinal studies demonstrate positive indications that high levels of fitness and PA have a causal link to high levels of cognition and academic achievement. Alongside already known physical health benefits, with the potential to improve cognition and academic performance, health promotion agencies and educationalists are viewing this topic keenly.

Despite the accumulating knowledge in the PA-cognition-academic performance field, there are still many unknown factors on how the three areas relate and interact. Unravelling how those relationships work to increase understanding and uptake of PA is now the priority of researchers. The first chapter in this thesis is a literature review outlining the current knowledge of this subject. It explains the PA theory, that PA can effect positive changes to the brain that facilitate processes required for cognition and academic performance, then summaries key research findings. The key themes, findings and methodological considerations are then detailed as a lead in to chapter 2 which gives the rationale for this study. For the first study, a multi-variable analysis approach is proposed to help understand how the key variables relate and inter-relate. Then to identify specific causal relationships, the second study details how to analyse how changes in PA, cognition and academic performance affect each other over time. Chapter 3 explains the aims and hypotheses of this study, giving methodology detail including study subjects, measures and data analysis techniques used for each of the studies.

The results of study 1 are detailed in chapter 4. Using a Structured Equation Modelling (SEM) approach, the study was able develop a model that explained how PA affects cognition and academic performance individually and cumulatively. The study also explained the mediating effect of cognition in the PA-academic performance relationship. Chapter 5 shows the results of a General Linear Mixed Model (GLMM) analysis that identified causal relationships PA had with areas of cognition and academic performance over a six month period. The studies in chapter 4 and 5 are presented in the form of separate research papers. Lastly, chapter 6 provides a discussion of the main findings, acknowledges the limitations and strengths of the research, explains implications of the studies for research and practice, then provides overall concluding remarks.

Chapter 1: Literature review.

1.1. Introduction.

Poor lifestyle choices are the major cause of ill health in Western societies. They are linked to conditions including cardiorespiratory illness, osteoporosis, type II diabetes and some cancers [3-7]. The evidence linking inactivity and diet to poor health was recorded as long ago as Hippocrates (460BC) and the Indian guru Sustra (600BC) [8]. Today, the World Health Organization (WHO) recognises physical inactivity is the fourth leading risk of death (6%) after high blood pressure (13%), tobacco use (9%) and high blood glucose (6%) [9]. WHO and other health agencies acknowledge the best way to address lifestyle related health behaviours is education targeting children [10-15]. For example, a 2005 review of 20 longitudinal studies of physical activity and body composition in youth showed that increased physical activity is protective against weight and fatness gains over childhood and adolescence [7]. A systematic review demonstrated that physical activity during childhood has numerous health benefits and that the more the physical activity, the greater the health benefit [5]. Another systematic review of 48 studies further supported the hypothesis that higher levels of habitual PA are protective against child and adolescent obesity [6]. Thus, the link between PA and physical health is well established.

Further to that, a body of knowledge has been emerging over the last century expanding on the holistic effects of PA, demonstrating cognitive, behavioural and academic benefits [1, 16-19]. Such findings have been identified in animal subjects [20], adult humans [21], and increasingly in children within school settings [22-24]. A wide range of studies with differing methodologies and measures consistently demonstrate positive relationships between PA and cognition [1, 2, 25]. This understanding represents an exciting prospect for enhancement of neurological health and academic performance in children. However, two key obstacles appear to be preventing the increase of PA in children within school settings. Firstly, the relationships between PA and cognition are complex and experts are still unsure exactly how they interact [1, 2]. Accordingly, it is difficult for educationalists to determine what actions to take. Secondly, busy school curricula and demands to focus on academic subjects are pushing PE and PA out of children’s daily school routines [18, 24]. Thus it is important for researchers to clarify positive relationships between PA and cognition and explain them to education authorities to warrant inclusion of curricular PE and structure it in the best way to promote physical and academic benefits for students.

Greater understanding of the diverse and complex relationships between PA and cognition has the potential for enhancing physical, neurological and cognitive health for people. This review will demonstrate the progression of knowledge about the relationship between PA and cognition and examine studies into the effect of PA on the cognitive and academic performance of children. Findings and methodologies will be discussed to identify study strengths and gaps in the current knowledge base to direct new research into this valuable developing field.

1.2. Impact of physical activity on cognitive function.

The relationship between PA and cognitive function is central to this literature review. Whereas the relationship between diet and physical activity with health has been known for millennia [8], understanding of the impact of physical health on cognition is relatively new [26]. This section provides details of key neurological structures and functions involved and impacted by PA then reviews current literature on the impact of PA on children's cognitive ability and academic achievement.

1.2.1. Neuro-physiological processes that occur during exercise.

Although it is widely accepted that aerobic exercise promotes many aspects of brain function, the neurobiological mechanisms for the benefits are not fully understood [27, 28]. Detailed studies and advances in scanning such as functional MRI and PET have enabled greater understanding of what happens in the brain during exercise [29]. In relation to movement required for PA, the motor cortex sends messages to the cerebellum which modulates and co-ordinates signals to produce fluid limb or body movements. Neurological connections are strengthened the more a movement pattern is performed. Beyond those core motor control processes, understanding of the impact of PA on the areas of the brain associated with learning is the focus of this literature review.

Physical activity promotes changes in the human brain due to increases in metabolism, oxygenation and blood flow in the brain [28]. Blood carries neurotrophins which are proteins that have been implicated in several functions of the nervous system, including axonal growth, synaptic plasticity, survival, differentiation, and myelination [30]. The hippocampus is a small region of the brain that forms part of the limbic system and is primarily associated with memory and spatial navigation [31]. Neurotrophins and neurotrophin related genes are upregulated in the hippocampus in response to exercise.

Hippocampal plasticity and memory are enhanced through hormonal and inflammatory factors including glucocorticoids, and neurotrophins—proteins that play roles in the growth and maintenance of the nervous and cardiovascular systems both developmentally and in adulthood [21]. Specific neurotrophins linked to hippocampal growth and function are serum BDNF (brain derived neurotrophic factor), Insulin-like growth factor-1 (IGF-1), vascular endothelial growth factor (VEGF) [20, 32]. Demonstrating the relationship between physical activity, BDNF and cognition, in a study of 114 university students, a strong correlation was found between BDNF in memory recognition accuracy tests in subjects with fitness above the 75th percentile [32]. Other studies have found PA promotes development of the prefrontal cortex of the brain [16], and increases grey matter volume, hippocampal volume, white matter integrity, and heightening of connectivity in the developing brain [33].

Hierarchical organization of the cerebral cortex was proposed in the 1870s by British neurologist, John Hughlings Jackson [34]. Remarkably, current understanding of neuroanatomy and brain development confirms that, with some areas of the prefrontal cortex developing until late adolescence [20]. The hippocampus and prefrontal cortex are key areas involved in cognitive function, and have important growth periods throughout childhood [29]. Khan and Hillman outline the implications of paediatric neural development [20]. Sulci and gyri formation is nearly complete by birth and by 2 years the brain achieves 80% of its adult weight. The brain achieves 95% of its maximum size by six years and undergoes a fourfold increase in volume from birth to adolescence which represents a period of rapid brain development. Gray matter volume, which consists of neuronal cell bodies, dendrites, and unmyelinated axons, peaks between 10 and 12 years in the frontal and parietal lobes while temporal lobe gray matter volume peaks at 16–17 years. The middle frontal gyrus involved in executive functioning does not fully mature until 20 years.

Some of the higher cognitive function areas of the prefrontal cortex continue developing until late adolescence [20]. That includes three higher-order integrative cortical areas called association areas which intervene between the sensory inputs and motor outputs and are sites of cognitive processing [34]. The limbic association area links emotion with many sensory inputs and is important in learning and memory. The posterior association links information from primary and unimodal sensory areas, and is important in perception and language. Then the anterior association area links information from other association areas and involved in memory, planning, and higher-order concept formation. An implication of this hierarchical growth model is that development of executive control - which consists of inhibition, working memory, and cognitive flexibility - is guided by the late maturation of the prefrontal cortex [20]. So it is important to maintain optimal physiological health to support and facilitate neural development through those formative years.

1.2.2. Impact of PA on cognitive function: Cross-sectional studies.

The authors and studies detailed in the previous section outline the knowledge base on underlying neurological processes that occur during PA. This section begins the analyses of research into how those PA processes impact the actual cognitive performance in children. The main purpose of cross-sectional studies designs is to identify possible relationships between PA and cognition. Hillman, et al, investigated the affect of a 20-minute burst of PA on 20 preadolescent children (average age 9.4 years) prior to engaging in formal assessments and academic testing [22]. For the within-subjects design, children completed baseline testing, then 10-12 days later performed like assessment after walking on a treadmill for 20 minutes increasing their heart rate to 60% of maximum potential. Assessment included electroencephalogram (EEG), electrooculographic (EOG) recording, and cardiorespiratory fitness assessment. Academic achievement was assessed using the Wide Range Achievement Test 3rd edition (WRAT3). That is an assessment covering reading, spelling and arithmetic and reliability tested for pre- and post- intervention testing. They also completed a neurobehavioural tool for investigating higher cognitive tasks of executive control and inhibition, the flanker task. For that task, subjects need to quickly state the direction of the middle arrow in a sequence of five (eg, <<>>< = right). Results showed significantly better performance for reading comprehension but no effect was observed for spelling or arithmetic. Flanker task performance improved significantly (5%). Scans showed a general increase in the Event Related Potential (ERP) P3 which is often used as a measure of cognitive function in decision making processes. They advise results are encouraging and show effective acute exercise interventions may be developed in schools in conjunction with cognitive control training, to promote enhanced academic achievement.

Khan and Hillman completed a randomized controlled trial that demonstrated eight and nine-year-olds receiving 9 months of PA five days per week exhibited greater improvements in attentional inhibition and cognitive flexibility [20]. Those findings were coupled with increased attentional resources during tasks requiring the upregulation of attentional inhibition and cognitive flexibility; an effect not observed for the control group. Overall, they advise PA appears to alter efficiency and flexible modulation of the executive control neural circuitry in children.

Despite the extensive detail in their reviews and studies, Khan and Hillman acknowledge three areas needing more detailed consideration and research: Links between PA and cognition have thus far focused on the ability to perform cognitive tasks, but there is limited evidence supporting a link between PA and the ability to acquire new learning [20]. Many studies focus on normally developing and healthy children and specifically preclude subjects with disabilities, so results cannot be generalized to such groups. They also advise neuroimaging evidence can be limited in generalizability due to lower sample size and subject variability so additional longitudinal and randomized controlled trials are needed to examine the association between changes in fitness, physical activity, brain, and cognition and elucidate how changes in physical activity and fitness predict changes in brain structure and function in children. Khan and Hillman advise that the dentate gyrus of the hippocampus in the adult brain continues to undergo neurogenesis, so the impact of PA and release neurotrophins in the hippocampus suggests mechanisms by which PA may affect cognition and brain health [20]. Evidence from rodent studies has revealed that several factors affect neurogenesis including stress, aging, environmental enrichment, and physical activity, such wheel running in rodents demonstrating enhanced performance on hippocampal-dependent tasks including spatial memory and novel object recognition [20]. With such findings and increased understanding of the benefits of PA, the US Institute of Medicine recommends schools facilitate more than 60 minutes MVPA for students through the school day for optimal classroom learning [20].

Such neurological findings extend well beyond animal studies. Using cognitive measures and MRI scans, Chaddock, et al, assessed 28 lower-fit and 21 higher-fit children [17]. They found higher-fit children displayed greater hippocampal volume and performed better in relational memory task. However, no differences in performance were observed across fitness levels for item memory performance and nucleus accumbens volume. They suggest that demonstrates the selectivity of fitness to specific aspects of memory and their neural substrates and advise their findings support for the selective link between the hippocampus, relational memory, and fitness.

Using similar assessment procedures, Chaddock, et al, measured 55 children aged 9-10 years to see the relationship between aerobic fitness, basal ganglia volume, and performance on a cognitive assessment and modified version of the flanker task [29]. MRI showed that higher-fit children (n25) exhibited larger volumes in basal ganglia, and they performed the flanker task managing the conflicting cues twice as well as lower-fit children (n30). However, flanker accuracy results were not significant - 5% interference for higher-fit children, 11% interference for lower-fit children. The two measures together suggest that cognitive enhancement through increased fitness is directly related to differential volumes of brain regions involved in cognitive function [29].

Dwyer, et al, completed a thorough cross-sectional analysis of the relationship between academic performance and PA in nearly 8000 Australian children aged 7-15 years from 109 different schools [35]. Student's scholastic ability was measured by a trained school representative and rated on a 5-point likert scale (1=poor, 2=below average, 3=average, 4=above average, 5=excellent) plus students completed a 3-point self-rating scale (1= not as good as most, 2= about the middle, 3= better than most). Physical measures taken of standing long jump (muscular power), sit-ups and push-ups (muscle force and endurance), sit and reach (joint mobility), dynamometry (muscular force and power), 50 metre sprint, 1.6 kilometre run, BMI, skin folds and lung function. Physical work capacity (PWC) was measured using a Monark cycle ergometer with three ascending output levels over a three minute period. Students nine years and older also completed a questionnaire on exercise and sport involvement. Positive relations were found between school ratings of scholastic ability and physical fitness, capacity and activity, with weak but consistent associations with muscle force, endurance and power. Subjects with higher scholastic ratings completed the 50m run faster, completed more sit-ups, and jumped further in the standing long jump. Relations with push-ups and joint mobility were weaker. One area of inconsistency was found with significant positive relationships between cardiorespiratory endurance (1.6km run) and academic ability, but a weak relationship between PWC per kg of lean body mass and academic ability. As cardiorespiratoty endurance, muscular force and power and PA were all related to scholastic ability, they advise it cannot be concluded that one fitness component alone is related to academic ability. Overall, they found correlations did not appear to increase or decrease for age or between measures. Because of the large sample size and and range of children, associations are not likely due to selection bias. As the study was cross-sectional, causation links between PA and cognition not able to be gained.

In a very specific study by Davis, et al, 171 overweight children aged 7-11 years, two groups were set up to engage in an afterschool exercise activity [36]. Over 13 weeks, children were assigned randomly to low-dose activity (20 min/day) (n55), high-dose activity (40 min/day) (n56), plus a control group with no intervention (n60) [36]. All children completed a range of pre and post intervention cognitive tests, and 20 children in the high-dose activity group were given pre and post intervention fMRI scans. From the study, blinded, standardized evaluations showed specific dose-response benefits of exercise on executive functioning and mathematics achievement. Researchers found the improvement in mathematics remarkable as no additional academic instruction was provided. The improvement observed on achievement was specific to mathematics, with no benefit to reading. That supports the notion that PA improves general higher executive functioning that mathematics may demand. The high-dose group resulted in mean planning scores 3.8 points, or a quarter of a standard deviation, higher than the control condition. Increased prefrontal cortex activity and reduced posterior parietal cortex activity due to the exercise program were observed. Limitations of the study are that the sample was overweight children aged 7-11 years and only stated to be of black or white race, so results may not be generalisable for standard fit children and those of other ethnicities.

Positive correlations between physical health and cognition are not limited to Western cultures. Chang and Chen acknowledge many Asian cultures place a strong emphasis on children to succeed academically, often at the expense of curricular PA [37]. They completed a cross-sectional study of 476 students aged 11-12 in Taipei, Taiwan examining the relationships between academic performance, physical education performance, fitness and BMI. Students were from a high socioeconomic area of Taipei. Measures were taken retrospectively from school records for children in grade 6 who enrolled in the five years 2006-2011 – approximately 60-70 students each year. The school followed national measures tracking children’s performance in mathematics and Chinese, with fitness measures consisting of BMI, flexibility, abdominal strength, lower body strength, and cardiovascular endurance. The school data was analysed using regression analysis which significant positive relationships between Chinese, mathematics and physical fitness for both boys and girls. Strongest relationships were found between academic performance and cardiovascular tests and BMI, medium relationships were found between abdominal and lower body strength, with no significant relationship identified with flexibility. In spite of the positive findings, the authors note limitations of the study. As data was analysed retrospectively, findings can only be correlational and could not identify causative relationships. Further, the data gained at elementary school level was for school record purposes and collection processes did not follow the rigor required for research purposes.

Despite many encouraging results, causality between PA and cognitive health is still elusive. Shephard notes that even in studies where physically active students have had an unequivocal academic advantage over their sedentary peers, it is unclear whether intelligence led to success in sport, whether involvement in an activity program enhanced academic performance, or whether both academic success and a predilection for physical activity are related to some third factor, such as a genetic characteristic that favours both academic and physical development [24].

Table 1: Summary of findings from cross-sectional studies into the relationship between physical activity and cognition

Authors and Date	Sample	Location	Intervention	Outcome measure	Outcomes
Hillman, et al (2009)[22]	20	Kansas, USA	Within subjects design. 20 minutes PA prior to cognitive testing.	WRAT3 Flanker test Neuroelectric imaging.	Improved reading comprehension. Improved Flanker task performance. Increased P3 neural activity.
Hillman & Khan (2014)[20]	Not stated	USA	Additional PA five days a week for nine months.	Not stated	Improved attentional inhibition and cognitive flexibility. Improved attention.
Chaddock, et al (2010)[23]	28 lower-fit and 21 higher-fit children.	USA	No intervention. MRI imaging and cognitive testing.	MRI imaging Kaufman Brief Intelligence Test Flanker Task ADHD Rating Scale V	support for the selective link between the hippocampus, relational memory, and fitness.
Chaddock, et al (2010)[29]	25 higher-fit and 30 lower-fit children.	USA	No intervention. MRI imaging and cognitive testing.	MRI imaging Kaufman Brief Intelligence Test Flanker Task	Higher-fit children had larger basal ganglia volume. PA promotes basal ganglia development and cognitive function.
Dwyer, et al (2001)[35]	7961 children	Australia	No intervention. Analysis of school performance and physical ability.	Academic performance rated on 5-point Likert scale. BMI, skinfold and Seven PA measures. Questionnaire on sport involvement.	Positive relations between academic performance and almost every PA measure. Unable to make direct link with academic performance and one specific area of PA.
Davis, et al (2011)[36]	171 overweight children: High dose PA – n56. Low dose PA – n55. Control group – n60	USA	13 week PA instruction by trained PE specialist: High dose: 40 minutes/day Low dose: 20 minutes/day	Cognitive Assessment System and Woodcock-Johnson Tests of Achievement III School results and performance. Pre and post intervention fMRI scans.	Improvement in mathematics. No benefit to reading. High-dose group mean planning scores a quarter of a standard deviation, higher than the control. Increased neurological activity.
Chang & Chen (2011)[37]	476 children 11-12-years old	Taipei, Taiwan	No intervention. Regression analysis of standard school data.	National school measures of performance in mathematics and Chinese and five fitness measures.	Significant positive relationships between Chinese, mathematics and physical fitness. Limitations of the quality of school data used for research purposes.

1.2.3. Impact of PA on cognitive function: Longitudinal and experimental studies.

Whereas cross-sectional studies can identify relationships between variables, longitudinal and experimental studies can measure changes in performance with an intervention to help ascertain causality. One of the first longitudinal studies into the affect of PA on children's performance at school was completed in Vanves, Paris, France, in 1950. Shephard gives an English translation of the Vanves' findings [24]. Students at an experimental school had their normal timetable modified in their last year of primary school. The school week was increased from 32 to 41.5 hours, students had siestas from 1-1.30pm, and 4.30-5pm. Academic instruction was reduced by 26% and was limited to the mornings, with a range of PA in afternoons such as gymnastics, swimming, training, sports, and outdoor activities. Students attending the experimental school were given regular vitamin supplements. The Vanves study found children's school results were comparable to other schools in Paris (randomised control groups), but noted students were more calm and attentive, fewer disciplinary problems and absences for sickness than control classes. Despite being a pioneering study into longitudinal relationships between PA and cognition, Shephard acknowledges it is difficult to generalise the findings because experimental sample was small, it is not clear how the control group was matched in terms of size and socioeconomic status, and the treatment was more than just PA with increased school time, vitamins, and siesta. Further, it is not possible to compare the styles and level of academic instruction students had at the different schools. But credit must be given to the researchers for their groundbreaking longitudinal study.

A South Australian longitudinal study investigating the impact of increased PA on physical health of more than 500 children had encouraging findings [38]. Over 14 weeks, children aged 10 years were assigned to three groups: an endurance fitness programme 1 ¼ hours per day (n216), a skill programme and existing physical education programme [38]. The fitness group showed significant gains in fitness and decreases in body fat compared to both control groups. The experiment group continued with the daily fitness programme and were assessed two years later and the physical benefits had maintained or increased. The study was focussing on physical health and not designed to assess academic performance in detail, but found no evidence of loss in reading and arithmetic ability despite the loss of 45-60 minutes formal teaching.

In the Trois Rivieres study in Quebec, Canada, Shephard, et al, analysed the effect of increasing PA at school for students over a six year period [39]. The study followed 546 students from one urban and one rural school through Grades 1-6, aged 6-12 years. The experiment group undertook one hour extra PE per day, taught by a specialist physical educator, and control students received a standard 40 minute daily PE lesson taught by a nonspecialist. Thus, the control group received 13-15% more academic instruction than the experiment group. In the first year, the control group had higher average grades, but in Grades 2-6, the experiment group had higher grades, significantly in years 2, 3, 5, and 6. They concluded that the longitudinal study supported findings from cross-sectional data that academic performance is maintained or even enhanced by an increase in a student's level of habitual PA, despite a reduction in curricular or free time for the study of academic material. In an interesting follow up to the Trois Rivieres study, 86 participants completed a range of structured and semistructured questions that underwent quantitiative and qualitative analysis [40]. Some of the key findings were 94.9% of the experiment group had mostly positive recollections to PE compared to 82.1% in the control group. Both groups advocated curricular PE should be increased.

The effect of increased curriculum based PA was assessed on 754 children over two years in an affluent suburb in Southern California [41]. The average age of subjects at baseline was 9.5 years. The experiment group (n330) engaged in a Sports, Play, and Active Recreation for Kids (SPARK) programme that was run by specialist physical educators three days per week through the 36 week school year. Control students (n424) engaged in usual curriculum based physical education activities. Academic achievement was measured using the schools' standard Metropolitan Achievement Tests – MAT6 and MAT7. The study was interesting because under the MAT testing, both control and experiment groups decreased their scores in almost every area assessed. The authors as state that is likely because they had falsely inflated baseline scores. As the decline was in both groups, it was not considered due to the study or impact of additional PA for the experiment group. Further, although it was not significant, the experiment group reduction was least. Although there were no changes in academic performance, the study allays fears that academic performance would be sacrificed due to increase of PA.

The Physical Activity Across the Curriculum (PAAC) study was a 3-year cluster randomized controlled trial in 24 elementary schools in Kansas, USA, with a primary focus of decreasing

BMI and improving physical health of students [18]. One of the secondary aims was to assess changes in academic achievement in children who engaged in PAAC compared to children in control schools. There were 14 experiment schools (814 students) and 10 control schools (713 students). The experiment PAAC classes engaged in 90 minutes PA per week additional to the existing 60 minutes per week. All children wore accelerometers through the day to record their levels of PA at home and school. PAAC classes structured two 10-minute in-class physical activity sessions per day. Children were in grades two and three at baseline, and four and five at the end of the study. Academic achievement for reading, writing, mathematics and oral language skills were measured using the formal Wechsler Individual Achievement Test (WIAT) – 2nd Edition. In relation to the study's primary aim, the PAAC group increased MVPA but there was no significant reduction in BMI compared to the control group. A further breakdown found those in the experiment group who engaged in more than 75 minutes PAAC per week showed significantly lower BMI than those who engaged in less than 75 minutes PAAC [18]. In relation to cognitive function and the four academic areas measured (composite, reading, mathematics and spelling), PAAC students scored significantly better than the control group [18]. That indicates the neurophysiological mechanisms from PA that promote cognitive function are more complex that can be drawn from a straight relationship between BMI, and MVPA may be a more useful measure.

'The Early Childhood Longitudinal Study (ECLS), Kindergarten Class of 1998 to 1999' was a multistage study designed to gather a range of health and education data for 5316 children from kindergarten to grade 5 at elementary school in 2004. Carlson, et al, completed a secondary analysis of the data to gauge the impact of PA on children's academic performance [33]. Participation in PA was measured by physical education teachers who reported the number of times each week students engaged in PE and the duration of the activity. Groups were labeled low (0-35 minutes / week), medium (36-69 minutes / week), and high (70-300 minutes / week). Academic achievement was measured using standard education mathematics and reading tests and other assessment batteries. Results found girls in the high activity group had a small benefit in mathematics and reading, but there was no positive or negative association for boys. The study acknowledges exposure to PA in the sample was much lower than national guidelines and recommendations, and more conclusive findings could have been gained if PA levels could have been manipulated, quoting other studies where PA increase resulted in academic improvement. Similarly, other measures were taken for the ECLS study so may have been able to be set up more rigorously for a correlational analysis of variables associated with PA and cognition or academic performance. Nonetheless, a strength of the study is that being a retrospective secondary data analysis eliminates possible bias in data collection. So the findings that time spent in PA did not harm academic achievement and have a possible modest favourable effect are valid and give a good indication for further detailed specific analysis in that area.

Table 2: Summary of findings from longitudinal and experimental studies into the relationship between physical activity and cognition

Authors and date	Sample	Location	Intervention	Outcome measure	Methodological considerations	Outcomes
Hervet, R (1952), cited in Shephard (1997)[24]	Experiment group school. N not stated. Control groups at unspecified schools. N not stated	Vanves, Paris, France	26% reduction in academic instruction with corresponding increase of PA.	No formal measures, subjective teacher reporting and grades.	Many additional uncontrolled variables inhibit correlations, interpretation and generalizability	Academic results remained consistent. Better behaviour. Less sick days.
Dwyer, et al (1983)[38]	500 children. Experiment group N – 216.	South Australia	14 week, 1 ¼ hr fitness instruction. Continued post intervention and re-evaluated after two years.	Body fat and fitness levels. School results.	Study focus was on physical health and academic performance was not a focus so not measured in detail.	Fitness benefits maintained. No loss in academic results despite the loss of 45-60 minutes teaching
Shephard, et al. (1994)[39] Study done 1970-1977	Total children 546. Experiment & Control groups, N not stated	Trois Rivieres, Quebec, Canada	1 hr extra PE per day at school taught by specialist. Control children had 40 minute standard PE per day. Completed over 6 year period.	Children's fitness levels and academic grades.	Unclear of numbers in control and experiment groups. Limited consideration of uncontrolled variables.	Years 2-6, control group academic results significantly better despite 13-15% less academic instruction
Sallis, et al (1999)[41]	Experiment N – 330 Control N - 424	Southern California	Additional PA taught by specialist 3 days each week.	Standard school educational assessment tests.	Queries on accuracy of baseline assessment tests.	Experiment group academic performance slightly better but not significantly. Study allays fears increased PA causes lower academic performance
Donnelly, et al (2009)[18]	Experiment group N – 814. Control group N – 713	Kansas, USA.	90 minutes additional PA per week over two year period.	MVPA, BMI, school grades and standardized cognitive WIAT assessment.	Thorough and rigorous measures of PA, health, school grades and cognitive function.	Increase of MVPA, but no change to BMI. Significantly better performance in academic subjects.
Carlson, et al (2008)[33]	Each year children categorized	USA	No additional intervention.	Teacher report of children's	Secondary analysis of ECLS data.	Time spent in PA did not harm

Study done 1998-99	in 3 groups: Low, medium or high activity levels.			activity levels. Measured five points over two years.	No manipulated experiment variables. Extensive record of control variables such as SES and ethnicity.	academic achievement and had a possible modest favourable effect.

1.2.4. Impact of PA on cognitive function: Reviews and meta-analyses.

One of the first detailed analyses into the relationship between PA and cognitive function was completed in 1934 by Davis and Cooper [42]. They reviewed 41 studies completed over the previous 30 years [42]. Seven studies were of high school students and the remainder at college/university level. Examples cited include a 1921 study at Harvard University where attendance of athletes (n348) and non-athletes (n1252) was similar, and the non-athletes' academic performance was slightly better, but not statistically significant [42]. Harvard repeated the study in 1928, and again found no statistical difference in academic performance between groups. A 1931 Pennsylvania State College study found the non-athletes (n48) scored slightly higher in achievement test scores, but correlation between intelligence test and achievement test scores was higher for athletes (n48) [42].

Overall, Davis and Cooper found a range of results supporting and opposing positive relationships between health and cognition. Results showed non-athletes performed slightly better at school work than athletes, but the difference was not statistically significant. The main causes of conflicting findings they found at that time is still pertinent in 2016: agreement on definition of athlete and non-athlete, validity of tools used to measure scholastic ability, unequal numbers in experiment and control groups, variances in study timeframes, and researcher bias. That rich review has become foundational in the field of PA and cognition. Since then, research methodologies have become tighter and more accurate, and physiology and neurology understanding have increased exponentially. Researchers are able to choose a wider range of valid tools and measures to examine the complex relationships between PA and cognitive ability.

In almost a replica of the Davis and Cooper paper 70 years later, in 2003 Sibney and Etnier meta-analysis of 44 studies into the relationship between PA and cognitive abilities [2]. They found all included studies reported significant and positive effects of physical activity within physical education and cognition in youth, regardless of the study design and all types of physical activity. The greatest effects were seen with perceptual skills and academic readiness tests. That review included four large-scale longitudinal studies analysed in the previous section where students spent additional time in PE at the expense of time spent in academic classes where significant improvements in academic performance were found in three studies [24, 38, 39, 41].

A 2008 review of 17 studies by Trudeau and Shepherd on the impact of PA on academic performance of children in primary and secondary school also found positive relationships between PA and school results [25]. Combined analysis of the seven quasi-experimental studies showed that the enriched PE programmes demanded a substantial reduction in the time allocated for academic tuition but academically children achieved at least equally despite the reduced teaching time. Also, despite the variety of physical interventions, all studies reported significant increase in physical fitness measures of the children. Ten cross-sectional studies also showed positive association between PA and academic achievement, but they advise limitations of interpretation and generalisability because many studies did not control confounders such as socio-economic status which is the strongest predictor or academic achievement in children, and a strong predictor of participation in PA. Overall, they advise studies strongly suggests that limiting school time allocated to PE instruction, school PA and sports programmes does not have a negative impact on students' academic achievement.

Despite concurrence about a positive relationship between PA and cognition, neither of the reviews by Sibney and Etnier nor Trudeau and Shepherd could clearly support the possibility that participation in physical activity causes improvements in cognitive performance. Although findings on that direction were encouraging, there were limitations about causality due to the small number of true experimental studies and by potential confounding variables in these studies. Sibney and Etnier found 57 different methods of cognitive assessment used by investigators many with poor or unknown psychometric properties [2]. They also advise further research needed that include valid and reliable dependent measures and in which potential confounds are controlled are needed to establish whether a causal relationship exists, to clarify the types and durations of physical activity that may benefit cognitive performance, and to target possible mechanisms underlying the observed relationship [2]. Trudeau and Shepherd's review did not find any randomised control trials and they also acknowledge quasi-experimental and cross sectional studies can have limitations determining causality [25].

Charles Hillman is party to many influential studies in the field of PA and cognition [17, 20, 22, 26]. Hillman, et al, completed a review of 14 studies examining PA and neuroelectric concomitants of cognition during childhood [1]. The review included information from some adult studies but with the purpose of better describing the relationship between PA and cognition in children. They found PA and cardiovascular fitness have short and medium-term benefits for neurocognitive performance in youth [1]. The studies used laboratory measures such as fMRI and neuroelectic monitors to measure neurological activity on subjects performing a range of cognitive tasks and formal assessments. They found increased fitness and PA improve cognitive function and brain health, with higher-fit children demonstrating attributes such as greater attention, faster information processing, and higher scores in standardised achievement tests. Only one study which provided neutral findings did not show any improvement in cognitive function.

In a further, current analysis, for the Copenhagen Consensus, 24 researchers from eight countries met in 2016 to reach an evidence-based consensus on the effects of PA on youths aged 6-18 years [43]. The authors concur on the physical health benefits for children then expand stating that PA and cardiorespiratory fitness are beneficial to brain structure, brain function and cognition in children and youth. They advise that PA before, during and after school promotes scholastic performance in children and youth, with even a single session of moderate PA having an acute benefit to brain function, cognition and scholastic performance. Likewise, developing mastery of fundamental movement skills was identified to be beneficial to cognition and scholastic performance.

In the final and most detailed meta-analysis reviewed, in June 2016, eight researchers including many already quoted in this literature review started from a database of 6237 articles and identified 137 key articles to consider [44]. Additional consideration will be given to that study because it covers many of the individual areas already explored in this review. It included a range of cross-sectional, acute, longitudinal, and randomized and nonrandomized intervention studies of children aged 5-13 years identifying the onset of puberty results in both physical and cognitive changes that differentiate adolescents from children [44]. The authors used the Downs and Black method for assessing the quality of methodology of intervention trials, which rates the evidence of studies A, B, C or D[45]. The review focused on two specific questions: Among children age 5–13 yr, do PA and physical fitness influence cognition, learning, brain structure, and brain function? And among children age 5–13 yr, do PA, physical education (PE), and sports programs influence standardized achievement test performance and concentration/attention [44]?

For the first question, the authors identified 64 key studies. Overall, they found promising results showing relations among PA, cognition, brain structure, and brain function, with no negative effects on children. The 26 cross-sectional and cohort-based studies involving PA provided positive support for the relationship between PA and cognitive function, with greater amounts or enhanced forms of PA being associated with greater improvements in cognitive function. However, using the Downs and Black criteria, the authors advise a number of methodological weaknesses in those studies especially a lack of information about estimates of random variability in the outcome data (22/26), or power (26/26), and information about the time of day at which the cognitive measures were assessed was not provided (22/26). Although they advise that cross-sectional literature was only able to provide correlational evidence, researchers generally used precautions to control for potential confounders which added credibility to their findings indicating that children with higher levels of fitness display significantly better cognitive performance compared with children with lower levels of fitness [44].

Only two longitudinal studies met the criteria for review by the authors, which were completed over nine and 12 month periods. Overall, they gave indication that higher fitness is associated with better cognitive performance across time, and support the concept that PA has a causal impact on positive cognitive function. Other studies reviewed include 16 acute PA interventions which found inconsistent positive cognitive results and no negative results. The 11 randomized controlled trial design studies considered consistently demonstrated significant improvements in the treatment groups, particularly for tasks involving executive functioning. The literature investigating cognitive function using neurological imaging showed PA and aerobic fitness supported brain function such as increased P3 amplitude and latency, higher activity in prefrontal cortex areas EF (executive functioning), midbrain and hippocampus (memory). Overall, the findings support the benefits of daily PA on the neural network supporting EF. The authors advise findings are encouraging, but preliminary and should serve to direct and motivate future research using RCT and larger sample sizes [44].

"Evidence summary statement: The literature suggests that PA has a positive influence on cognitive function as well as brain structure and function; however, more research is necessary to establish causality, to determine mechanisms, and to investigate long-term effects. Therefore, based on the current information available the evidence category rating is B" [44].

The second question expanded on the first, with authors identifying 73 key studies looking specifically at educational outcomes, focusing on the specific effects of PA and PE on children age 5–13 years on standardized achievement test performance and concentration/attention [44]. They refined further that to three specific categories: the relationship between academic achievement and physical fitness (*n* = 27); studies of PA, including the relationship between PA levels and academic achievement and the effects of participation in acute PA and PA interventions on academic achievement (*n* = 35); and the relationship between academic achievement and PE (*n* = 12).[44]

Most of the cross-sectional studies (20/24) looking at academic achievement and physical fitness showed a positive relationship. But again, the authors found methodological issues impacting the reliability of the findings such as varying and inconsistent measures of fitness and academic achievement, poor control of confounders, and 95% of studies did not give statistical power [44]. Three longitudinal studies also showed promising relationships but did not identify causality and had similar methodological short-comings. The authors advise the failure to include appropriate moderators is a critical shortcoming of this literature in that first area. Some 32 cross-sectional studies investigated the relationship between PA and academic achievement. Similar to the cross-sectional studies of fitness and academic achievement, the differences in methodology, measurements used, and control for confounders vary widely, which may account for the inconsistent results. Ten studies into acute PA before lessons found notable increase of time-on-task (TOT) during the lesson, but did not have significant ongoing effects [44] Overall, the authors stated the studies of acute PA interventions had mixed results, likely owing to the differences in tasks administered, the nature of the task, and the type of PA. Six other kinds of study reviewed looked at PA intervention, physically active classroom lessons, classroom PA breaks, after-school fitness programs, additional school PA, and specialised programs, but they had consistent varying findings and methodological issues [44]. Twelve studies reviewed examined the relationship between existing levels of curricular PE and academic achievement using cross-sectional, longitudinal, acute and intervention methodologies. The results of intervention studies that increased time spent in PE did not show a positive effect on academic achievement and attention, with the exception of one retrospective study.

Two specific findings in relation to the second question were that PA in the classroom has more effect when the PA is integrated into the curriculum rather than being implemented as a break from academic content and positive academic results from PA appeared more in mathematics than literacy subjects [44] "*Evidence summary statement*: Overall, the literature suggests that PA and PE have a neutral effect on academic achievement. Thus, because of the limitations in the literature and the current information available, the evidence category rating is C"[44].

This thorough review by key researchers in the field shows the increasing knowledge base in the area of PA and cognition in children with exciting potential it has. They acknowledge despite promising findings, rigorous research is still in its infancy and it is important future studies establish a clear purpose with appropriate measures of PA, cognition and academic ability with suitable methodology. When cross-sectional studies are completed, the authors advise researchers study a wide range of fitness and/or PA scores to get a clearer picture of possible impact on both cognition and academic achievement [44]. Longitudinal research and follow-up assessments for randomized control trial designs are recommended to provide a better understanding of causation and the longevity of PA effects on cognition and academic achievement [44].

Table 3: Summary of findings from reviews and meta-analyses into the relationship between physical activity and cognition

Authors & Date	Review type	Methodological considerations	Key findings and recommendations
Davis & Cooper (1934)[42]	41 papers over a 30 year period.	Inconsistent measures and used. Variances in experiment and control groups, and study timeframes. Possible researcher bias.	Non-athletes slightly better academically but not statistically significant.
Sibney & Etnier (2003)[2]	Meta-analysis scaled from to 44 studies.	Included longitudinal and cross-sectional studies. Inconsistent cognitive assessment validity.	All studies show positive relationship between PA and cognition. Limitations in determining causality.
Trudeau & Shephard (2008)[25]	Review of 17 studies.	Seven quasi-experimental and 10 cross sectional studies. Limits in generalizability due to uncontrolled variables.	Strong evidence in links between PA and academic ability. No loss in academic performance despite reduction in academic tuition. Limitations in determining causality.
Hillman, et al (2011)[1]	Review of 14 studies.	Focus on reviewing neurological processes and mechanisms during PA, using neurological scans and cognitive testing.	All studies but one showed positive relationships between PA with neurological health and cognitive performance. One study showed no positive or negative effects.
Bangsbo, et al (2016)[43]	Consensus meeting with 24 researchers.	Researchers considered effects of PA on 6-18 year-olds.	Concurrence on physical health benefits. PA improves brain function, cognition and academic performance.
Donnelly, et al (2016)[44]	Meta-analysis scaled from 6237 to 137 studies.	Rigorous analysis of studies with varying methodologies. Subjects children aged 5-13 years. Two key focus questions of the review.	Strong links between PA and cognition but causation not established. Neutral affect of PA and PE on academic achievement – more study needed. Methodological considerations given for future research.

1.3. Effects of physical activity on academic performance.

The focus of this review is to identify types of PA that can be an effective intervention to promote performance of children at school. As many of the studies reviewed look at general cognitive ability, the relationship between cognition and academic performance is explained and defined. This section finishes outlining the specific potential benefits PA has for children within the school setting. Arguably, the main role and function of schools is to promote and develop academic success in students. The educational focus is still largely the three Rs – Reading, wRiting and aRithmetic – also defined as literacy and numeracy. When reading school Education Review Office (ERO) reports, student performance in those core areas can often be the educational measure of success, particularly at primary school level. As

Rassmussen and Laukin identify, it is ironic that improvement in academic performance seems to be needed to justify inclusion of PE in school curriculum [46].

The studies reviewed present to interchangeably use cognitive and academic measures to rate the effectiveness of PA against. Cognition can be defined as engagement in higher cognitive functions such as those outlined in section 1.3.1, and academic performance is how the child uses such cognitive functions in the school environment to complete curriculum based learning tasks. On that basis, studies on children using either cognitive or academic measures against PA are appropriate to consider and the terms can be considered equally. The overall findings and consensus demonstrating a positive association between PA and cognition is strong evidence to support maintaining or increasing existing curriculum based PA to foster academic success.

With such an abundance of information demonstrating the overall benefits of PA, it is important to understand the present levels of PA in schools and the level of support it is given. In 2010, a WHO expert panel recommended children engage in a minimum 60 minutes of moderate-vigorous intensity physical activity (MVPA) per day and the proportion of children and adolescents that participate in daily school physical education should increase by 2% year on year until 2020 [9]. Ironically, Donnelly, et al, perceptively note that schools may in fact be a barrier for interventions to promote PA because children are required to sit quietly for the majority of a six-hour school day to receive academic lessons [18]. Furthermore, Shepherd advises many schools view physical education negatively, with physical educators having to argue to maintain even limited PE classes [47]. In school PE classes, the variance in quality and levels of PA within activities is noted, so many of the studies quoted in this paper engaged specialist physical educators to direct intervention (eg, [35, 36, 39]). Larouche, et al, advise that specialist teachers trained in PE are needed to run PE to ensure activities have adequate levels of PA [40]. Donnelly, et al, also specifically considered the impact of curricular PE on cognition and academic achievement and found no significant relationship [44].

Some of the first studies into the impact of PA and cognition found non-athletes outperformed athletes, but not to a significant level [42]. Indications from those studies are that the results were unexpected with a largely educationally based preconception that intelligent children would spend less time engaged in PA and more time in academic activity.

More current studies in this literature review show such a mindset appears to be decreasing [1, 2, 25], but still remains to some degree [46]. Information about the benefits of PA for cognition appears to be having limited overflow to academically focused school systems. On the contrary, in attempts to improve student grades, schools often cut PE at the expense of subjects considered to be core academic [2, 48]. The prevailing thought is that curriculum based PA is time taken away from academic lessons and comes at the cost of scholastic performance [43]. However, at the worst, studies reviewed in this paper found increasing PA at school had no impact on academic performance, and most found improvement in school-work [39, 41, 43]. Furthermore, Shephard found an experiment group that had increased curricular PE performed better academically than a control group that had increased study [24].

The findings in this literature review raise important questions: If the links between PA and good academic performance are so strong, why are schools reluctant or resistant to include and promote PA? If there is no evidence at all that increased PA reduces children's academic performance, why is PA not being increased, and to the contrary most likely decreasing? And most pertinently, what are the barriers preventing the evidence on the positive impact of PA on children's learning from being accepted, promoted and actively included in our children's daily learning and curriculum? Further research is clearly needed to clarify the relationships between PA and cognition then explain the findings in a way that schools can understand and make appropriate decisions on curricular based PA to maximise the potential cognitive and academic benefits for children.

1.4. Summary of literature review

1.4.1. Key themes and findings.

This literature review has shown the developing knowledge base around the relationship between PA and cognition. Early studies of university students expected non-athletes to out-perform athletes academically, but found no significant differences [42]. Then a range of studies showed possible positive correlations [42]. Relationships between PA and cognition have since been investigated further using a variety of measures and methodologies showing consistent convincing associations.

The increasing understanding of the neurological and cognitive benefits of PA, especially for children is an exciting developing field. Neurologists such as Hillman and Chaddock explain the neurological processes that occur during exercise then cross-sectional studies demonstrate a consistent strong relationship between PA and cognition [1, 23, 29, 36, 37]. Those relationships were further recognised in the section reviewing longitudinal and experimental studies, many of which also showed strong signs that PA has a positive causal effect on cognition [18, 33, 38, 39, 41, 44]. The researchers who completed meta-analyses further confirm such relationships[1, 2, 25], with the 2016 Copenhagen Consensus [43], and meta-analysis by Donnelly, et al [44], showing the relationship between PA and cognitive health is now considered almost as irrefutable as the relationship between PA and physical health.

This review highlighted that although there is a positive relationship between PA and cognition which have been demonstrated in school environments, curricular PA and PE is often on the decline [24]. That is often due to a perceived necessity to focus on academic subjects [24, 46]. A finding from many studies which is especially important for educators, is that increasing PA during school time does not impair achievement, even when it takes away classroom time (eg[24, 33, 36, 38, 41]). To the contrary, studies have shown better test results when children increased PA compared to a control group that had increased study [24, 39, 41]. It is likely that such information on the benefits of PA may not filtering through to schools. However, it must be noted that there is not much evidence suggesting that merely increasing curricular PE has cognitive benefits, and more structured and specific PA interventions are likely required [43].

Many specific patterns have been identified in the research. Amongst the vast complexities of neurological function, interaction and growth, scientists are becoming clearer on the neurophysiological processes that occur during PA. Hillman and his contemporaries outline particular benefits to areas of the hippocampus associated with memory [20] But even with the advances in scanning including PET, MRI, and fMRI, they advise the best measures of the effect of PA on the brain are behavioural and actual performance [20].

Another important finding from the literature is the importance of appropriate research methodology. Even back in 1934, Davis and Cooper noted in their meta-analysis that methodological considerations limited the generalisability of findings [42]. Past and current studies have rigorous methodology with rich and valid results but need to be interpreted correctly within the scope and purpose of the study and measures used, and thus can have limited generalisability [43]. Likewise suitable measures and methods are essential for this present study. Fuller details of methodological considerations are included in the next section of this review.

1.4.2. Methodological considerations

The studies reviewed in this paper invariably show a large range of different formal and informal measures for both physical and cognitive health which makes it difficult to compare and contrast findings. Instead of being considered a weakness, such differences should be viewed as strengths. Human function - and particularly cognition – is a dynamic, multi-faceted, cultural and context specific feature that cannot brought down to narrow, one-size-fits-all definitions. Van Sluijs, et al, also found their review of 57 studies had different methodological approaches that were necessary for each study's purpose, and calculating a common measure of outcome would not valid or informative [47]. How do we measure and compare cognitive and physical relationships, needs and abilities of children in present-day urban and rural New Zealand with a ground-breaking 1950s study in France or a 2011 study in densely urban Taiwan?

An important consideration acknowledged in many papers is that although cross sectional studies can identify and confirm relationships they cannot identify causation [2, 24, 25]. The measure used to gauge PA in many studies is often self-assessment or teacher assessment, and not actual. There are potential accuracy and reliability issues with such reporting. As PA is clearly a key variable to be isolated and assessed to explain its impact on cognition it is important to ensure a strong and reliable measure. Clearly, there will be many positive influences on cognition and academic development other than PA. That may include genetics, SES, age, sex, diet, parent education level and support, or teacher ability. Dwyer, et al, found additional variables that impacted children's scholastic performance were having breakfast, going to bed later for girls, playing a musical instrument, having a parent who exercised at least twice a week, and SES [49]. For example, some school-based studies found limited effect was found for interventions targeting children from low socioeconomic populations and strong evidence that school based interventions worked with involvement of the family or community [47]. The meta-analysis by Donnelly, et al, in particular explains the importance of identifying and isolating such confounding variables to best understand the impact of PA on cognition and academic achievement [44].

It must also be acknowledged that some studies have shown limited or no significant relationship between PA and cognition [41, 42]. Further, there can be a bias towards publishing studies showing positive results, so there may be unpublished papers and theses showing limited or no relationship. However, such results should be expected and receive more recognition. Probability and standard deviation acknowledges there must be studies and results varying from the norm. Those studies highlight the complexity of human performance and cognition and can be analysed further for valuable qualitative data on that subject.

A possible limitation of the studies and interventions reviewed in this paper is that they are largely school-based so have limited ability to consider after school and weekend PA levels of children. It is positive that children can be encouraged and enforced to participate in curricular PA, but they still spend much time away from school where they are increasingly inactive and sedentary [49]. Although children tend to be more active at school, stronger associations and relationships between PA and cognition may be able to be drawn if the child's PA level was fully tracked both in and out of school.

1.4.3. Conclusions.

Excellent research over the last 100 years and especially the last 20 years has confirmed the positive relationship between PA and cognitive function. As would be expected, such a discovery opens a raft of questions that researchers have begun to address in studies such as those in this review. The cross sectional studies in this review isolate variables and confirm relationships. Longitudinal and quasi-experimental studies expand on those relationships and although they could not conclusively identify if PA had a causal effect on cognition they demonstrated positive correlations towards causation [2, 25]. The task for researchers is no longer to prove the relationship between PA and cognition but to unravel the many specific interactions to direct and enable individuals and populations to use that knowledge to maximize the potential benefits. One of the most important relationships to identify is causation: Do smart people exercise or does exercise make people smart? Such knowledge has huge potential in the active promotion of neurological health.

The complexity of neurological function and range of methodologies used in the studies in this review show the necessity to use the most appropriate and robust interventions, measures and research techniques to clarify such interactions in the vitally important relationship between PA and cognition. As with each of the studies considered in this paper, we need to consider the individual purposes of the study and rigorously determine the best way to measure and achieve them. Once individually suitable purposes and measures have been identified and completed the studies have provided us with strong data to make analyses, conclusions and recommendations. Therefore the key aspects to consider for this present study are likewise to identify key purposes and directions to investigate the relationship between PA and cognition and academic function and the best measures and methodologies to reach those.

But identifying relationships between PA and cognition is only the first part of the task for the researcher. Even with the evidence to date showing increased curricular PA has no negative effect on academic performance and indications it provides benefits, educationalists seem reluctant to or unsure how to utilise that knowledge. To attain the potential neurological, cognitive and academic benefits of PA, the researcher must be able to explain findings clearly and disseminate the information in a manner that can be easily adopted and enacted in a busy school curriculum.

Chapter 2: Rationale for current study.

Chapter 1 reviewed a range of foundational and rigorous studies with different methodologies that support a positive relationship between PA and cognition with a particular focus on children [1, 2, 25, 43, 44]. However, the complexities and intricacies of the associations between neurological function, cognition and academic performance are still not fully understood. Further to such gaps in the knowledge base about PA and cognition, many schools are not actively promoting curricular PA, and PA levels are decreasing in many populations [2, 43, 47, 48]. Consequently, there is a risk that children may not be gaining the full physical and cognitive benefits of PA.

The present study uses a twofold approach to increase understanding of the relationships between PA and cognition, and presents the information in a manner it can be adopted by schools and other agencies that support the positive development of children. Firstly, a cross-sectional secondary analysis of a dataset is completed using structural equation modelling (SEM) to isolate variables and characterise relationships. That study defines and explains the key interacting factors in the PA-cognition-academic performance relationship. Then a longitudinal analysis of an expanded dataset is completed to examine potential causal relationships. By examining changes in PA and cognition over a six month period, longitudinal analyses enables an understanding of the impact a given variable has upon another over that period.

2.1. Understanding the health/cognition relationship: a multi-variable approach.

In spite of the significant bodies of literature outlining the physical and cognitive relationships and benefits of PA, there is still a poor uptake in health promotion programmes in homes and schools [18, 47]. It is clear that the links between knowledge and action are complex, and that multiple variables need to be considered to promote lasting engagement in health promoting behaviours. It is important to understand the multiple interacting relationships between health promotion variables before we can overcome barriers to populations enacting good health practices. On that basis, a structured equation modelling analysis was used for the first analysis because SEM can consider mediating effects between variables and more than just direct relationships.

Furthermore, although there is evidence of wider cognitive benefits of PA, it appears that schools and families do not appreciate such a potential wider impact [18, 47]. That is likely due to the complexity of the key interacting factors. The teaching then uptake of health-related behaviours and their impact on cognition and other behaviours clearly needs additional insights and a new approach. Researchers and educationalists need to understand how PA, body size, neurocognition, academic achievement, and classroom behaviour interact. Increasing understanding of how those variables interact will support the ultimate goal of increasing uptake of health-related behaviours. Therefore a key focus of this study is to increase understanding of how body size and PA interact with cognitive function, classroom behaviour, and academic performance in primary school-aged children.

2.2. Physical activity and cognition: Exploring and identifying causal relationships.

Possibly one of the main reasons for a slow uptake on the PA/cognition message is lack of clear understanding of causation. For health authorities and schools to recognise the full importance of PA, it is essential to identify any positive causal relationship between PA with academic performance and the magnitude of possible effects. The longitudinal studies reviewed in Chapter 1 reported inconclusive findings regarding causation. The Vanves, South Australian, SPARK and ECLS studies identified increased PA did not negatively impact children's academic performance [24, 33, 38, 41]. As stated in the literature review, those studies were not set up with methodology or measures to explore causation. However, findings from the Trois Rivieres and PAAC studies did give indication that PA had a causative effect on cognition [18, 39]. Three key meta-analyses acknowledge longitudinal or experimental studies are needed to identify causation [2, 25, 44]. That is because causation can only be established when variables are measured at different times, to establish if an intervention has impacted change. But as shown above, even within a longitudinal analysis, it is still important to ensure variables are recognised and measured correctly to identify and isolate causal relationships.

2.3. Purpose of current study.

The literature review has clearly shown the complexities around the PA/cognition relationship. There are different types of PA, different measures of cognition and academic performance, and other factors that influence cognition and academic success in children. Therefore, to explore and explain the PA/cognition relationship further, this present study addresses the two separate and specific issues outlined in 2.1 and 2.2. Each of those issues is considered with the overarching purpose to identify factors and influences that promote a positive relationship between PA and cognition. When those are better understood, the information can be used to help direct those working with children to promote their cognitive health and academic success.

Chapter 3: Method

One of the key recurring findings from the literature around the impact of PA on cognition over the last 80 years is the importance of using the most appropriate methodology to identify and explain relationships. Moreover, to choose the correct methodological approach, researchers need to identify the specific questions they want to address and purposes of the study. Chapter 2 identified two distinct purposes of this study, each of which will require different and suitable methodological approaches. This section will outline the aims and hypotheses of this study, detail the variables that need to be considered to answer those, then detail the methodology that will be used.

3.1. Aims and hypotheses

The link between PA and cognition has drawn increasing attention over recent years. However, the studies reviewed have shown that many facets of the relationship are not understood. Does PA have an equal relationship with cognition, academic results and behaviour? Does PA have an effect on cognition independent of other confounding variables? And most importantly, does PA have a positive causative effect on cognition? The task for researchers now is to establish exactly how the PA / cognition relationship works and how the components of each interact with other confounding or mediating factors. Explaining specific interactions will give a clearer understanding of how direct input to promote the physical and cognitive health of children. The aim of Study 1 is:

- To develop and test a conceptual model that explains the cross-sectional associations among physical activity, cognition and academic performance, and potential moderating/mediating factors in children aged 7-10 years.

The hypotheses of the first study are:

A. That cognition has a mediating effect in the relationship between PA and AA.
B. That a mediating effect of cognition in the relationship between PA and AA is present for boys and girls.
C. That a mediating effect of cognition in the relationship between PA and AA is present in the different school years of 3, 4 and 5.

D. That a mediating effect of cognition in the relationship between PA and AA is present for children of New Zealand European descent and children of other ethnicities.
E. That a mediating effect of cognition in the relationship between PA and AA is present in students of low, medium and high decile schools.

Causation is the key relationship that eludes researchers, but has the biggest potential for neurological and cognitive health. Therefore, the second aim of this study is:

- To establish if physical activity has a causal relationship towards cognition and academic achievement in children aged 7-10 years.

The hypotheses for the second study is:

A. That increased PA over a two-month period has a positive causal effect promoting cognition and academic achievement of children aged 7-10 years after six-months.
B. That a positive causal relationship between PA and cognition is independent of sociodemographic variables for children aged 7-10 years.

3.2. Participants and procedures: Secondary data analysis

The data for this study was taken from an existing study called *Healthy Homework: A Physical Activity and Nutrition Intervention for Children* [50], which aimed to measure the effectiveness of a six-week school-based intervention to encourage healthy lifestyle habits in children. It measured a number of key health and lifestyle variables of some 675 children aged 7-10 years from 16 schools from Auckland (14) and Otago (6) in New Zealand. All measurements were taken at baseline (T_0), immediately post-intervention (T_1), and 6-months post-intervention (T_2). Healthy Homework was set up with eight control group and eight experiment group schools. However, in the present studies, data from both groups were pooled (the purpose of both analyses was not to evaluate HH interventions or compare and contrast experiment and control groups).

For Study 1, all subjects were considered at baseline (T_0) to explore the relationships between variables impacting cognition and PA. For Study 2, changes in PA were compared to changes in cognition, academic performance and behaviour over time, evaluating differences in the measures between T_0, T_1, T_2. Any potential impact of the HH intervention and other confounding variables were be considered and adjusted for.

3.3. Informed consent and ethical considerations

Schools and the parents of children in this study were given study information and signed informed consent protocols as part of the *Healthy Homework* (HH) study [51]. That study's research application stated use of the data for comparative purposes with future studies is not ruled out [51]. All HH study data has been stored according to the participants' number codes to ensure anonymity and confidentiality, with data stored electronically in a password-protected document [51]. Data will continue to be stored in that manner, and only accessed by researchers working on the two new studies detailed in this study.

3.4. Measures and instruments

3.4.1. Physical Activity

A pedometer is a device that senses body motion and counts footsteps. Le Masurier and Tudor Locke found pedometers reliable for measuring actual steps taken for a free-living ambulatory populations [52]. For this study, the primary measure of PA was made using two sealed New Lifestyles pedometers (NL-1000). The NL-1000 is a pedometer/accelerometer hybrid which can record time spent in moderate to vigorous physical activity (MVPA) each day. The study authors advise prior research they completed identified the NL-1000 as having one of the most accurate mechanisms for counting steps in overweight and non-overweight children [53]. Details of how the pedometers were issued and monitored are outlined in the Health Research Council Research Project Full Application [50]. Children were given one pedometer for home and one for school. At each assessment (T_0, T_1, and T_2), measurements were taken over five consecutive days (three weekdays, two weekend days). Each participant was issued with two sealed pedometers labelled as 'school' and 'home'. The 'school' pedometer was worn during school hours while the 'home' pedometer was left inside a collection tray in the classroom. As the children prepare to leave for the day, the teacher ensured they place the 'school' pedometer in the tray and attach the 'home' pedometer. When the children arrive at school the next day, the teacher asked the children to switch the pedometers over again. Teachers were given an alarm to remind them to initiate the changeover at 9am and 3pm each day. A pedometer compliance questionnaire was sent home for a caregiver to complete the day before the pedometers were returned.

3.4.2. Cognition

The cognitive abilities of children were measured using the standardised assessment CNS Vital Signs. It is a web-based battery of seven tests that are frequently used in neuropsychological analysis (CNSVS, www.cnsvs.com). The tests cover a span of cognitive domains, and are known to be sensitive to most of the causes of mild cognitive dysfunction [54]. Verbal memory (VBM), visual memory (VIM) cover memory. Finger tapping test (FTT) and symbol digit coding (SDC) generate a composite score for "psychomotor speed." The Stroop Test (ST) generates simple and complex reaction times and is used to generates a domain score for reaction time or information processing speed. The Shifting Attention Test (SAT) measures the subject's ability to shift from one instruction set to another quickly and accurately. The Continuous Performance Test is a measure of vigilance or sustained attention. The seven tests are scored individually and combined to give scores in nine different areas: VBM, VIM, Composite Memory, Processing Speed, Executive Function, Psychomotor Speed, Reaction Time, Complex Attention, and Cognitive Flexibility. Results for each domain are given in terms of participant's raw score, a standardised score which is adjusted for their age, and their percentile attainment compared to results of a database of 1069 age-matched, cognitively normal subjects aged 8-90 years [54]. Four of the nine CNSVS measures were considered for this study: Composite Memory (recognize, remember, and retrieve words and geometric figures), Executive Function (recognize rules, categories, and manage or navigate rapid decision making), Psychomotor Speed (perceive, attend, respond to complex visual-perceptual information and perform simple fine motor coordination), and Reaction Time (react, in milliseconds, to a simple and increasingly complex direction set) [55].

CNSVS bases its content and construct validity on the fact the tests in the battery are computerized versions of validated neuropsychological tests [54]. The results of the CNSVS test battery have been shown to correlate with conventionally administered neurocognitive testing and also show good levels of test-retest reliability in participants aged from 7-90 [54]. In their analysis of the validity and reliability of CNSVS, Gualtieri and Johnson say the presumption of equivalence is supported to a degree [54]. With respect to test-retest reliability, CNSVS is a reliable battery of tests with all reliability coefficients significant (P<.050) [54]. One of the biggest advantages of using CNSVS is its ease of administration which gives it good inter-rater reliability [54].

The authors note possible limitations of CNSVS that could have effect for this study. It was originally set up for clinical screening [54], and not intended as paediatric cognitive measure instrument. Gualtieri and Johnson say data base needs to be expanded in some groups including children under 10-years old.[54] However, none of those limitations should impact this current study. The core assessments have construct validity so can be used as an accurate indicator of childrens' overall cognitive ability. Furthermore, the results from CNSVS were not considered in isolation but were compared and analysed with subjects' academic results. Lastly, having good retest validity means CNSVS can give good indication of subjects' cognitive change over time which was a key consideration of this study. It must be noted that the Complex Attention section of CNSVS was not considered for analysis in this study because it was not completed in the original Healthy Homework study. Healthy Homework Project because it could not be administered appropriately in a group setting. Therefore, there are eight separate CNSVS measures considered in this analysis.

3.4.3. Academic achievement

To understand the New Zealand school system and academic rating system, it is important to note that children start primary school in Year 1 at five years of age. The academic performance of children is recorded using the standard New Zealand Ministry of Education electronic Assessment Tools for Teaching and Learning (e-asTTle). The e-asTTle is the electronic form of the asTTle developed by the MoE to assess student's achievement and progress in reading, writing and mathematics [56]. Reading and mathematics assessments were developed primarily for students in years 5–10, but because they test curriculum levels 2–6 are be used for students in lower and higher year levels. The e-asTTle writing tool has been developed for the assessment of students in years 1–10.

The asTTle measures were set by education experts who are knowledgeable about the demands of the test or assessment for which a standard is to be set, understand the meaning of scores at various levels on the scales used to summarize examinees' performances, and fully comprehend the definitions of achievement associated with the performance standards [57]. It has data obtained from its standardisation of hundreds of curriculum based tasks from tens of thousands of primary and secondary school students. Data was analysed to create underlying comparison norms for teachers to interpret test performance. It was designed so that valid and reliable interpretations could be made – for diagnostic, summative, and/or formative purposes – about teaching and learning decisions

[57]. Hattie, et al, astutely observe in relation to asTTle, but also for consideration of any measure, that a test in itself is neither reliable nor valid, it is the interpretation or use that it is applied that is reliable or valid [57]. Accordingly, the exact purpose of the e-asTTle measures were stated for each of the studies.

3.4.4. Confounding variables

The main purpose of this study is to identify how PA may impact cognition in children. This section has outlined the key independent variables that was measured and considered in that relationship. However, one of the key findings in the literature review is that there are many other confounding factors that may influence cognition. For example, as well as additional PA, the experiment group in foundational Vanves study were also given vitamin supplements and afternoon siestas [24]. Further, demographic details such as age, sex and SES of children were not recorded [24]. It is unlikely all confounding variables can be fully considered, but it is essential to recognise and adjust for as many of the key influences and confounders as possible.

Demographic variables are shown to have a key impact in children's performance at school. SES is recognised as one of the main influences on children's academic success [25, 35, 58]. Although SES was not measured of children in this study, the decile rankings of their schools was taken. Decile is a New Zealand Ministry of Education rating system for school funding based on SES with 1 being low and 10 being high. Decile reflects the extent to which the school draws their students from low socio-economic communities, rather than the SES mix of the school or individual students. For example, low decile schools have the highest proportion of students from low socio-economic communities. Age and sex will also have a bearing on children's cognitive and academic performance. The children in this study were aged 7-10 years. As there will be clear educational differences in the abilities of children of different ages, when comparisons are made children will be grouped in their same school year. New Zealand MoE figures show girls perform better than boys in all literacy measures across all years of schooling, with sex differences in reading decreasing during secondary schooling and sex differences in writing increasing [59]. At primary school level especially, girls also perform better at maths than boys but to a lesser degree [59].

Many studies have been published linking a good diet to good performance for children at school. For example, a study of 5200 grade 5 students in Nova Scotia, Canada, found an independent association between overall diet quality and academic performance [58]. The Cebu longitudinal health and nutrition survey in the Philippines found evidence supporting a causal link between nutrition and academic success in preschool children, advising a dollar invested in an early childhood nutrition program could return at least three dollars worth of gains in academic achievement [60]. In a two-year longitudinal US nutrition study of children who received nutritional supplements (974 experiment group, 199 in control gro;up) children attending the intervention schools, regardless of ethnic background, were significantly more likely to perform better at maths, and although not statistically significant, a similar trend was found for reading [61]. Therefore, it is important to note that as well as the PA intervention, subjects in this study were also given education about healthy eating. Their dietary habits were monitored by parents completing a proxy diet questionnaire.

3.5. Data analysis

This thesis comprises two separate but related studies, each of which demands its own specific analysis technique. The literature review showed that a relationship between PA and cognition has been established but there is uncertainty exactly how they interact. For the first study exploring relationships, a structured equation modelling (SEM) approach was used. The advantage of using SEM is that it can consider mediating effects between variables and more than just direct relationships and has robust multi-group analysis function to consider relationships and patterns for different subgroups of subjects. The second study explored causal relationships between PA and cognition using a generalised linear mixed model (GLMM) approach. A GLMM method considers change over time so was used to assess differences in the data recorded at T_0, T_1, and T_2. Identifying change over time is necessary to determine cause-and-effect relationships between PA and cognition. GLMM is also able to adjust for random factors such as school clustering. Further detail about each methodological approach was given in each of the individual chapters.

Chapter 4: Study 1 - Physical activity, cognition and academic performance: an analysis of mediating and confounding relationships in primary school children.

ABSTRACT

Background: Exploring the relationship between physical activity, cognition and academic performance in children is an important but developing academic field. One of the key tasks for researchers is explaining how the three factors interact. The aim of this study was to develop and test a conceptual model that explains the associations among physical activity, cognition, academic performance, and potential mediating factors in children.

Methods: Data were sourced from 601 New Zealand children aged 6-11 years. Weekday home, weekday school, and weekend physical activity was measured by multiple pedometer step readings, cognition by four measures from the CNS Vital Signs assessment, and academic performance from the New Zealand Ministry of Education electronic Assessment Tools for Teaching and Learning (e-asTTle) reading and maths scores. A Structured Equation Modelling approach was used to test two models of variable relationships. The first model analysed the physical activity-academic performance relationship, and the second model added cognition to determine the mediating effect of cognition on the physical activity-academic performance association. Multigroup analysis was used to consider confounding effects of sex, ethnicity and school socioeconomic decile status.

Results: The initial model identified a significant association between physical activity and academic performance ($r = 0.225$). This direct association weakened ($r = 0.121$) when cognition was included in the model, demonstrating a partial mediating effect of cognition. While cognition was strongly associated with academic performance ($r = 0.750$), physical activity was also associated with cognition ($r = 0.138$). Subgroups showed similar patterns to the full sample, but the smaller group sizes limited the strength of the conclusions.

Conclusions: This cross-sectional study demonstrates a direct association between physical activity and academic performance. Furthermore, and importantly, this study shows the relationship between physical activity and academic performance is supported by an independent relationship between physical activity and cognition. Larger sample sizes are needed to investigate confounding factors of sex, age, socioeconomic status, and ethnicity.

Future longitudinal analyses could investigate whether increases in physical activity can improve both cognition and academic performance.

Keywords: Physical activity, cognition, academic performance, school, children, mediation, SEM, multigroup analysis.

4.1 Background

Over the course of the last century, a multidisciplinary field of knowledge has developed that has identified several cognitive and academic benefits of regular physical activity (PA) [1, 2, 16-19, 25]. The idea that PA can enhance cognitive and academic ability has consequently received significant attention in health and education fields [22-24]. It is recognised that PA triggers change in the human brain due to increases in metabolism, oxygenation and blood flow providing hormones that promote neurological health [20, 32]. Those changes are particularly important for the developing paediatric brain [20, 23]. Researchers are now clarifying how relationships between PA and cognition interact to guide the best way forward to promote neurological, cognitive and academic benefits for children.

Sibley and Etnier completed a meta-analysis of 44 studies into the relationship between PA and cognitive abilities [2]. They found all included studies reported significant and positive effects of PA within physical education (PE) and cognition in youth, regardless of the study design and type of PA [2]. The greatest effects were seen with perceptual skills and academic readiness tests [2]. A review of 17 studies by Trudeau and Shepherd on the impact of PA on academic performance of children in primary and secondary school also found positive relationships between PA and school results [25]. Combined analysis of the seven quasi-experimental studies showed that the enriched PE programmes demanded a substantial reduction in the time allocated for academic tuition but academically children achieved at least equally despite the reduced teaching time [25]. Ten cross-sectional studies showed positive association between PA and academic performance [25]. Despite concurrence about a positive relationship between PA and cognition, both reviews note limitations due to the small number of true experimental studies and by potential confounding variables. For example, Sibley and Etnier found 57 different methods of cognitive assessment used by investigators, many with poor or unknown psychometric properties [2]. In another meta-analysis, Hillman et al, completed a review of 14 studies examining PA and neuroelectric concomitants of cognition during childhood [1]. They found PA and cardiovascular fitness have short and medium-term benefits for neurocognitive performance in youth [1]. The studies used laboratory measures to measure neurological activity on subjects performing a range of cognitive tasks and formal assessments. They found increased fitness and PA improve cognitive function and brain health, with higher-fit children demonstrating attributes such as greater attention, faster information processing, and higher scores in standardised achievement tests. Only one study which provided neutral findings did not show any improvement in cognitive function.

Furthermore, two detailed studies from 2016 provide strong support for the relationship PA has with cognition and academic performance [44, 62]. For the Copenhagen Consensus, 24 researchers from eight countries met to reach an evidence-based consensus on the effects of PA on children and youths aged 6-18 years [43]. The authors concur that PA and cardiorespiratory fitness are beneficial to brain structure, brain function and cognition in children and youth [43]. They advise that PA before, during and after school promotes scholastic performance in children and youth, with even a single session of moderate PA having an acute benefit to brain function, cognition and scholastic performance [43]. In the other study, eight key researchers in the PA-cognition field started from a database of 6237 articles and identified 137 key articles to consider [44]. The review focused on two specific questions: Among children age 5–13 years, do PA and physical fitness influence cognition, learning, brain structure, and brain function? And among children age 5–13 years, do PA, PE, and sports programs influence standardized achievement test performance and concentration/attention? They found promising results showing relations among PA, cognition, brain structure, and brain function, with no negative effects on children. The 26 cross-sectional and cohort-based studies involving PA provided positive support for the relationship between PA and cognitive function, with greater amounts or enhanced forms of PA being associated with greater improvements in cognitive function [44]. For the second question, the authors stated the studies of acute PA interventions had mixed results, likely owing to the differences in tasks administered, the nature of the task, and the type of PA [44]. However, authors advise a number of methodological weaknesses including a lack of information about estimates of random variability in the outcome data, information about the time of day at which the cognitive measures were assessed was not provided, varying and inconsistent measures of fitness and academic performance, and poor control of confounders. They particularly noted many studies did not give statistical power of the findings, including 95% of the studies relating to the second question [44].

The analyses above show that excellent research has established that PA is associated with both cognition and academic performance for children. However, few studies have investigated how the three areas of PA, cognition and academic performance interact. Does a relationship between PA and cognition necessarily lead to better academic performance? Does an independent relationship between PA and academic performance relationship exist, or does it act through cognition? Is the PA-cognition-academic performance relationship the same for different groups of children? Specifically, does the relationship between PA and academic performance remain once cognition is accounted for? Therefore, the aim of this study is to develop and test a conceptual model that explains the cross-sectional associations among PA, cognition and academic performance in children aged 7-10 years.

4.2 Methods

Participants

A total of 675 participants (326 male, 349 female) were part of an eight-week randomised controlled trial: *Healthy Homework* was a curriculum-based, classwork and homework schedule designed to promote PA and healthy eating [49]. This study analyses data collected from participants at baseline, prior to receiving any intervention. Eligibility criteria for the schools were as follows: a school with more than 100 students, location within Auckland or Dunedin cities, and a contributing, full primary, or composite structure that included at least one class each of students in school years 3-5. A total of 16 primary schools from Auckland (n = 10) and Dunedin (n = 6) were selected to participate in the study. Socioeconomic decile ratings of participating schools ranged from 3 to 10 (median [IQR] = 8 [6, 9]). Decile is a New Zealand Ministry of Education rating system for school funding based on SES with 1 being low and 10 being high. Decile reflects the extent to which the school draws their students from low socio-economic communities, rather than the SES mix of the school or individual students. For example, low decile schools have the highest proportion of students from low socio-economic communities. Students were selected to participate from one Year 3, one Year 4, and one Year 5 class from each school; simple random sampling was used in instances where there were two or more classes per year. Written parental consent and student assent were obtained for children to participate in the study. Ethical approval was obtained from the Auckland University of Technology Ethics Committee (10/159).

Measures

Demographic information was obtained from the school records and included sex, age, school, ethnicity and socioeconomic decile. All demographic variables were partitioned into groups: Decile (Low 1-5, Mid 6-8, and High 9-10); School year (Year 3, Year 4, and Year 5); and Ethnicity (New Zealand European and Non-New Zealand European). Ideally, socioeconomic decile groupings would be 1-3, 4-7, and 8-10, and a greater range of specific ethnic groups would be analysed, but the total numbers for lower socioeconomic decile students and non New Zealand European ethnic groups were too small for multi-group analysis to be completed (Table 4).

PA was assessed using sealed NL-1000 pedometers (New Lifestyles Inc, Lee's Summit, MO) over five consecutive days (three weekdays, two weekend days). NL-1000 pedometers have a multiday memory function that automatically stores step counts by day of week for up to seven days. Previous research has established the validity of these pedometers for measuring steps in children [63]. Two pedometers were assigned to each child: one clearly labelled 'School' and the other 'Home'. The 'School' pedometer was worn during school hours, while the 'Home' pedometer was left inside a collection tray in the classroom. At the conclusion of the school day, each child placed their 'School' pedometer in the tray and attached their 'Home' pedometer. Upon arrival at school the next day, the teacher reminded the children to switch over their pedometers again. This resulted in three measures of PA: average weekday steps at home, average weekday steps at school, and average steps at weekend.

The cognitive abilities of children were measured using CNS Vital Signs (CNSVS): a standardised cognitive screen assessment suitable for participants aged 7-90 years [54]. CNSVS is a web-based assessment battery with seven tests that are scored individually and combined to give scores in nine different areas. Four of the nine CNSVS measures were considered for this study: Composite Memory (recognize, remember, and retrieve words and geometric figures), Executive Function (recognize rules, categories, and manage or navigate rapid decision making), Psychomotor Speed (perceive, attend, respond to complex visual-perceptual information and perform simple fine motor coordination), and Reaction Time (react, in milliseconds, to a simple and increasingly complex direction set) [55]. The other domains could not be used because of the difficulty in administering the Complex

Attention Test, and the four remaining domains used combinations of the same base assessment.

Academic performance was measured using the NZ Ministry of Education electronic Assessment Tools for Teaching and Learning (e-asTTle). The e-asTTle assessments have more than 2000 curriculum based assessment items standardised on over 50,000 students covering curriculum levels 2—4 to assess student's achievement and progress in reading, writing and mathematics and the Maori equivalents of panui, tuhituhi, and pangarau [56, 57, 64, 65]. Assessments can be completed at any time during the school year. Measures are norm-referenced and used to evaluate children's progress through the school year [57]. Regardless of items present in a test, e-asTTle can be used to compare progress and performance within students and between students to that of national norms and curriculum achievement objectives and levels [64]. Teachers create their own multi-choice assessment as the e-asTTle software generates a test that selects the best set of items meeting the teacher's content and difficulty constraints [64]. For this study, testing was completed only for reading and maths, with 12 questions for each subject to be completed within 10 minutes. Thus, raw scores ranged from 0-12. The e-asTTle software converts raw scores into measures that align with a child's curricular needs [64]. Raw scores were sufficient for the current analyses because they give a measure of academic performance for students in relation to peers of the same school year. For the purpose of this research, a research team conducted both the reading and maths assessments, which were done using pen and paper with a time limit. Researchers marked total scores, and results were entered into a computer by research assistants.

For each school, CNSVS and e-asTTle baseline measures were collected by a team of researchers on one day. Pedometers were issued to children and height and weight measures taken on a separate day within a month by trained researchers. CNSVS assessment was completed before the e-asTTle test, with at least 30 minutes between the two. The CNSVS assessment was conducted in groups using school computer facilities or libraries and assisted by at least three researchers. Group sizes and types of computers depended on the facilities and computers provided by the school. Researchers introduced the test beforehand while instructions for each test appeared on the screen before each test started. Researchers were available for the children in case they did not understand the instructions or if children clicked it away too quickly. CNSVS was introduced for the research purposes and is not part of routine school assessment practice.

The e-asTTle assessments were introduced and explained by the researchers. While the attitude questions were read out by the researchers, waiting for all children to go through them and ensuring that they understand them, the reading test was then conducted before the math test with a time limit of ten minutes. The e-asTTle assessment is part of normal school assessment procedures undertaken throughout the academic year.

Statistical Analysis

All variables were checked for normality, skewness and outliers. The distribution of the CNSVS composite memory item was skewed positively, but that reflects what is to be expected in the general population thus data were not transformed [54]. The other CNSVS measures were normally distributed. The two e-asTTle and three pedometer variables were normally distributed with no problematic outliers.

To analyse the data, this study used Structured Equation Modelling (SEM). SEM is appropriate to test and analyse this multifaceted field as it is able to consider individual and total relationships between variables and their mediating effects. Further, it has a robust multi-group analysis process to assess model fit for subgroups to ensure valid interpretation of between group differences. Analysis was completed using bias-corrected bootstrapping (200 samples) for 95% confidence intervals."

The extent of missing values was assessed on the full study cohort. Trial analyses were completed on four different datasets to ascertain any differences in analysis: Dataset A (data for at least 5/9 variables present with Expectation Maximisation (EM) imputed missing values, N=601); Dataset B (data for all variables present, N=202); Dataset C (data for at least 7/9 variables present); Dataset D (data for at least 5/9 variables present using FIML analysis, N=601). Results from those analyses are shown in Appendix 2. To minimize loss of data, subjects with data for at least five of the nine variables included in the model were retained (Dataset A). That reduced the study cohort from 675 to 601. The IBM SPSS Missing Value Analysis (MVA) was performed on the 601 participants with the EM method specified to generate a data set with imputed values for Structural Equation Modelling (SEM). Dataset A was chosen over Dataset D because analyses for all subjects in the overall model were comparable, but the imputed missing values from the EM process were required for later multigroup analysis. Based on inspection of missing data patterns and EM data imputation, data are assumed to be missing at random (MAR). Preliminary descriptive statistics were obtained for the subjects and bivariate analyses completed to screen for relationships between variables. Prior to completing an SEM analysis, a confirmatory factor analysis (CFA) was completed on the individual latent variables: PA, cognition and academic performance. The cognition latent variable demonstrated its four measured indicators provided a good fit with the data (x2 (2) = 3.31, p=0.191, RMSEA = 0.033, TLI = 0.988). The CFA model for PA and academic performance was unidentifiable due to correlated error terms in the three pedometer step indicators and two e-asTTle indicators respectively.

The hypothesized models are in Figure 1 and Figure 2. Circles represent latent variables, and rectangles represent measured variables. The hypothesized models examined the strength of association between PA, Cognition and academic performance. Academic performance was considered a latent variable with two indicators: (asTTle maths and reading scores). It was hypothesized that PA (a latent variable with three indicators: mean weekday steps home, mean weekday steps school, and mean weekend steps) was associated with higher levels of academic performance (Model 1, Figure 1). Additionally, it was hypothesized that Cognition would mediate the strength of association between PA and academic performance (Model 2, Figure 2). Cognition was a latent variable with four indicators (CNSVS Composite Memory, Executive Function, Psychomotor Speed, and Reaction Time).

4.3 Results

4.3.1 Assumptions

Data for 601 students (49.8% male) aged 6.5-10.8 years residing in New Zealand were available for analyses (Table 4). Overall, bivariate analyses demonstrate consistent small to medium significant relationships between the areas of cognition and academic performance of participants, and pedometer steps showed trivial relationships with cognition and academic performance variables (Appendix 1).

Table 4. Study 1: Descriptive statistics of 601 subjects used in analyses.

Age									
	Male			**Female**			**Total**		
	N	M + SD	Min + Max	N	M + SD	Min + Max	N	M + SD	Min + Max
School Year 3	91	7.74 ±0.548	6.78, 8.75	96	7.65 ± 0.661	6.48, 9.25	187	7.69 ± 0.609	6.48, 9.25
School Year 4	103	8.68 ± 0.598	7.60, 9.86	105	8.76 ± 0.593	7.61, 9.89	208	8.72 ± 0.595	7.60, 9.89
School Year 5	106	9.62 ± 0.521	8.11, 10.8	100	9.77 ± 0.537	8.75, 10.8	206	9.70 ± 0.534	8.11, 10.8
Total	300	8.73 ± 0.942	6.78, 10.8	301	8.74 ± 1.05	6.48, 10.8	601	8.74 ± 0.995	6.48, 10.8

Ethnicity			
	Male (n=300)	**Female (n=301)**	**TOTAL (n=601)**
Maori	17 (5.7%)	22 (7.3%)	39 (%6.5)
Pacific Island	12 (4%)	13 (4.3%)	25 (4.2%)
Asian	34 (11.3%)	65 (21.6%)	99 (16.5%)
Other	8 (2.7%)	11 (3.7%)	19 (3.2%)
NZ European	229 (76.3%)	190 (63.1%)	419 (69.7%)
Total	**300 (100%)**	**301 (100%)**	**601 (100%)**
Decile			
Decile 3	23 (7.7%)	18 (6.0%)	41 (6.8%)
Decile 4	7 (2.3%)	13 (4.3%)	20 (3.3%)
Decile 5	14 (4.7%)	33 (11.0%)	47 (7.8%)
Decile 6	42 (14.0%)	47 (15.6%)	89 (14.8%)
Decile 7	44 (14.7%)	44 (14.6%)	88 (14.6%)
Decile 8	61 (20/3%)	46 (15.3%)	107 (17.8%)
Decile 9	46 (15.3%)	38 (12.6%)	84 (14.0%)
Decile 10	63 (21.0%)	62 (20.6%)	125 (20.8%)
Total	**300 (100%)**	**301 (100%)**	**601 (100%)**
School year			
Year 3	91 (30.3%)	96 (31.9%)	187 (31.1%)
Year 4	103 (34.3%)	105 (34.9%)	208 (34.6%)
Year 5	106 (35.3%)	100 (33.2%)	206 (34.3%)
Total	**300 (100%)**	**301 (100%)**	**601 (100%)**

4.3.2 Structured Equation Modelling

Although the chi-square fit statistic for Model 1 was significant, other indicators of model fit supported good fit with the data (χ^2 (4) = 13.5, *p* = 0.009, RMSEA = 0.063, CFI = 0.983, TLI = 0.958, PNFI = 0.391). Greater academic performance was marginally associated with higher levels of PA (standardised coefficient = 0.225, *p* <0.001) (Table 5.). The model accounted for 5.1% variance in academic performance. The final Model 1 with standardized coefficients is in Figure 1.

Table 5. Significance outputs and 95% bias-corrected confidence intervals from SEM models.

	Sample Size	Model 1				Model 2											
		PA-AP: Direct				PA-AP: Direct				PA-Cognition: Indirect				Cognition-AP			
		B	LCL	UCL	*P*	β	LCL	UCL	*P*	β	LCL	UCL	*P*	B	LCL	UCL	*P*
Full sample	601	.225	.129	.310	< .01	.121	.008	.197	< .05	.138	.010	.274	< .05	.750	.659	.828	< .05
Male	300	.191	.044	.355	< .05	.087	-.037	.231	.181	.163	-.094	.352	.181	.716	.600	.856	< .01
Female	301	.277	.120	.460	< .01	.169	.055	.338	< .05	.147	-.046	.317	.096	.778	.664	.906	< .01
NZEuro	419	.214	.100	.352	< .01	.083	-.039	.187	.243	.177	.022	.321	< .05	.730	.620	.835	< .05
NonNZEuro	182	.189	.000	.335	.071	.179	-.002	.340	.052	.049	-.233	.272	.752	.818	.649	.939	< .05
Decile 1-5	108	.351	.086	.554	< .05	-.018	-.970	.287	.909	.398	-.076	.718	.069	.869	.521	1.496	.094
Decile 6-8	284	.146	-.094	.278	.222	.152	-.019	.278	.071	-.011	-.193	.167	.977	.706	.552	.826	< .05
Decile 9-10	209	.198	.060	.338	< .05	.009	-.156	.182	.730	.253	.032	.448	< .05	.813	.000	.920	.056

Note: PA=Physical Activity; academic performance=Academic Performance; NZEuro=New Zealand European ethnicity; NonNZEuro=Non New Zealand European ethnicity; β = s;tandardised coefficient; LCL= lower 95% confidence limit, UCL = upper 95% confidence limit using bias-corrected bootstrapping

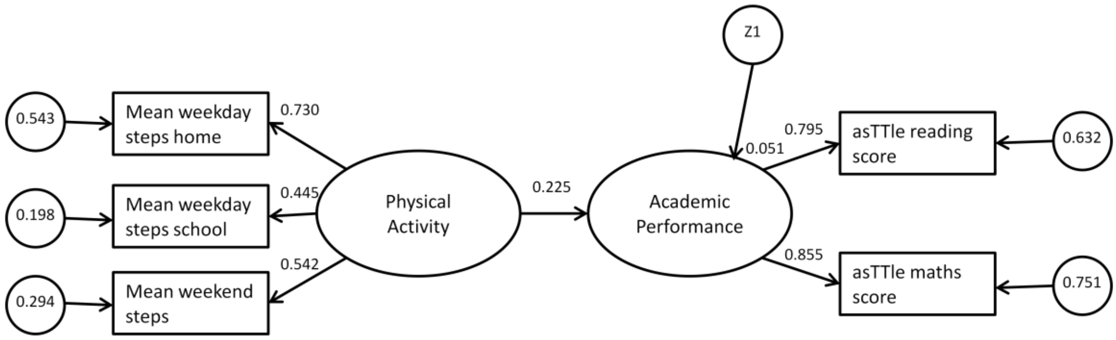

Figure 1. Two variable model explaining the relationship between Physical Activity and Academic Performance. Structured Equation Model explaining the relationship between physical activity, and academic performance (Model 1), χ^2 (4) = 13.5, *p* = .009, RMSEA = 0.063, CFI = 0.983, TLI = 0.958, PNFI = 0.391.

Model 2 tests the hypothesis that some of the PA-academic performance relationship is mediated by cognition (Fig. 2). Similarly, the chi-square statistic for Model 2 was significant but other model fit indicators support good fit with the data (χ^2 (24) = 67.582, p = .000, RMSEA = .055, CFI = .963, TLI = .944, PNFI = .628). The indirect association of PA on academic performance is shown in the PA–cognition pathway (standardised coefficient = 0 .138, $p < 0.05$). The total relationship between PA and academic performance is gained by adding the relationships PA-academic performance and PA-cognition (0.259). Over half (60.2%) of the variance in academic performance was accounted for by PA and cognition.

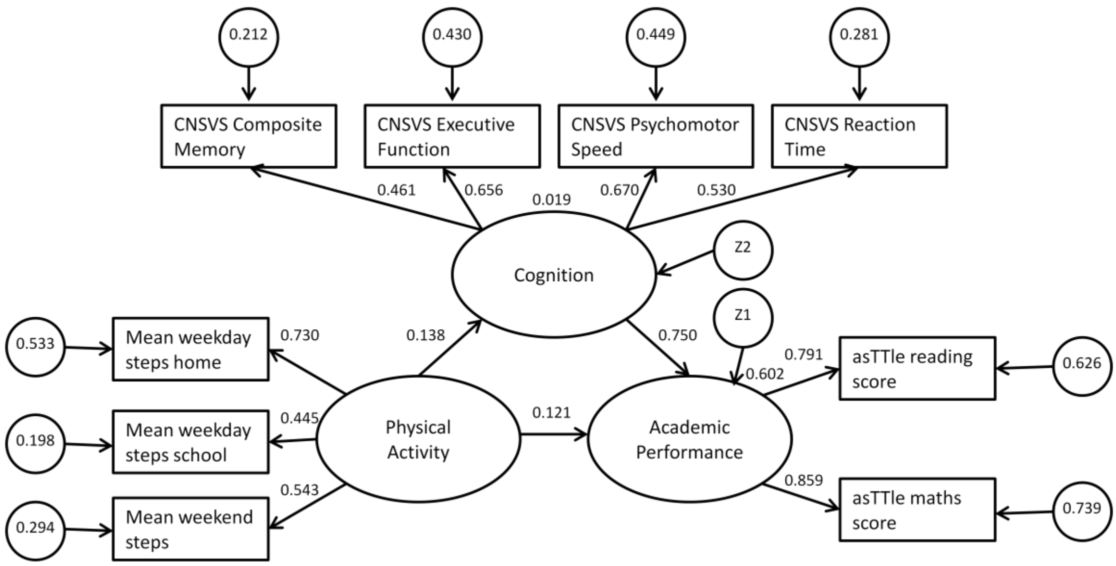

Figure 2. Three variable model explaining the relationships between Physical Activity, Cognition and Academic Performance. Structured Equation Model explaining the relationship between PA, cognition and academic achievement (Model 2), χ^2 (24) = 67.6, *p* = .000, RMSEA = 0.055, CFI = 0.963, TLI = 0.944, PNFI = 0.628

4.3.3 Structured Equation Modelling – subgroup analyses

For sex, measurement invariance testing revealed a lack of equivalence for the scalar and residual models for Model 1. However, Model 2 achieved appropriate fit. Model 2 shows that higher levels of PA was not significantly associated with greater academic performance in boys (standardised coefficient = 0.087, *p* =0.222). Model 2 shows a significant small direct relationship between PA and academic performance for girls (standardised coefficient = 0.169, $p < 0.05$). For age grouping by school year, no analysis was able to be completed. Both Model 1 and Model 2 had acceptable fit indices for the configural and metric models, but the scalar and residual model fit indices were significantly lower. As such, the Models are not equivalent for different age groups and group comparison cannot be made [66].

Model fit data for the multigroup analysis is shown in Appendix 3. Model fit indices for the two ethnic groups for both models were adequate across all four tests of measurement invariance. Thus, model fit is supported for comparison between ethnic groups. For New Zealand European students, Model 1 showed greater academic performance was marginally associated with higher levels of PA (standardised coefficient = 0.214, $p < .01$). Similar relationships, although not significant, were shown for non-New Zealand European students (standardised coefficient =0.189, $p = 0.225$). Model 2 shows for New Zealand European students, PA was not associated with academic performance (standardised coefficient = 0.083, $p = 0.171$). However, PA was associated with cognition (standardised coefficient = 0.177, $p < 0.05$). None of the PA pathways in Model 2 were significant for non-New Zealand European students (Table 5).

For socioeconomic decile groupings, model fit indices for both models were adequate across all four tests of measurement invariance. For students from low socioeconomic decile schools, Model 1 showed a moderate significant relationship between PA and academic performance (standardised coefficient = 0.351, $p < 0.05$ and standardised coefficient = 0.198, $p < 0.05$, respectively). The relationship was not significant for students in the mid socioeconomic decile schools (standardised coefficient = 0.146, $p = 0.167$). For students from low socioeconomic decile schools, Model 2 showed no significant relationship between PA and academic performance (standardised coefficient = 0.018, $p = 0.909$), or between PA and cognition (standardised coefficient = 0.398, $p = 0.141$). For students from mid socioeconomic decile schools, Model 2 shows a small significant relationship between PA and academic performance (standardised coefficient = 0.152, $p <0.05$), but not between PA and cognition (standardised coefficient = -0.011, $p = 0.904$). Lastly, students from high socioeconomic decile schools showed no significant relationship between PA and academic performance in Model 2 (standardised coefficient = 0.009, $p = 0.887$); however, there was a small significant relationship between PA and cognition (standardised coefficient = 0.253, $p < 0.01$).

4.4 Discussion

One of the key outstanding questions in the PA-cognition-academic performance relationship is whether the association between PA and academic performance relationship is independent or if it is mediated by cognitive ability. This study explains three aspects to the relationships: (1) the individual relationships PA has with cognition and academic performance; (2) the mediating effect of cognition on the PA-academic performance relationship; and (3) the overall relationship between PA, cognition and academic performance.

This cross-sectional study supports the growing body of research showing consistent positive relationships between PA and cognition [1, 17, 44], and between PA and academic performance [25, 35, 39]. A key focus of this study was to examine those relationships further, to determine whether the association between PA and academic performance remained after considering cognition. As hypothesized for the full sample, cognition was shown to reduce the strength of association between PA and academic performance. Further, the mediating effect of cognition on the association between PA and academic performance is only partial as a small significant relationship between PA and academic performance remained. Additionally, when considering the positive association between PA and cognition, the total association between PA and academic performance is greater in Model 2 than Model 1.

The present findings differ from a similar model tested by van der Niet et al, that characterised the relationship between physical fitness, executive functioning and academic achievement in 263 children (145 boys, 118 girls) aged 7-12 years in the Netherlands [67]. In their two-variable model of physical fitness and academic achievement, the relationship was slightly greater than the equivalent PA-academic performance relationship for Model 1 in this study. When adding executive functioning to their model, they also found a stronger relationship in the physical fitness-executive functioning than PA-cognition for Model 2 in this study. However, the main difference was in considering mediating effects. By adding executive functioning, the physical fitness-academic achievement relationship dropped completely, showing a complete mediating effect of executive functioning [67]. Model 2 in this study, however, only found a partial mediating effect of cognition. In other words, van der Niet et al, found that executive functioning explained all of the variance in academic achievement, whereas the present study identified PA and cognition had independent relationships with academic performance. The differences between the two studies may be due to a number of factors including indicator measures used in assessment and participant differences. The key for both studies is they further help explain essential considerations in the PA cognition field by demonstrating the different level executive functioning and cognition affect the PA-academic performance relationship and the importance of considering independent and mediating effects of variables.

The present study also considered whether the hypothesised models were equivalent for demographic sub-groups (sex, age, ethnicity and school socioeconomic decile). However, due to small sub-group sample sizes, a lack of statistically significant results across the multigroup analyses precludes robust conclusions across all groups. Research in larger samples may improve the power to detect differences between groups. Previous research has shown that the relationships between PA, cognition and academic performance may differ by sex. For example, in a retrospective analysis of 5316 children, Carlson et al, found that girls in a high activity group performed better academically than those in medium and low activity groups [33]. No differences between groups were noted for boys [33]. Other studies have identified PA-cognition and PA-academic performance relationships for children of many different ethnic origins including US [33], Dutch [67], French [24], Australian [38], and Taiwanese [37], but none were identified that consider differences in the relationship on the basis of ethnicity. SES or school socioeconomic decile is the last confounding variable this study considered. Although SES is recognised as one of the main influences on children's academic success [25, 35, 58], none of the papers reviewed for this study were shown to adjust or consider for SES. Also, this study's use of a school-level socioeconomic decile as a measure of SES may not fully elucidate the effect of this confounding indicator. Future studies should incorporate the two important confounders of an individual-level SES indicator and the educational level of parents.

The measures used in this study have potential limitations. Pedometers give a valid and reliable indicator of overall volume of physical activity and have been used widely among student populations [63], but do not consider the intensity of the steps or time of day. High intensity aerobic activity and activity immediately prior cognitive assessment have been linked to greater cognitive function and academic performance [1, 17, 22]. Furthermore, pedometers do not monitor other aspects of fitness that have been linked to cognitive function such as acute effects of activity, cardiorespiratory fitness, resistance exercise, or combinations of exercise and activity [22, 35, 37]. Similarly, the two e-asTTle measures are well researched and robust, but additional school-based assessments such as writing could provide greater insights to children's academic performance. Although CNSVS showed consistent strong relationships between its different measures and with academic measures both at bivariate and SEM analysis stages, the CNSVS measures used in this study do not consider all areas of cognition. Students were not familiar with the CNSVS assessment and thus results may reflect this unfamiliarity rather than difficulty with the cognitive demands and content. Differences in PA, cognition and academic performance due to age is an important potentially confounding factor for analysis [20, 22]. Accordingly, this study aimed to analyse children by school year. However, the school year multigroup analysis was not able to proceed due to a lack of measurement equivalence. Also, classroom behaviour is also shown to have a strong influence on a child's cognition and academic performance [24, 25, 38, 39]. Initially behaviour was considered for the model, however the behaviour indicator variables had a high degree of missing values and were thus removed from the model. A final limitation is that while this study concludes a positive association between PA and cognition, and PA and academic performance, it cannot ascribe direction in those relationships. Although the theoretical assumption is that increased PA leads to better cognition and academic performance as indicated in the models, bidirectional relationships are possible, and high levels of cognition and academic performance may lead to increased PA. One of the key questions in the PA/cognition field is: are smart children active or does being active make children smart? Future studies need to ensure enough participants to enable subgroup analysis to consider confounding factors. Furthermore, longitudinal research is needed to examine PA, cognitive and academic changes over time which will provide clearer understanding to possible causal relationships.

4.5 Conclusions

This study showed a positive association between PA and academic performance for the whole study cohort. Importantly, this study further showed that relationship remains when considering the mediating effect of cognition. Thus, the model tested identified PA is associated with academic performance directly and indirectly through cognition. Studies with larger sample sizes are needed to investigate important confounding factors such as sex, age, SES and ethnicity.

4.6 List of abbreviations

CFA: Confirmatory Factor Analysis

CFI: Comparative Fit Index

CNSVS: CNS Vital Signs

EM: Estimation maximization

MAR: Missing at random

MCAR: Missing completely at random

MNAR: Missing not at random

MVA: Missing values analysis

NonNZEuro: Non-New Zealand European Ethnicity

NZEuro: New Zealand European ethnicity

PA: Physical Activity

PE: Physical education

PNFI: Parsimonious Normed Fit Index

RMSEA: Root mean square error of approximation

SEM: Structured Equation Modelling

SES: Socio-economic status

TLI: Tucker-Lewis Index

Chapter 5: Study 2 – Does exercise make kids smart: a six month longitudinal study.

ABSTRACT

Background: The relationship between physical activity, cognition and academic performance in children is an important but developing academic field. Identifying causal relationships is a key task for researchers. Do smart kids exercise, or does exercise make them smart? The aim of this study was to develop and test a conceptual model that explains causal relationships between physical activity, cognition and academic performance in primary school children.

Methods: Data were sourced from 675 New Zealand children aged 6-11 years. Weekday home, weekday school, and weekend physical activity was measured by multiple pedometer step readings, cognition by four measures from the CNS Vital Signs assessment, and academic performance from the New Zealand Ministry of Education Assessment Tools for Teaching and Learning (asTTle) reading and maths scores. Measures were taken at baseline, eight week, and six month intervals. Data were analysed for 613 students identified with data for at least 14 of the 27 variables. A generalised linear mixed model analysis was used to measure changes in physical activity, cognition and academic performance over those three time periods to identify causal relationships. Confounding effects of sex, school year, and the socioeconomic decile of the school were considered.

Results: No significant relationships were identified for three of the cognitive domains. However, significant, positive relationships were observed between physical activity change at two-months and executive functioning change at six-months (0.043), reading change at six-months (0.032), and maths change at two-months (0.031). Regression coefficients indicate that a 100% increase in physical activity after two months could affect a 5.9% improvement in executive functioning and reading at six-months and 4.8% improvement in maths at two-months. Results were adjusted for age, sex and school socioeconomic decile.

Conclusions: This six-month longitudinal analysis identified increase physical activity led to small but significant improvements in executive functioning, reading, and maths. The small associations suggest that substantial improvements in PA would be required to generate meaningful improvements in cognition and academic achievement. Suggestions are made for further research into the long-term effects of PA on brain function on children advising considerations for suitable measures of PA, cognition and academic achievement. Further, timeframes longer than six-months are recommended to identify long-term changes.

Keywords: Physical activity, cognition, academic performance, school, children, causation.

5.1 Background

High levels of physical activity (PA) have been linked with cognitive benefits, positive behavioural traits, and academic performance in school children[1, 16-19]. Cross-sectional studies show consistent relationships between PA and cognition [17, 20, 22]. Similar relationships have been identified in school settings between PA and academic performance [22, 35-37, 68]. Such cross-sectional studies have identified positive relationships PA has with cognition and academic performance, but they cannot identify causation. Similarly, our previous study demonstrated PA has independent relationships with cognition and academic performance but could not ascribe causation [68]. Now we need to answer the key question: Do smart children exercise, or does exercise make children smart? To determine causation, changes in subjects' performance and abilities need to be measured over time.

Findings of five key longitudinal studies are detailed below. The Vanves study was completed in 1950 in Vanves, Paris, France [24]. Academic instruction was reduced by 26%, with a range of interventions added including PA in afternoons, but children were calmer, more attentive, and school results were comparable to other schools [24]. A South Australian study investigating the impact of increased PA on physical health of more than 500 children 10-years-old over 14 weeks [38]. Children were assigned to three groups: an endurance fitness programme 1 ¼ hours per day, a skill programme, and existing physical education programme, and assessed two years later [38]. The study found no evidence of loss in reading and arithmetic ability despite the loss of 45-60 minutes formal teaching [38]. The Trois Rivieres study analysed the effect of one hour extra PE for students taught by a specialist PE teacher over a six year period [39]. The control group received 13-15% more academic instruction than the experiment group. In the first year, the control group had higher average grades, but in Grades 2-6, the experiment group had higher grades, significantly in years 2, 3, 5, and 6 [39]. A secondary analysis of the 'The Early Childhood Longitudinal Study (ECLS), Kindergarten Class of 1998 to 1999' comparing children in low, medium and high activity groups also found girls in the high activity group had a small benefit in mathematics and reading, but there was no positive or negative association for boys [33]. In the last longitudinal study considered, Physical Activity Across the Curriculum (PAAC) was a 3-year cluster randomized controlled trial in 24 elementary schools in Kansas, USA, with a primary focus of decreasing BMI and improving physical health of students and a secondary aim to assess changes in academic achievement [18]. The experiment classes engaged in 90 minutes additional PA per week and were found to score significantly better than the control group for reading, writing, mathematics and oral language skills [18].

These longitudinal studies show PA likely has causal links with cognition, but each study has shortcomings that limit conclusions on causation. It is difficult to generalise the Vanves findings because experimental sample was small, it is not clear how the control group was matched in terms of size and SES, and the treatment included more than just PA [24]. The Australian study was focussing on physical health and not designed to assess academic performance in detail. The ECLS study found differences between boys and girls [33], but none of the other studies consider sex effects. SES is recognised as one of the main influences on children's academic success [25, 35, 58], but none of the papers adjust for SES.

Furthermore, the importance of appropriate measures and methodology to understand the PA, cognition, academic performance relationship was identified in a thorough 2016 meta-analyses by Donnelly et al [44]. The authors started from 6,237 articles but using the Downs and Black checklist that considers methodology rigor [45], only identified 137 articles suitable to consider [44]. The 27-point Downs and Black checklist considers methodological strengths including validity characteristics, clarity of hypothesis and outcome measure details, participant compliance, and study power [45]. The review found PA has a positive influence on cognitive function as well as brain structure and function but noted limitations on conclusions due to weaknesses including a lack of information about estimates of random variability in the outcome data, statistical power not being stated, larger sample sizes needed, and lack of randomised controlled trials [44]. They only identified two longitudinal studies that were robust enough to be considered in their review [44]. Particularly, they advise more research is necessary to establish causality, to determine mechanisms, and to investigate long-term effects [44]. Therefore, the aim of this study is to develop and test a conceptual model that explains causal relationships between PA, cognition, and academic performance over a six month longitudinal period for primary school children 7-10 years old.

5.2 Methods

Participants

A total of 675 participants (326 male, 349 female) were part of an eight-week randomised controlled trial: *Healthy Homework* was a curriculum-based, classwork and homework schedule designed to promote PA and healthy eating [50]. All measurements were taken at baseline (T_0), immediately post-intervention (T_1), and six-months post-intervention (T_2). The study comprised eight control and eight experimental schools. As this study is not to evaluate HH interventions or compare and contrast experiment and control groups, data from both groups were pooled for analysis. Eligibility criteria for the schools were as follows: a school with more than 100 students, location within Auckland or Dunedin cities, and a contributing, full primary, or composite structure that included at least one class each of students in school years 3-5. A total of 16 primary schools from Auckland (n = 10) and Dunedin (n = 6) were selected to participate in the study. Socioeconomic decile ratings of participating schools ranged from 3 to 10 (median [IQR] = 8 [6, 9]). Decile is a New Zealand Ministry of Education (MoE) socioeconomic rating system for school funding based on SES with 1 being low and 10 being high. Decile is a rating of the whole school, and not specific to individual students. It is common to have children from a range of SES within one school, with socioeconomic decile being an average representation of the school's surrounding area. Students were selected to participate from one Year 3, one Year 4, and one Year 5 class from each school; simple random sampling was used in instances where there were two or more classes per year. All children in each participating class were invited to take part in the evaluation (i.e., no formal inclusion or exclusion criteria). Written parental consent and assent was obtained for children to participate in the study. Ethical approval was obtained from the Auckland University of Technology Ethics Committee (10/159).

Measures

PA was assessed using sealed NL-1000 pedometers (New Lifestyles Inc, Lee's Summit, MO) over five consecutive days (three weekdays, two weekend days). Research has established the validity of these NL-1000 pedometers for measuring steps in children [63]. NL-1000 pedometers have a multiday memory that automatically categorizes data according to the day of the week which enables step count for weekdays and weekends to be collected [69]. Pedometers were used to gain three measures of PA: average weekday steps at home, average weekday steps at school, and average steps at weekend.

The cognitive abilities of children were measured using CNS Vital Signs (CNSVS): a standardised cognitive screen assessment suitable for participants aged 7-90 years [54]. CNSVS is a web-based assessment battery with seven tests that are scored individually and combined to give scores in nine different areas. Four of the nine CNSVS measures were considered for this study: Composite Memory (recognize, remember, and retrieve words and geometric figures), Executive Function (recognize rules, categories, and manage or navigate rapid decision making), Psychomotor Speed (perceive, attend, respond to complex visual-perceptual information and perform simple fine motor coordination), and Reaction Time (react, in milliseconds, to a simple and increasingly complex direction set) [55]. The other domains could not be used because of the difficulty in administering the Complex Attention Test, and the four remaining domains used combinations of the same base assessment.

Academic performance was measured using the MoE electronic Assessment Tools for Teaching and Learning (e-asTTle). The e-asTTle assessments have more than 2,000 curriculum-based assessment items standardised on over 50,000 students covering curriculum levels 2—4 to assess student's achievement and progress in reading, writing and mathematics and the Maori equivalents of panui, tuhituhi, and pangarau [56, 57, 64, 65]. Measures are norm-referenced and used to evaluate children's progress through the school year [57]. Teachers create their own multi-choice assessment as the e-asTTle software generates a test that selects the best set of items meeting the teacher's content and difficulty constraints [64]. For the purpose of this research, a research team conducted both the reading and maths assessments, which were done using pen and paper with a time limit. Researchers marked total scores (0-12), and results were entered into a computer by research assistants. Testing was completed within 10 minutes. The e-asTTle software converts raw scores into measures that align with a child's curricular needs [64]. Raw scores were sufficient for the current analyses because they give a measure of academic performance for students in relation to peers of the same school year. Demographic information was obtained from the school records and included sex, age, school, ethnicity and decile.

<u>Study Protocol</u>

Two pedometers were assigned to each child: one clearly labelled 'School' and the other 'Home'. The 'School' pedometer was worn during school hours, while the 'Home' pedometer was left inside; a collection tray in the classroom. At the end of the school day, each child placed their 'School' pedometer in the tray and attached their 'Home' pedometer. Upon arrival at school the next day, the teacher reminded the children to switch over their pedometers again. Pedometers were issued to children and height and weight measures taken on one a separate day within a month by trained researchers. For each school, CNSVS and e-asTTle baseline measures were collected by a team of researchers on one day. CNSVS assessment was completed before the e-asTTle test, with at least 30 minutes between the two. The CNSVS assessment was conducted in groups using school computer facilities or libraries and assisted by at least three researchers. Group sizes and types of computers depended on the facilities and computers provided by the school. Researchers introduced the test beforehand while each instruction for each test appeared on the screen before each test started. CNSVS was introduced for the research purposes and not part of routine school assessment practice. Thus, as it is not part of the students' normal education practice and procedures, they may have struggled with it being an unfamiliar task and not necessarily had difficulty with the cognitive demands and content. Researchers were available for the children in case they did not understand the instructions or if children clicked it away too quickly. The e-asTTle assessments were introduced and explained by the researchers. While the attitude questions were read out by the researchers, waiting for all children to go through them and ensuring that they understand them, the reading test was then conducted before the math test with a time limit of ten minutes. Students are used to e-asTTle assessments through the year as part of their normal school routines.

Statistical Analysis

All variables were checked for normality, skewness and outliers. Three students were identified to have special needs and removed from the analysis because the cognitive and academic measures are not specific enough to cater for their needs and abilities. The distribution of the CNSVS composite memory item was skewed positively, but that reflects what is to be expected in the general population thus data were not transformed [54]. The other CNSVS measures were normally distributed. The two asTTle variables were normally distributed with no problematic outliers. One problematic outlier was identified with weekday steps, and removed from the analysis.

The extent of missing values was assessed on the full study cohort. To minimize loss of data, subjects with data for at least 14 of the 27 variables included in the model were retained. That reduced the study sample from 675 to 613. A Missing Values Analysis (MVA) was completed on the Independent Variables (IVs) of the three pedometer step readings. Data were found to be Missing Completely at Random (MCAR) (Little's MCAR test: Chi-Square = 2035.014, DF = 2004, Sig. = .309). Expectation Maximization was then used to impute missing values for the IVs. An MVA was then completed on the Dependent Variables (DVs) of the four CNSVS measures and two asTTle measures. The DV data were not found to be MCAR (Little's MCAR test: Chi-Square = 3256.650, DF = 3046, Sig. = .004). Based on inspection of separate variance t-tests and missing DV data patterns, data are assumed to be missing at random (MAR). Missing data for CNSVS and asTTle measures is due to a child not being present in class when the test was being taken. EM was then used to impute missing values for the DV data. In a detailed study, Dong and Peng found as long as data are MAR, EM data imputation produced statistically significant results to $p<.001$ when removing 20%, 40% and 60% data from a complete dataset of 432 subjects [70].

Changes in the cognitive and academic outcome variables over the two-month and six-month periods were analysed using generalised linear mixed models (GLMMs). The GLMM analysis adjusted for fixed (age, sex) and random (subjects nested in schools) effects. A normal probability distribution and an identity link function were used for continuous variables. Pairwise comparisons between time points (T_1 - T_0 and T_2 - T_0) were adjusted using the sequential Bonferroni technique. All analyses were completed using IBM SPSS 24 (Armonk, NY: IBM Corp)

5.3 Results

5.3.1 Assumptions

Demographic data for the full cohort of 675 students (48.3% male) aged 6.5-10.8 years residing in New Zealand were available for analyses (Table 6). There was an even spread of children across the three school years (3: 32.1%, 4: 34.4%, 5: 33.5%). The majority of students were of New Zealand European ethnicity (68.1%). Students were from schools of predominantly high socioeconomic decile. Body measure sizes were only gained for 620 students (male 307, female 313), with average BMI and WHtR slightly higher for girls as would be expected. Table 7 and table 8 show the with mean, median, SD and inter-quartile range for cognitive and academic measures respectively for the 613 students considered in this analysis with EM imputations for missing data, then all 675 students with no imputation for missing data.

Table 6. Descriptive statistics of all subjects at baseline.

Age									
	Male			Female			Total		
	N	M + SD	Min + Max	N	M + SD	Min + Max	N	M + SD	Min + Max
School Year 3	103	7.71, ±0.55	6.65, 8.75	114	7.70, ±0.67	6.48, 9.25	217	7.70, ±0.62	6.48, 9.25
School Year 4	109	8.70, ±0.60	7.60, 9.86	123	8.75, ±0.57	7.61, 9.89	232	8.73, ±0.58	7.60, 9.89
School Year 5	114	9.64, ±0.52	8.11, 10.84	112	9.80, ±0.54	8.75, 10.83	226	9.72, ±0.53	8.11, 10.84
Total	326	8.71, ±0.96	6.65, 10.84	349	8.74, ±1.04	6.48, 10.83	675	8.73, ±1.00	6.48, 10.84

Ethnicity			
	Male	**Female**	**TOTAL**
Maori	22 (6.7%)	32 (9.2%)	54 (8.0%)
Pacific Island	13 (4.0%)	15 (4.3%)	28 (4.1%)
Asian	36 (11.0%)	73 (20.9%)	109 (16.1%)
Other	11 (3.4%)	13 (3.7%)	24 (3.6%)
NZ European	244 (74.8%)	216 (61.9%)	460 (68.1%)
Total	**326**	**349**	**675**
Decile			
Decile 3	25 (7.7%)	25 (7.2%)	50 (7.4%)
Decile 4	9 (2.8%)	13 (3.7%)	22 (3.3-%)
Decile 5	14 (4.3%)	44 (12.6%)	58 (8.6%)
Decile 6	47 (14.4%)	53 (15.2%)	100 (14.8%)
Decile 7	46 (14.1%)	52 (14.9%)	98 (14.6%)
Decile 8	68 (20.9%)	51 (14.6%)	119 (17.6%)
Decile 9	49 (15%)	41 (11.7%)	90 (13.3%)
Decile 10	68 (20.9%)	70 (20.1%)	138 (20.4%)
Total	**326**	**349**	**675**
School year			
Year 3	103 (15.3%)	114 (16.9%)	217 (32.1%)
Year 4	109 (16.1%)	123 (18.2%)	232 (34.4%)
Year 5	114 (16.9%)	112 (16.6%)	226 (33.5%)
Total	**326**	**349**	**675**

Body size measures						
	Male (n=307)		**Female (n=313)**		**Total (n=620)**	
	M + SD	Min + Max	M + SD	Min + Max	M + SD	Min + Max
Weight	30.66, ± 6.83	16.55, 71.43	30.25, ± 7.13	16.80, 67.10	30.45, ±6.98	16.55, 71.43
Height	133.04, ± 7.39	113.80, 157.30	131.66, ± 27.70	111.40, 155.55	132.34, ±7.58	111.40, 157.30

Waist	60.97, ± 7.65	48.65, 100.60	60.82, ± 8.18	43.20, 96.70	60.90, ±7.92	43.20, 100.60
BMI	17.17, ± 2.51	12.56, 28.87	17.28, ± 2.74	12.73, 31.57	17.23, ±2.63	12.56, 31.57
WHtR	0.46, ±0.05	0.37, 0.64	0.46, ±0.05	0.34, 0.66	0.46, ±0.05	0.34, 0.66

Table 7. Descriptive statistics of the four cognitive domains and two academic domains for all 675 students with no imputation for missing data.

	Mean	Median	Standard Deviation	25th %ile	50th %ile	75th %ile
Baseline						
Composite Memory	25.53	14.00	27.56	1.00	14.00	42.00
Executive Functioning	53.97	53.00	23.99	33.00	53.00	73.00
Psychomotor Speed	44.20	45.00	25.03	23.00	45.00	63.00
Reaction Time	39.59	34.00	29.70	12.00	34.00	66.00
Reading Proficiency	4.90	5.00	3.22	2.00	5.00	8.00
Maths proficiency	5.94	6.00	3.34	3.00	6.00	9.00
Two-month						
Composite Memory	25.67	12.00	28.09	1.00	12.00	47.00
Executive Functioning	63.91	68.00	25.23	42.00	68.00	87.00
Psychomotor Speed	49.04	47.00	26.14	27.00	47.00	70.00
Reaction Time	43.10	42.00	29.79	16.00	42.00	68.00
Reading Proficiency	6.13	6.00	2.65	4.00	6.00	8.00
Maths proficiency	6.52	7.00	2.95	4.00	7.00	9.00
Six-month						
Composite Memory	26.78	16.00	27.95	2.00	16.00	45.00
Executive Functioning	64.85	69.00	25.12	45.00	69.00	88.00
Psychomotor Speed	47.89	47.00	26.14	25.00	47.00	68.00
Reaction Time	39.09	34.00	29.75	12.00	34.00	63.00
Reading Proficiency	6.39	7.00	2.56	5.00	7.00	8.50
Maths proficiency	7.47	8.00	2.51	6.00	8.00	10.00

Table 8. Descriptive statistics of the four cognitive domains and two academic domains for 613 students considered in final analyses including EM imputed data for missing values.

	Mean	Median	Standard Deviation	25th %ile	50th %ile	75th %ile
Baseline						
Composite Memory	25.96	22.23	25.02	2.00	22.23	37.00
Executive Functioning	54.01	53.81	20.06	41.66	53.81	63.37
Psychomotor Speed	44.02	42.00	21.85	30.00	42.00	58.00
Reaction Time	39.21	36.71	27.14	16.00	36.71	61.00
Reading Proficiency	4.97	5.00	3.13	2.00	5.00	6.00
Maths proficiency	6.04	6.00	3.25	3.00	6.00	8.97
Two-month						
Composite Memory	25.90	21.00	25.77	2.00	21.00	40.00
Executive Functioning	64.54	66.00	22.22	53.00	66.00	82.00
Psychomotor Speed	49.19	47.51	23.34	34.00	47.51	66.00
Reaction Time	43.59	42.00	28.00	18.50	42.00	66.00
Reading Proficiency	6.23	6.71	2.56	4.00	6.71	8.00
Maths proficiency	6.60	7.00	2.86	4.00	7.00	9.00
Six-month						
Composite Memory	26.85	21.02	25.67	4.00	21.02	40.00
Executive Functioning	64.91	66.77	22.88	50.00	66.77	86.00
Psychomotor Speed	48.10	48.02	22.88	33.00	48.02	61.00
Reaction Time	39.30	37.00	27.34	14.00	37.00	55.00
Reading Proficiency	6.45	7.00	2.42	5.00	7.00	8.00
Maths proficiency	7.53	8.00	2.37	6.00	8.00	9.00

As the GLMM analyses consider the 613 students with EM imputed missing data, table 8 were considered. The results show only small changes in mean for composite memory, mean scores for psychomotor speed and reaction time increased at two-months, then dropped at six-months. Executive functioning mean increased at two-months, then no change at six-months. Reading and maths proficiency means increased at two-months, then had smaller increases at six-months.

5.3.2 General Linear Mixed Model analysis.

To determine if changes in PA lead to changes in the cognition and academic proficiency measures, a General Linear Mixed Model analysis was completed of the 613 subjects. The analysis adjusted for confounding factors of sex, age (school year), and the impact of SES through considering the socioeconomic decile differences between schools.

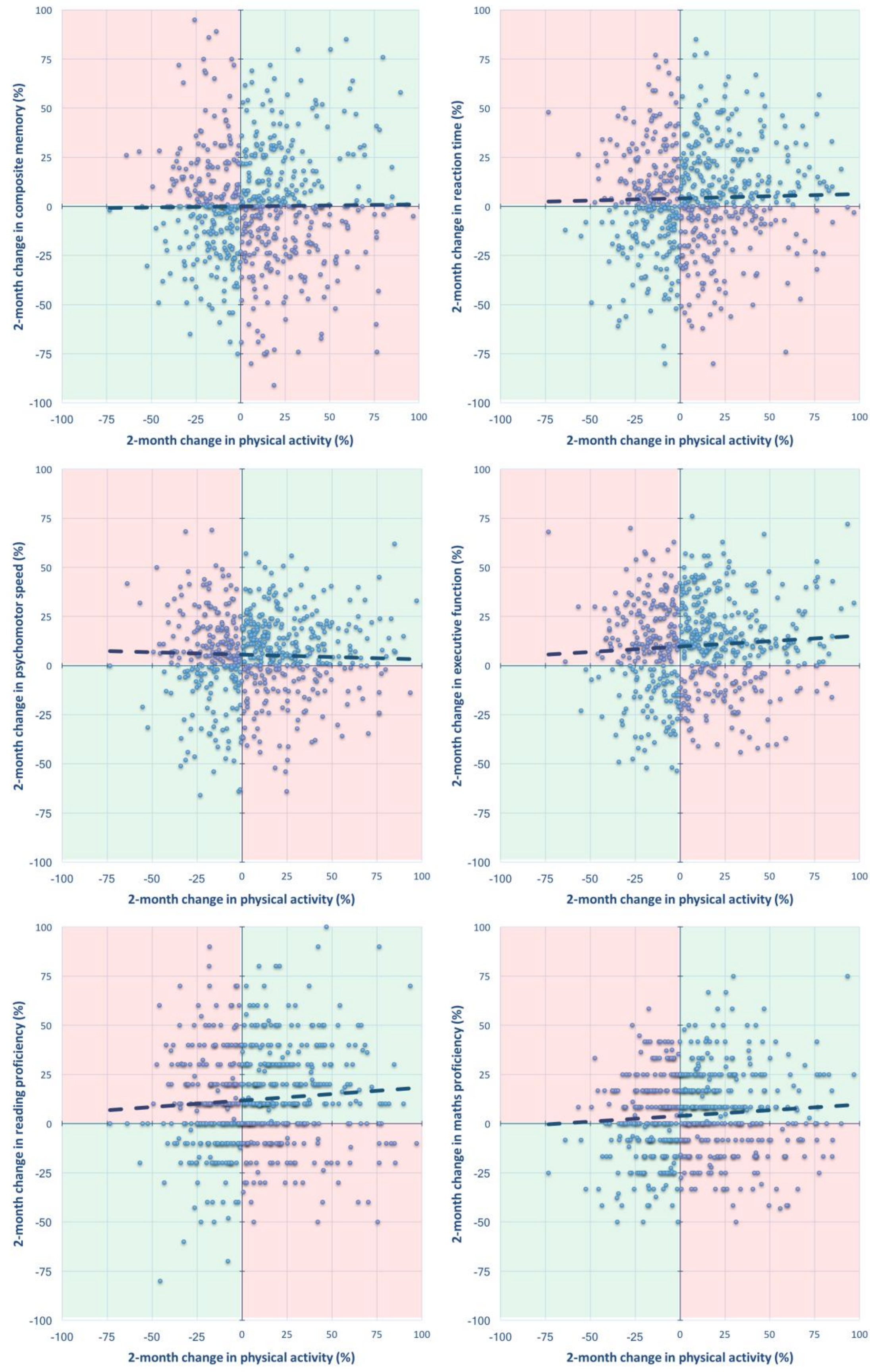

Figure 3: Scatterplot;s of two-month changes in physical activity compared with two-month changes in cognitive and academic outcome measures. The hashed line is the line-of-best-fit.

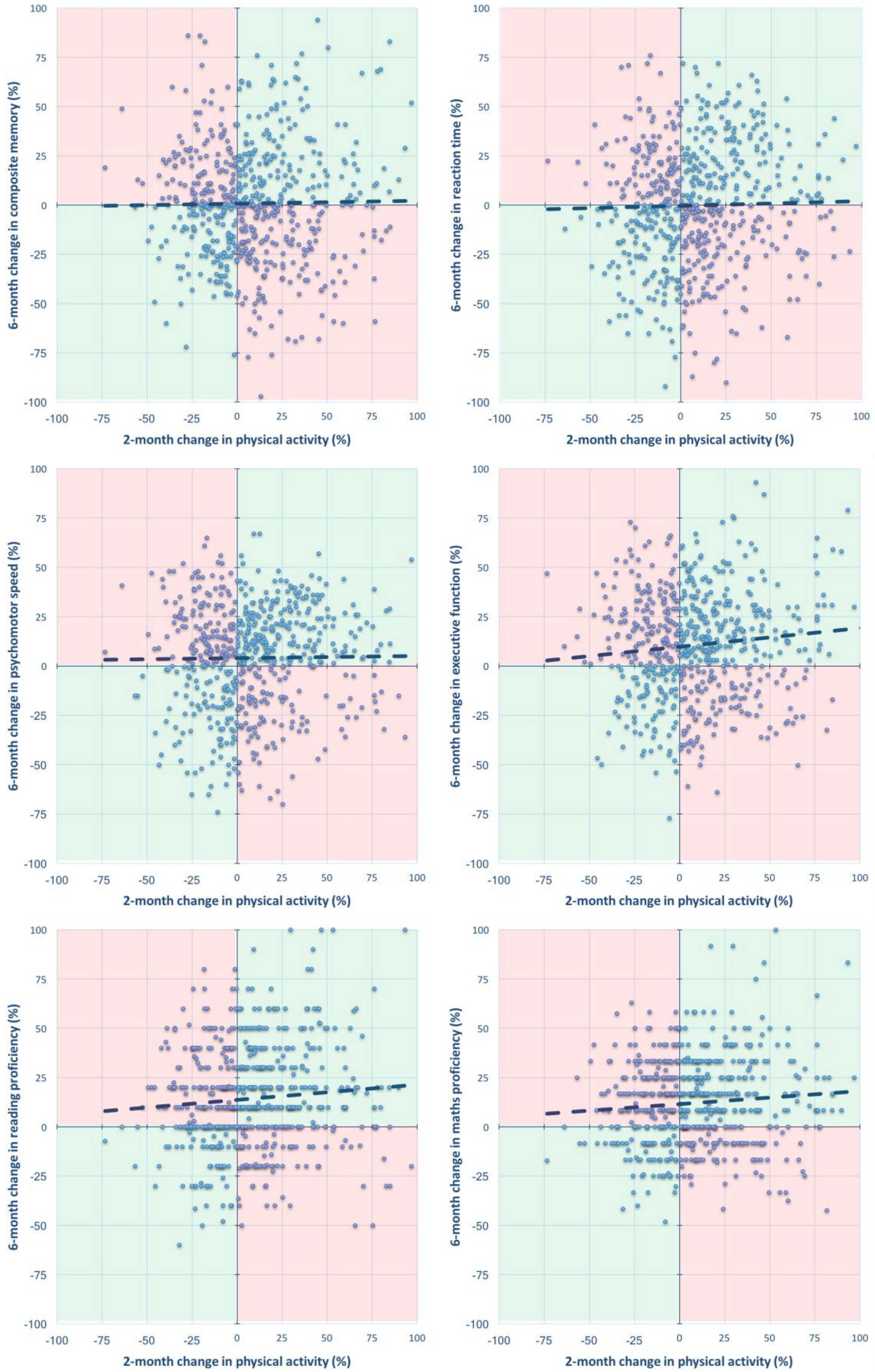

Figure 4: Scatterplots of two-month changes in physical activity compared with six-month changes in cognitive and academic outcome measures. The hashed line is the line-of-best-fit.

Figures 1 and 2 show the unadjusted associations between two-month changes in physical activity and two- and six-month (respectively) changes in all cognitive and academic outcomes. The hashed lines depict the regression slopes, which were significant for executive functioning, reading proficiency, and maths proficiency ($P < 0.05$ for both time points), but not for composite memory, reaction time, or psychomotor speed. All significant associations were positive; in other words, as two-month changes in PA increased, so did the two- and six-month changes in executive functioning, reading proficiency, and maths proficiency.

Table 9 shows the mean change for all students at the two-month and six-month intervals from the generalised mixed model, adjusted for age, sex, and school clustering. The β coefficient indicates the percentage change to each domain associated with a 1% increase in PA at two-months. Significant, positive relationships were observed between PA change and executive functioning change at six-months (0.043), PA change and reading change at six-months (0.032), and PA change and maths change at two-months (0.031). No other associations were significant, although the relationship between PA change and maths change at six-months approached significance ($P = 0.060$).

Table 9. Associations between changes in physical activity at two-months with changes in cognitive/academic outcomes at two-months and six-months.

Domain	*Mean % change (LCL, UCL)*	β (LCL, UCL)	*P*
Composite Memory change			
@two-months	-0.058 (-2.63, 2.52)	-0.010 (-0.073, 0.053)	0.755
@6 months	1.00 (-1.56, 3.56)	-0.010 (-0.072, 0.052)	0.674
Reaction Time change			
@two-months	4.24 (1.95, 6.52)	0.004 (-0.051, 0.060)	0.878
@6 months	-0.240 (-2.81, 2.33	0.023 (-0.040, 0.085)	0.480
Psychomotor Speed change			
@two-months	5.35 (3.52, 7.18)	-0.037 (-0.081, 0.008)	0.106
@6 months	4.19 (1.91, 6.48)	-0.004 (-0.060, 0.051)	0.884
Executive Function change			
@two-months	10.5 (8.49, 12.5)	0.043 (-0.006, 0.091)	0.083
@6 months	10.7 (8.35, 13.0)	0.059 (0.002, 0.115)	0.043
Reading Proficiency change			
@two-months	12.4 (10.2, 14.5)	0.029 (-0.023, 0.081)	0.268
@6 months	14.1 (11.9, 16.3)	0.059 (0.005, 0.113)	0.032
Maths Proficiency change			
@two-months	4.39 (2.59, 6.19)	0.048 (0.004, 0.092)	0.031
@six-months	12.7 (10.8, 14.5)	0.044 (-0.002, 0.089)	0.060

β = standardised coefficient; LCL= lower 95% confidence limit, UCL = upper 95% confidence limit using bias-corrected bootstrapping

5.4 Discussion

To our knowledge, this is the first study investigating the effects of changes in PA on change in cognitive ability and academic performance in school children over a six-month period. Our findings suggest that small gains in specific areas of cognition and academic function – namely executive functioning, reading, and maths – can be obtained with increased PA. Although the gains appear small, they could represent meaningful impact for children and their learning. For example, a 1% increase in PA after two months was associated with a 0.059% increase in executive functioning and reading after six months; if students doubled their PA (100% increase), that would theoretically affect a 5.9% improvement in those two areas. Likewise, doubling of PA is associated with a 4.8% positive change in maths after 2 months.

The present results concur with other studies that have found increased PA is associated with improvement in executive functioning and maths [36, 61]. Interestingly, those studies did not find a relationship between PA and reading, but in the present study increased PA had a positive effect on reading at the six-month mark. Other longitudinal studies have indicated that PA has a positive impact on maths and reading scores [18, 33]. Importantly, the present analyses adjusted for potential confounding factors such of sex [33], age [20, 22], and SES [25, 35, 58]. That indicates that the significant relationships PA had executive functioning, reading proficiency and maths proficiency is independent of such confounding factors.

However, this study did not identify any significant relationships between increased PA and executive functioning or reading proficiency at 2 months, a borderline relationship with maths proficiency at 6 months, and no relationship with composite memory, psychomotor speed, and reaction time. Most other longitudinal studies that investigated the relationship between PA and cognition analyse change over periods longer than six-months [18, 33, 38, 39]. It is possible that six-months was not a long enough time span to notice gradual cognitive changes. In addition, the measures used in this study have potential limitations. Pedometers give a valid and reliable indicator of overall volume of physical activity and have been used widely among student populations [63], but do not consider the intensity of the steps or time of day. High intensity aerobic activity and activity immediately prior cognitive assessment have been linked to greater cognitive function and academic performance [1, 17, 22]. Furthermore, pedometers do not monitor other aspects of fitness that have been linked to cognitive function such as acute effects of activity, cardiorespiratory fitness, resistance exercise, or combinations of exercise and activity [22, 35, 37]. Similarly, the two e-asTTle measures are well researched and robust, but additional school-based assessments such as writing could provide greater insights to children's academic performance. The CNSVS measures used in this study give a good insight to cognitive function, but as a screen assessment CNSVS may not have been sensitive enough to detect changes in some areas. Thus, a significant relationship was only identified in Executive Function. Students were not familiar with the CNSVS assessment and thus results may reflect this unfamiliarity rather than difficulty with the cognitive demands and content. A last possible limitation is use of school decile as a measure of SES. It would have been better to have the SES for each individual child and not the school as a whole. Lastly, the lack of relationships may simply mean there were no relationships with increased PA and those domains with this population in this study.

Identifying causation is one of the key questions in the PA/cognition field. Are smart children active or does being active make children smart? The results of this study provide some evidence that the more a child increases PA after two months, the greater the improvement in executive functioning, reading and maths after six months. To examine the relationships further, future studies could consider wider ranges of PA, cognition, and academic performance than the measures used in this study. Further, as this study demonstrated small cognitive and academic gains over a short period, future studies should be completed over longer timeframes which will give greater opportunity to identify how changes in PA can make larger quantifiable changes in cognition and academic performance.

5.5 Conclusions

This six-month longitudinal study provides some support for the theory that increased PA improves cognition and academic performance in children. The analysis identified small but significant improvements in executive functioning, reading, and maths (but not composite memory, psychomotor speed, or reaction time) with increased PA, after adjustment for age, sex, and school clustering. While this reinforces that PA may have a role to play in children's learning, the relatively small magnitude of the associations suggest that substantial improvements in PA would be required to generate meaningful improvements in cognition and academic achievement. Further research into the long-term effects of PA on brain function would provide additional information regarding the potential benefits of increasing PA in school children.

5.6 List of abbreviations

BMI: Body Mass Index

CNSVS: CNS Vital Signs

GLMM: General Linear Mixed Model

MAR: Missing at random

MCAR: Missing completely at random

MNAR: Missing not at random

MVA: Missing values analysis

NonNZEuro: Non-New Zealand European Ethnicity

NZEuro: New Zealand European ethnicity

PA: Physical Activity

PE: Physical education

SES: Socio-economic status

WHtR: Weight to Height Ratio

Chapter 6. Discussion

6.1. Findings

With a strong emphasis in schools for children to perform well in academic subjects, support for physical activity at school and home are weaning [18, 47, 48]. Yet, there is growing knowledge base for the PA theory that suggests more active children learn better. Thus, the first step of this study was to establish if PA has an independent relationship with academic performance, or if cognitive ability is the only factor impacting a child's ability to learn. The study hypothesised that cognition has a mediating effect in the relationship between PA and academic performance.

As would be expected, a strong relationship was identified between cognition and academic performance. Moreover, use of an SEM analysis, was able to explain the added effect of PA to that relationship. As hypothesized, cognition was shown to have a mediating effect on the association between PA and academic performance. It is important to note that the effect between PA and academic performance was still present because the mediating effect of cognition was only partial. Furthermore, PA is shown to have an indirect relationship with academic performance through cognition, and a greater total association with academic performance through cognition. Therefore, this study supports the growing body of literature demonstrating the relationship PA has with cognition and academic performance, and importantly for school settings that the relationship between PA and academic performance is both supportive and independent of cognitive ability.

Now the relationships between PA, cognition and academic performance have been established, the second study answered a key question in the PA cognition research field: Does exercise make kids smart? Findings from the second study suggest that gains in specific areas of cognition and academic function can be obtained with increased overall PA. Thus, PA presented to be causative towards cognitive and academic function for students. This study identified that doubling PA could represent an improvement of 5-6% in areas of executive functioning, reading and maths for students. That represents possible for benefits for student learning in many areas through the increase of PA.

6.2. Strengths and limitations

6.2.1. Sample

Each of the two studies had just over 600 subjects for final analysis, which is a relatively large sample size. Large study cohorts help reduce sample bias and increase statistical power of findings. That could be seen clearly in Study 1, where the SEM analysis found significant results for the full sample but not for subgroup analysis. The smaller subgroup samples limit the generalisability of the findings because analysis results were not significant so the important potential confounding factors of sex [33], school year, and ethnicity could not be considered. Future studies could include larger samples to ensure confounding factors of a low SES [25, 35, 58]or socioeconomic decile school, and non-New Zealand European ethnicity. Using the different GLMM analysis for Study 2, adjustment could be made for the important confounding factors of sex, age [20, 22] and SES or school socioeconomic decile.

6.2.2. Measures

With the vast array of studies into the subject of PA and cognition, there have been many different measures of PA, cognition, and academic performance. Donnelly et al, advise such differences in measures can limit interpretation and comparison between different studies [18]. Until a consensus or guideline can be given for suitable measures, it is important to make sure measures are robust and suitable. All of the measures used in this study have demonstrated to be appropriate and reliable indicators for variables assessed. More thorough analysis of variables may have been gained by including additional aspects of PA such as intensity, frequency, duration, cardiorespiratory fitness, resistance exercise, or combinations of exercise and activity [22, 35, 37]. Other cognitive or academic performance assessments may also provide greater data on cognition and academic performance. For example, this study only included assessment of reading and maths, but adding a writing measure may have given greater insights to subjects' academic performance.

Donnelly et al state in their thorough meta-analysis, it is important to identify the most appropriate measures for PA, cognition and academic performance [44]. However, that does not mean all studies need to have the same measures. It is of the utmost importance that the measures are suitable for individual study's purposes. Researchers must fully understand the measures being used to account for their strengths and limitations. The two studies for this paper demonstrate such knowledge and have explained and adjusted for measurement limitations.

6.2.3. Methods

The literature review detailed many cross-sectional studies showing the relationship PA has with cognition and academic performance. The biggest strength of the SEM analysis for the first study is how it explained direct, indirect, mediating and total relationships between the three variables. Although the multigroup analysis found similar patterns to the full cohort, the results were not significant. That meant the important confounding factors of sex, ethnicity, school socioeconomic decile (SES), and school year (age) could not be considered in the first study. A final limitation of the first study is that while it concludes a positive association between PA and cognition, and PA and academic performance, it cannot ascribe direction in those relationships. Longitudinal research is needed to examine PA, cognitive and academic changes over time which will provide clearer understanding to possible causal relationships. Thus, the aim of the second study was to explain causal relationships between PA, cognition, and academic performance required a different methodological approach, and used a GLMM analysis. That approach was suitable as it was able to compare changes in PA, cognition and academic performance over the three time points to identify students who increased PA levels had corresponding small increases in three areas of cognition and academic performance. Further, the GLMM analysis was able to adjust for important confounding factors.

6.3. Implications for research and practice.

As shown in the literature review, many quality cross-sectional studies have demonstrated a relationship between PA and cognition, and PA and academic performance. The next step for researchers is to explain how those relationships interact. One of the strongest recurring themes in the literature is the necessity for appropriate measures and methodology [1, 2, 25, 44]. The first aspect to consider for these studies is that it used a secondary analysis of existing data from another study. The quality longitudinal ECLS study also used secondary data [33]. Using existing data is useful for researchers because it reduces the time required for setting up the study and data collection. However, difficulties can arise if the measures used for the initial study are not specific enough for the purpose of secondary analysis. The two studies in this paper found the PA, cognition and academic performance measures adequate for analysis to demonstrate patterns and relationships, but if other measures were set up and used and set up specifically to assess the areas being analysed, that may have given more suitable performance indicators and results.

Although there are many cross-sectional studies already demonstrating the relationship between PA and cognition or academic performance exist, the SEM analysis in Study 1 shows a cross-sectional analysis can still be used to add further important knowledge. The SEM analysis demonstrates that valuable information about mediating and confounding factors in the PA-cognition-academic performance relationship can still be added to this field with cross-sectional studies. Further studies should also aim to explain how variables inter-relate, beyond just identifying a relationship is present. SEM or any other methodology that can further explain independent relationships whilst considering indirect effects or interactive relationships is required to broaden our understanding of the PA-cognition-academic performance relationships. Further studies should also consider the mediating and confounding effects of important variables including age, sex, SES, parent educational level, and ethnicity. It was unfortunate confounding variables of SES, gender and ethnicity could not be fully considered in Study 1 due to the small sub-group sample size. That demonstrates the importance of ensuring an optimal sample size for future studies.

The GLMM analysis approach for Study 2 also proved to be suitable for addressing the aim of identifying causal relationships. The analysis was able to identify small but significant changes and effects over the short span of six months. However, term of six months may have been long enough for quantifiable changes to cognition and academic performance. Longer term research into the effects of PA on brain function would provide additional information regarding the potential benefits of increasing PA in school children. Further, such as Study 1, there are also the considered limitations of the measures and tools and study population. A more robust way of analysing the longitudinal effects of PA on cognition and academic achievement is to first ensure a large enough sample size to consider important demographic differences such as age, sex, SES, ethnicity and parent education level. Then tools will need to be used to accurately measure the three areas being studied. For PA, a more detailed measure of types of activity including type, length, intensity and frequency would be needed. Cognitive changes should be measured by a thorough and child specific assessment such as the Wechsler Individual Achievement Test (WIAT) – 2nd Edition. Liaison with teaching experts is needed to identify what areas of academic performance or achievement should be measured beyond maths and reading such as writing and art. Then appropriate timeframes for measuring performance on those three areas needs to be identified such as six, 12, 18 and 24 months to enable time for the child to make a measurable change, plus enough time to identify significant changes.

Beyond the scope and direction of this study, other questions still remain unanswered in the PA-cognition-academic performance field: How long does it take for the effects of PA to come into effect? What is the optimal form of PA to promote cognitive and academic benefits? How long does the effect of PA last: hours, days, weeks, months? Despite those unanswered questions, overall, the two studies completed for this paper contribute to and support the PA theory, that increased PA leads to greater cognitive function and academic performance for primary school children [24, 39, 41, 43].

Given such a growing and consistent knowledge base, the New Zealand Ministry of Education and Ministry of Health needs to look beyond current teaching practice and information delivery techniques to support the increase of appropriate PA for children. As authors have identified, PE and PA are often the first thing removed from school curricula to allow more time for academic subjects [18, 24]. From personal discussion with teachers, they advised that they know students should be more active to promote physical and cognitive health, but they have pressures to fit in all the other academic and administration tasks in the school day. Teachers need to be empowered and supported at higher governmental and management levels to actively increase PA for children – even at the expense of other, more academic, subjects.

One of the key tasks for researchers, health professionals and educationalists must be how to translate it into practice. What needs to be done to promote the uptake of PA? With management level support, strategies need to be set up and supported to enhance the quality and quantity of PA for children in school, extra-curricular, and at the home environment. Information and direction need to be presented to teachers in a succinct and clear manner that enables them to increase PA within their daily curriculum. For example, as identified in the two Studies in this paper, teachers need to be shown that successful academic performance is associated with cognition and PA independently and cumulatively, then even an increase in the one PA area of daily steps taken can create a significant improvement to learning. Therefore, robust research and data from this emerging PA-cognition-academic performance area need to be disseminated to the appropriate educational leaders and governmental agencies who have the power to support change in education practice.

6.4. Conclusions

The positive impact PA can have on the cognition and academic performance of school children has shown to be an exciting, yet still somewhat confusing subject. How PA, cognition and academic performance interact, and the impact of additional confounding variables is becoming a major research field. Adding to such research, this study presented a two-fold approach towards understanding the relationships between PA, cognition and academic performance: the cross-sectional SEM analysis added insights to the mediating effect of cognition in the PA-academic performance relationship, and the longitudinal GLMM analysis showed areas where increased PA is likely to have contributed to cognitive and academic improvement. Each study identified new insights in their own right and added knowledge to this increasing field. Strengths and limitations of the studies are identified, but they provide clear evidence to demonstrate the validity of the PA theory that PA contributes to cognitive and academic improvement for primary school children. Possibly one of the most exciting findings is the potential that doubling the number of steps taken through the day could improve reading, maths and executive functioning by 5-6%. Important demographic confounding factors were considered for both studies, indicating the findings apply to students of different sex, age, socioeconomic decile, and ethnicity.

These studies have added to the current body of knowledge and also given direction for future research. Detailed consideration of the measures and methodologies used show strengths and limitations, and give direction how ongoing research may best answer specific questions. Researchers need to continue to explain the complex relationships between PA, cognition and academic achievement and present the information in a way that health professionals, educationalists and families understand. And most importantly, from this research clear guidelines and directions are needed to enable children to access the potential cognitive and academic benefits of increased PA.

Appendix 1. Study 1: Bivariate analysis of measures.

Table 10. Bivariate analysis of nine measures from final model of all 675 subjects.

		Mean weekday steps home	Mean weekday steps school	Mean weekend steps	CNSVS Composite Memory	CNSVS Executive Functioning	CNSVS Psychomotor Speed	CNSVS Reaction Time	asTTle Reading proficiency	asTTle Maths proficiency
Mean Weekday Steps Home	Pearson Correlation	1	.279**	.344**	.044	.082	.071	-.009	.158**	.145**
	Sig. (2-tailed)		.000	.000	.357	.121	.156	.843	.000	.001
	N	555	536	431	440	357	403	453	511	508
Mean Weekday Steps Schooll	Pearson Correlation	.279**	1	.219**	-.031	.077	.069	.044	.080	.132**
	Sig. (2-tailed)	.000		.000	.498	.125	.149	.328	.058	.002
	N	536	610	434	475	394	437	496	564	561
Mean Weekend Steps	Pearson Correlation	.344**	.219**	1	-.063	.069	-.029	-.086	.009	.015
	Sig. (2-tailed)	.000	.000		.236	.234	.595	.098	.861	.756
	N	431	434	445	358	297	331	373	416	413
CNSVS Composite Memory	Pearson Correlation	.044	-.031	-.063	1	.218**	.206**	.227**	.256**	.301**
	Sig. (2-tailed)	.357	.498	.236		.000	.000	.000	.000	.000
	N	440	475	358	514	375	420	460	500	496

CNSVS Executive Functioning	Pearson Correlation	.082	.077	.069	.218**	1	.350**	.278**	.328**	.397**
	Sig. (2-tailed)	.121	.125	.234	.000		.000	.000	.000	.000
	N	357	394	297	375	427	366	385	414	411
CNSVS Psychomotor Speed	Pearson Correlation	.071	.069	-.029	.206**	.350**	1	.361**	.326**	.358**
	Sig. (2-tailed)	.156	.149	.595	.000	.000		.000	.000	.000
	N	403	437	331	420	366	472	421	461	457
CNSVS Reaction Time	Pearson Correlation	-.009	.044	-.086	.227**	.278**	.361**	1	.309**	.263**
	Sig. (2-tailed)	.843	.328	.098	.000	.000	.000		.000	.000
	N	453	496	373	460	385	421	534	517	513
asTTle Reading	Pearson Correlation	.158**	.080	.009	.256**	.328**	.326**	.309**	1	.687**
	Sig. (2-tailed)	.000	.058	.861	.000	.000	.000	.000		.000
	N	511	564	416	500	414	461	517	609	605
asTTle Maths	Pearson Correlation	.145**	.132**	.015	.301**	.397**	.358**	.263**	.687**	1
	Sig. (2-tailed)	.001	.002	.756	.000	.000	.000	.000	.000	
	N	508	561	413	496	411	457	513	605	605

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 11. Bivariate analysis of nine measures from final model of 601 subjects (nMiss <=5/9 variables).

		Mean weekday steps home	Mean weekday steps school	Mean weekend steps	CNSVS Composite Memory	CNSVS Executive Functioning	CNSVS Psychomotor Speed	CNSVS Reaction Time	asTTle Reading proficiency	asTTle Maths proficiency
Mean Weekday Steps Home	Pearson Correlation	1	.280**	.345**	.044	.082	.071	-.007	.158**	.145**
	Sig. (2-tailed)		.000	.000	.357	.121	.156	.890	.000	.001
	N	519	503	414	440	357	403	450	509	506
Mean Weekday Steps School	Pearson Correlation	.280**	1	.227**	-.030	.072	.071	.037	.067	.123**
	Sig. (;2-tailed)	.000		.000	.513	.153	.138	.409	.114	.004
	N	503	563	416	473	393	436	489	551	548
Mean Weekend Steps	Pearson Correlation	.345**	.227**	1	-.063	.069	-.029	-.088	.009	.015
	Sig. (2-tailed)	.000	.000		.236	.234	.595	.089	.861	.756
	N	414	416	426	358	297	331	372	416	413
CNSVS Composite Memory	Pearson Correlation	.044	-.030	-.063	1	.222**	.205**	.232**	.257**	.298**
	Sig. (2-tailed)	.357	.513	.236		.000	.000	.000	.000	.000
	N	440	473	358	507	373	419	456	495	491
CNSVS Executive Functioning	Pearson Correlation	.082	.072	.069	.222**	1	.345**	.269**	.324**	.396**
	Sig. (2-tailed)	.121	.153	.234	.000		.000	.000	.000	.000
	N	357	393	297	373	423	365	382	412	409

CNSVS Psychomotor Speed	Pearson Correlation	.071	.071	-.029	.205**	.345**	1	.358**	.324**	.356**
	Sig. (2-tailed)	.156	.138	.595	.000	.000		.000	.000	.000
	N	403	436	331	419	365	469	420	459	455
CNSVS Reaction Time	Pearson Correlation	-.007	.037	-.088	.232**	.269**	.358**	1	.308**	.259**
	Sig. (2-tailed)	.890	.409	.089	.000	.000	.000		.000	.000
	N	450	489	372	456	382	420	522	510	506
asTTle Reading	Pearson Correlation	.158**	.067	.009	.257**	.324**	.324**	.308**	1	.676**
	Sig. (2-tailed)	.000	.114	.861	.000	.000	.000	.000		.000
	N	509	551	416	495	412	459	510	589	585
asTTle Maths	Pearson Correlation	.145**	.123**	.015	.298**	.396**	.356**	.259**	.676**	1
	Sig. (2-tailed)	.001	.004	.756	.000	.000	.000	.000	.000	
	N	506	548	413	491	409	455	506	585	585

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Strength of correlations are gauged using the guidelines by Cohen[71]:

Small (r = .10 to .29 or r = -.10 to -.29). Medium (r = .30 to .49 or r = -.30 to -.49). Large (r = .50 to 1.0 or r = - .50 to -1.0).

Appendix 2. Study 1: Goodness of fit analyses for SEM datasets.

Table 12. SEM model analyses: Goodness of fit for datasets.

	Sample size	Chi-squared	Degrees of freedom	Probability level	CFI	RMSEA	NNFI (TLI)	PNFI
Levels of acceptable significance (Hooper et al)	n/a	Low x2 relative to DF 2-5	n/a	insignificant p value (p>0.050)	>0.95	<0.06 <0.03 excellent fit	>0.95	<0.5 ideal but not essential
Data set A – full model	601	67.582	24	.000	.963	.055	.944	.629
Data set A - PA-AA model n601 EM	601	13.493	4	.009	.983	.063	.958	.391
Data set B - full model	202	31.807	24	.132	.973	.040	.959	.601
Data set C – full model	360	35.693	24	.059	.979	.037	;.968	.626
Data set D - Full model FIML	601	36.916	24	.045	.984	.030	.969	.510

Appendix 3. Study 1: Goodness of fit from multigroup analyses.

Table 13. Goodness of fit from multigroup analyses.

	Chi-squared	Degrees of freedom	Probability level	CFI	RMSEA	NNFI (TLI)	PNFI	Model comparison
Levels of acceptable significance (Hooper et al)	Low x2 relative to DF 2-5	n/a	insignificant p value (p>0.050)	>0.95	<0.06 <0.03 excellent fit	>0.95	<0.5 ideal but not essential	n/a
Sex: Configural	84.792	48	.001	.969	.035	.953	.621	.759
Sex: Metric	84.792	48	.001	.971	.032	.961	.695	.759
Sex: Scalar	84.792	48	.001	.914	.051	.902	.759	.759
Sex: Residual	84.792	48	.001	.886	.055	.886	.833	.759
Sex – PA-AA –Configural	14.007	8	.082	.989	.035	.973	.396	.224
Sex – PA-AA –Metric	14.007	8	.082	.987	.033	.976	.543	.224
Sex – PA-AA – Scalar	14.007	8	.082	.872	.086	.840	.697	.224
Sex – PA-AA – Residual	14.007	8	.082	.813	.091	.822	.854	.224
School year: Configural	118.040	72	.001	.944	.033	.916	.582	.652
School year: Metric	118.040	72	.001	.947	.029	.932	.671	.652
School year: Scalar	118.040	72	.001	.648	.069	.627	.547	.652
School year: Residual	118.040	72	.001	.601	.068	.641	.576	.652
School year – PA-AA – Configural	21.274	12	.047	.977	.036	.943	.381	.405
School year - PA-AA: Metric	21.274	12	.047	.977	.030	.962	.563	.405
School year - PA-AA: Scalar	21.274	12	.047	.471	.114	.433	.414	.405
School year - PA-AA: Residual	21.274	12	.047	.455	.099	.570	.514	.405

Decile: Configural	108.232	72	.004	.969	.029	.954	.610	.091
Decile: Metric	108.232	72	.004	.963	.029	.953	.700	.091
Decile: Scalar	108.232	72	.004	.919	.039	.914	.799	.091
Decile: Residual	108.232	72	.004	.882	.044	.894	.887	.091
Decile PA-AA: Configural	15.133	12	.234	.994	.006	.986	.390	.264
Decile PA-AA: Metric	15.133	12	.234	.991	.015	.985	.576	.264
Decile PA-AA: Scalar	15.133	12	.234	.911	.052	.904	.809	.264
Decile PA-AA: Residual	15.133	12	.234	.856	.056	.886	1.011	.264
Ethnicity: Configural	96.510	48	.000	.960	.040	.940	.616	.015
Ethnicity: Metric	96.510	48	.000	.952	.042	.936	.683	.015
Ethnicity: Scalar	96.510	48	.000	.907	.054	.893	.754	.015
Ethnicity: Residual	96.421	48	.000	.894	.054	.894	.842	.015
Ethnicity - PA-AA: Configural	15.108	8	.057	.987	.039	.968	.390	.002
Ethnicity - PA-AA: Metric	15.108	8	.057	.965	.054	.936	.521	.002
Ethnicity - PA-AA: Scalar	15.108	8	.057	.904	.075	.880	.703	.002
Ethnicity - PA-AA: Residual	15.108	8	.057	.883	.072	.889	.894	.002

Appendix 4. Study 1: BMC Public Health published article

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BMC Public Health

RESEARCH ARTICLE Open Access

Physical activity, cognition and academic performance: an analysis of mediating and confounding relationships in primary school children

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Abstract

Background: Exploring the relationship between physical activity, cognition and academic performance in children is an important but developing academic field. One of the key tasks for researchers is explaining how the three factors interact. The aim of this study was to develop and test a conceptual model that explains the associations among physical activity, cognition, academic performance, and potential mediating factors in children.

Methods: Data were sourced from 601 New Zealand children aged 6–11 years. Weekday home, weekday school, and weekend physical activity was measured by multiple pedometer step readings, cognition by four measures from the CNS Vital Signs assessment, and academic performance from the New Zealand Ministry of Education electronic Assessment Tools for Teaching and Learning (e-asTTle) reading and maths scores. A Structured Equation Modelling approach was used to test two models of variable relationships. The first model analysed the physical activity-academic performance relationship, and the second model added cognition to determine the mediating effect of cognition on the physical activity-academic performance association. Multigroup analysis was used to consider confounding effects of gender, ethnicity and school socioeconomic decile status.

Results: The initial model identified a significant association between physical activity and academic performance ($r = 0.225$). This direct association weakened ($r = 0.121$) when cognition was included in the model, demonstrating a partial mediating effect of cognition. While cognition was strongly associated with academic performance ($r = 0.750$), physical activity was also associated with cognition ($r = 0.138$). Subgroups showed similar patterns to the full sample, but the smaller group sizes limited the strength of the conclusions.

Conclusions: This cross-sectional study demonstrates a direct association between physical activity and academic performance. Furthermore, and importantly, this study shows the relationship between physical activity and academic performance is supported by an independent relationship between physical activity and cognition. Larger sample sizes are needed to investigate confounding factors of gender, age, socioeconomic status, and ethnicity. Future longitudinal analyses could investigate whether increases in physical activity can improve both cognition and academic performance.

Keywords: Physical activity, Cognition, Academic performance, School, Children, Mediation, SEM, Multigroup analysis

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Background

Over the course of the last century, a multidisciplinary field of knowledge has developed that has identified several cognitive and academic benefits of regular physical activity (PA) [1–7]. The idea that PA can enhance cognitive and academic ability has consequently received significant attention in health and education fields [8–10]. It is recognised that PA triggers change in the human brain due to increases in metabolism, oxygenation and blood flow providing hormones that promote neurological health [11, 12]. Those changes are particularly important for the developing paediatric brain [9, 12]. Researchers are now clarifying how relationships between PA and cognition interact to guide the best way forward to promote neurological, cognitive and academic benefits for children.

Sibley and Etnier completed a meta-analysis of 44 studies into the relationship between PA and cognitive abilities [6]. They found all included studies reported significant and positive effects of PA within physical education (PE) and cognition in youth, regardless of the study design and type of PA [6]. The greatest effects were seen with perceptual skills and academic readiness tests [6]. A review of 17 studies by Trudeau and Shepherd on the impact of PA on academic performance of children in primary and secondary school also found positive relationships between PA and school results [7]. Combined analysis of the seven quasi-experimental studies showed that the enriched PE programmes demanded a substantial reduction in the time allocated for academic tuition but academically children achieved at least equally despite the reduced teaching time [7]. Ten cross-sectional studies showed positive association between PA and academic performance [7]. Despite concurrence about a positive relationship between PA and cognition, both reviews note limitations due to the small number of true experimental studies and by potential confounding variables. For example, Sibley and Etnier found 57 different methods of cognitive assessment used by investigators, many with poor or unknown psychometric properties [6]. In another meta-analysis, Hillman et al., completed a review of 14 studies examining PA and neuroelectric concomitants of cognition during childhood [4]. They found PA and cardiovascular fitness have short and medium-term benefits for neurocognitive performance in youth [4]. The studies used laboratory measures to measure neurological activity on subjects performing a range of cognitive tasks and formal assessments. They found increased fitness and PA improve cognitive function and brain health, with higher-fit children demonstrating attributes such as greater attention, faster information processing, and higher scores in standardised achievement tests. Only one study which provided neutral findings did not show any improvement in cognitive function.

Furthermore, two detailed studies from 2016 provide strong support for the relationship PA has with cognition and academic performance [13, 14]. For the Copenhagen Consensus, 24 researchers from eight countries met to reach an evidence-based consensus on the effects of PA on children and youths aged 6–18 years [13]. The authors concur that PA and cardiorespiratory fitness are beneficial to brain structure, brain function and cognition in children and youth [13]. They advise that PA before, during and after school promotes scholastic performance in children and youth, with even a single session of moderate PA having an acute benefit to brain function, cognition and scholastic performance [13]. In the other study, eight key researchers in the PA-cognition field started from a database of 6237 articles and identified 137 key articles to consider [14]. The review focused on two specific questions: Among children age 5–13 years, do PA and physical fitness influence cognition, learning, brain structure, and brain function? And among children age 5–13 years, do PA, PE, and sports programs influence standardized achievement test performance and concentration/attention? They found promising results showing relations among PA, cognition, brain structure, and brain function, with no negative effects on children. The 26 cross-sectional and cohort-based studies involving PA provided positive support for the relationship between PA and cognitive function, with greater amounts or enhanced forms of PA being associated with greater improvements in cognitive function [14]. For the second question, the authors stated the studies of acute PA interventions had mixed results, likely owing to the differences in tasks administered, the nature of the task, and the type of PA [14]. However, authors advise a number of methodological weaknesses including a lack of information about estimates of random variability in the outcome data, information about the time of day at which the cognitive measures were assessed was not provided, varying and inconsistent measures of fitness and academic performance, and poor control of confounders. They particularly noted many studies did not give statistical power of the findings, including 95% of the studies relating to the second question [14].

The analyses above show that excellent research has established that PA is associated with both cognition and academic performance for children. However, few studies have investigated how the three areas of PA, cognition and academic performance interact. Does a relationship between PA and cognition necessarily lead to better academic performance? Does an independent relationship between PA and academic performance relationship exist, or does it act through cognition? Is the PA-cognition-academic performance relationship the same for different groups of children? Specifically, does the relationship between PA and academic performance remain once cognition is accounted for? Therefore, the aim of this study is to develop and test a conceptual model that explains the cross-sectional associations among PA, cognition and academic performance in children aged 7–10 years.

Methods

Participants

A total of 675 participants (326 male, 349 female) were part of an eight-week randomised controlled trial: *Healthy Homework* was a curriculum-based, classwork and homework schedule designed to promote PA and healthy eating [15]. This study analyses data collected from participants at baseline, prior to receiving any intervention. Eligibility criteria for the schools were as follows: a school with more than 100 students, location within Auckland or Dunedin cities, and a contributing, full primary, or composite structure that included at least one class each of students in school years 3–5. A total of 16 primary schools from Auckland ($n = 10$) and Dunedin ($n = 6$) were selected to participate in the study. Socioeconomic decile ratings of participating schools ranged from 3 to 10 (median [IQR] = 8 [6, 9]). Decile is a New Zealand Ministry of Education rating system for school funding based on SES with 1 being low and 10 being high. Decile reflects the extent to which the school draws their students from low socio-economic communities, rather than the SES mix of the school or individual students. For example, low decile schools have the highest proportion of students from low socio-economic communities. Students were selected to participate from one Year 3, one Year 4, and one Year 5 class from each school; simple random sampling was used in instances where there were two or more classes per year. Written parental consent and student assent were obtained for children to participate in the study. Ethical approval was obtained from the Auckland University of Technology Ethics Committee (10/159).

Measures

Demographic information was obtained from the school records and included gender, age, school, ethnicity and socioeconomic decile. All demographic variables were partitioned into groups: Decile (Low 1–5, Mid 6–8, and High 9–10); School year (Year 3, Year 4, and Year 5); and Ethnicity (New Zealand European and Non-New Zealand European). Ideally, socioeconomic decile groupings would be 1–3, 4–7, and 8–10, and a greater range of specific ethnic groups would be analysed, but the total numbers for lower socioeconomic decile students and non New Zealand European ethnic groups were too small for multi-group analysis to be completed (Table 1).

PA was assessed using sealed NL-1000 pedometers (New Lifestyles Inc., Lee's Summit, MO) over five consecutive days (three weekdays, two weekend days). NL-1000 pedometers have a multiday memory function that automatically stores step counts by day of week for up to seven days. Previous research has established the validity of these pedometers for measuring steps in children [16]. Two pedometers were assigned to each child: one clearly labelled 'School' and the other 'Home'. The 'School' pedometer was worn during school hours, while the 'Home' pedometer was left inside a collection tray in the classroom. At the conclusion of the school day, each child placed their 'School' pedometer in the tray and attached their 'Home' pedometer. Upon arrival at school the next day, the teacher reminded the children to switch over their pedometers again. This resulted in three measures of PA: average weekday steps at home, average weekday steps at school, and average steps at weekend.

The cognitive abilities of children were measured using CNS Vital Signs (CNSVS): a standardised cognitive screen assessment suitable for participants aged 7–90 years [17]. CNSVS is a web-based assessment battery with seven tests that are scored individually and combined to give scores in nine different areas. Four of the nine CNSVS measures were considered for this study: Composite Memory (recognize, remember, and retrieve words and geometric figures), Executive Function (recognize rules, categories, and manage or navigate rapid decision making), Psychomotor Speed (perceive, attend, respond to complex visual-perceptual information and perform simple fine motor coordination), and Reaction Time (react, in milliseconds, to a simple and increasingly complex direction set) [18]. The other domains could not be used because of the difficulty in administering the Complex Attention Test, and the four remaining domains used combinations of the same base assessment.

Academic performance was measured using the NZ Ministry of Education electronic Assessment Tools for Teaching and Learning (e-asTTle). The e-asTTle assessments have more than 2000 curriculum based assessment items standardised on over 50,000 students covering curriculum levels 2—4 to assess student's achievement and progress in reading, writing and mathematics and the Maori equivalents of panui, tuhituhi, and pangarau [19–22]. Assessments can be completed at any time during the school year. Measures are norm-referenced and used to evaluate children's progress through the school year [20]. Regardless of items present in a test, e-asTTle can be used to compare progress and performance within students and between students to that of national norms and curriculum achievement objectives and levels [21]. Teachers create their own multi-choice assessment as the e-asTTle software generates a test that selects the best set of items meeting the teacher's content and difficulty constraints [21]. For this study, researchers set up

Table 1 Descriptive statistics of 601 subjects used in analyses

	Age								
	Male			Female			Total		
	N	M + SD	Min + Max	N	M + SD	Min + Max	N	M + SD	Min + Max
School Year 3	91	7.74 ± 0.548	6.78, 8.75	96	7.65 ± 0.661	6.48, 9.25	187	7.69 ± 0.609	6.48, 9.25
School Year 4	103	8.68 ± 0.598	7.60, 9.86	105	8.76 ± 0.593	7.61, 9.89	208	8.72 ± 0.595	7.60, 9.89
School Year 5	106	9.62 ± 0.521	8.11, 10.8	100	9.77 ± 0.537	8.75, 10.8	206	9.70 ± 0.534	8.11, 10.8
Total	300	8.73 ± 0.942	6.78, 10.8	301	8.74 ± 1.05	6.48, 10.8	601	8.74 ± 0.995	6.48, 10.8
Ethnicity									
	Male (*n* = 300)			Female (*n* = 301)			TOTAL (*n* = 601)		
Maori	17 (5.7%)			22 (7.3%)			39 (%6.5)		
Pacific Island	12 (4%)			13 (4.3%)			25 (4.2%)		
Asian	34 (11.3%)			65 (21.6%)			99 (16.5%)		
Other	8 (2.7%)			11 (3.7%)			19 (3.2%)		
NZ European	229 (76.3%)			190 (63.1%)			419 (69.7%)		
Total	300 (100%)			301 (100%)			601 (100%)		
Decile									
Decile 3	23 (7.7%)			18 (6.0%)			41 (6.8%)		
Decile 4	7 (2.3%)			13 (4.3%)			20 (3.3%)		
Decile 5	14 (4.7%)			33 (11.0%)			47 (7.8%)		
Decile 6	42 (14.0%)			47 (15.6%)			89 (14.8%)		
Decile 7	44 (14.7%)			44 (14.6%)			88 (14.6%)		
Decile 8	61 (20/3%)			46 (15.3%)			107 (17.8%)		
Decile 9	46 (15.3%)			38 (12.6%)			84 (14.0%)		
Decile 10	63 (21.0%)			62 (20.6%)			125 (20.8%)		
Total	300 (100%)			301 (100%)			601 (100%)		
School year									
Year 3	91 (30.3%)			96 (31.9%)			187 (31.1%)		
Year 4	103 (34.3%)			105 (34.9%)			208 (34.6%)		
Year 5	106 (35.3%)			100 (33.2%)			206 (34.3%)		
Total	300 (100%)			301 (100%)			601 (100%)		

e-asTTle questions for reading with 10 questions and maths with 12 questions. Thus, raw scores ranged from 0 to 10 for reading, and 0–12 for maths. A research team conducted both the reading and maths assessments, which were done using pen and paper within a 10-min time limit. Researchers marked total scores, and results were entered into a computer by research assistants. The e-asTTle software converts raw scores into measures that align with a child's curricular needs [21]. Raw scores were sufficient for the current analyses because they give a measure of academic performance for students in relation to peers of the same school year.

For each school, CNSVS and e-asTTle baseline measures were collected by a team of researchers on one day. Pedometers were issued to children and height and weight measures taken on a separate day within a month by trained researchers. CNSVS assessment was completed before the e-asTTle test, with at least 30 min between the two. The CNSVS assessment was conducted in groups using school computer facilities or libraries and assisted by at least three researchers. Group sizes and types of computers depended on the facilities and computers provided by the school. Researchers introduced the test beforehand while instructions for each test appeared on the screen before each test started. Researchers were available for the children in case they did not understand the instructions or if children clicked it away too quickly. CNSVS was introduced for the research purposes and is not part of routine school assessment practice.

The e-asTTle assessments were introduced and explained by the researchers. The assessment started with a two minute reading attitude questions, but those are not included in this analysis. The reading test was then conducted before the math test with a time limit of

10 min. Students are used to e-asTTle assessment as part of normal school assessment procedures undertaken throughout the academic year. However, this testing was not part of school assessment procedures, and schools did not receive any data from e-asTTle assessment.

Statistical analysis

All variables were checked for normality, skewness and outliers. The distribution of the CNSVS composite memory item was skewed positively, but that reflects what is to be expected in the general population thus data were not transformed [17]. The other CNSVS measures were normally distributed. The two e-asTTle and three pedometer variables were normally distributed with no problematic outliers.

To analyse the data, this study used Structured Equation Modelling (SEM). SEM is appropriate to test and analyse this multifaceted field as it is able to consider individual and total relationships between variables and their mediating effects. Further, it has a robust multi-group analysis process to assess model fit for subgroups to ensure valid interpretation of between group differences. Analysis was completed using bias-corrected bootstrapping (200 samples) for 95% confidence intervals.

The extent of missing values was assessed on the full study cohort. To minimize loss of data, subjects with data for at least five of the nine variables included in the model were retained. That reduced the study cohort from 675 to 601. The IBM SPSS Missing Value Analysis (MVA) was performed on the 601 participants with the Expectation Maximisation (EM) method specified to generate a data set with imputed values for Structural Equation Modelling (SEM). Based on inspection of missing data patterns and EM data imputation, data are assumed to be missing at random (MAR). Preliminary descriptive statistics were obtained for the subjects and bivariate analyses completed to screen for relationships between variables. Prior to completing an SEM analysis, a confirmatory factor analysis (CFA) was completed on the individual latent variables: PA, cognition and academic performance. The cognition latent variable demonstrated its four measured indicators provided a good fit with the data ($\times 2$ (2) = 3.31, p = 0.191, RMSEA = 0.033, TLI = 0.988). The CFA model for PA and academic performance was unidentifiable due to correlated error terms in the three pedometer step indicators and two e-asTTle indicators respectively.

The hypothesized models are in Figs. 1 and 2. Circles represent latent variables, and rectangles represent measured variables. The hypothesized models examined the strength of association between PA, cognition and academic performance. Academic performance was considered a latent variable with two indicators: (asTTle maths and reading scores). It was hypothesized that PA (a latent variable with three indicators: mean weekday steps home, mean weekday steps school, and mean weekend steps) was associated with higher levels of academic performance (Model 1, Fig. 1). Additionally, it was hypothesized that cognition would mediate the strength of association between PA and academic performance (Model 2, Fig. 2). Cognition was a latent variable with four indicators (CNSVS Composite Memory, Executive Function, Psychomotor Speed, and Reaction Time).

Results

Assumptions

Data for 601 students (49.8% male) aged 6.5–10.8 years residing in New Zealand were available for analyses (Table 1). Overall, bivariate analyses demonstrate consistent small to medium significant relationships between the areas of cognition and academic performance of participants, and pedometer steps showed trivial relationships with cognition and academic performance variables.

Structured equation modelling

Although the chi-square fit statistic for Model 1 was significant, other indicators of model fit supported good fit with the data (χ^2 (4) = 13.5, $p = 0.009$, RMSEA = 0.063, CFI = 0.983, TLI = 0.958, PNFI = 0.391). Greater academic performance was marginally associated with higher levels of PA (standardised coefficient = 0.225, $p < 0.001$) (Table 2.). The model accounted for 5.1% variance in academic performance. The final Model 1 with standardized coefficients is in Fig. 1.

Model 2 tests the hypothesis that some of the PA-academic performance relationship is mediated by cognition (Fig. 2). Similarly, the chi-square statistic for Model 2 was significant but other model fit indicators support good fit with the data (χ^2 (24) = 67.582, $p = .000$, RMSEA = .055, CFI = .963, TLI = .944, PNFI = .628). The indirect association of PA on academic performance is shown in the PA–cognition pathway (standardised coefficient = 0 .138, $p <$ 0.05). The total relationship between PA and academic performance is gained by adding the relationships PA-academic performance and PA-cognition (0.259). Over half (60.2%) of the variance in academic performance was accounted for by PA and cognition.

Structured equation modelling – Subgroup analyses

For gender, measurement invariance testing revealed a lack of equivalence for the scalar and residual models for Model 1. However, Model 2 achieved appropriate fit. Model 2 shows that higher levels of PA was not significantly associated with greater academic performance in boys (standardised coefficient = 0.087, $p = 0.222$). Model 2 shows a significant small direct relationship between PA and academic performance for girls (standardised coefficient = 0.169, $p < 0.05$). For age grouping by school year, no analysis was able to be completed. Both Model

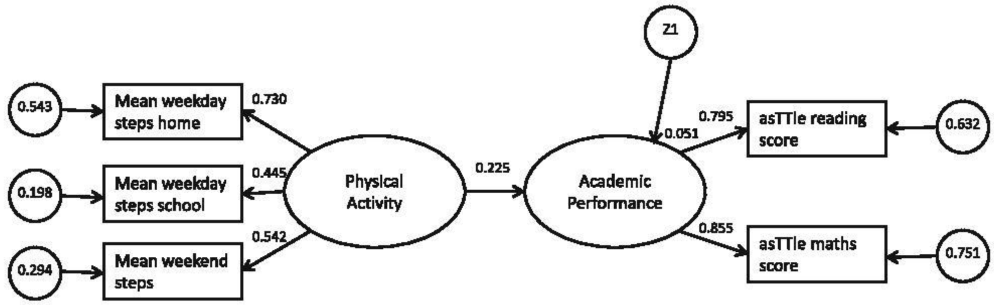

Fig. 1 Structured Equation Model explaining the relationship between physical activity, and academic performance (Model 1), χ^2 (4) = 13.5, p = .009, RMSEA = 0.063, CFI = 0.983, TLI = 0.958, PNFI = 0.391. Two variable model explaining the relationship between physical activity and academic performance

1 and Model 2 had acceptable fit indices for the configural and metric models, but the scalar and residual model fit indices were significantly lower. As such, the Models are not equivalent for different age groups and group comparison cannot be made [23].

Model fit indices for the two ethnic groups for both models were adequate across all four tests of measurement invariance. Thus, model fit is supported for comparison between ethnic groups. For New Zealand European students, Model 1 showed greater academic performance was marginally associated with higher levels of PA (standardised coefficient = 0.214, $p < .01$). Similar relationships, although not significant, were shown for non-New Zealand European students (standardised coefficient = 0.189, $p = 0.225$). Model 2 shows for New Zealand European students, PA was not associated with academic performance (standardised coefficient = 0.083, $p = 0.171$). However, PA was associated with cognition (standardised coefficient = 0.177, $p < 0.05$). None of the PA pathways in Model 2 were significant for non-New Zealand European students (Table 2).

For socioeconomic decile groupings, model fit indices for both models were adequate across all four tests of measurement invariance. For students from low socioeconomic decile schools, Model 1 showed a moderate

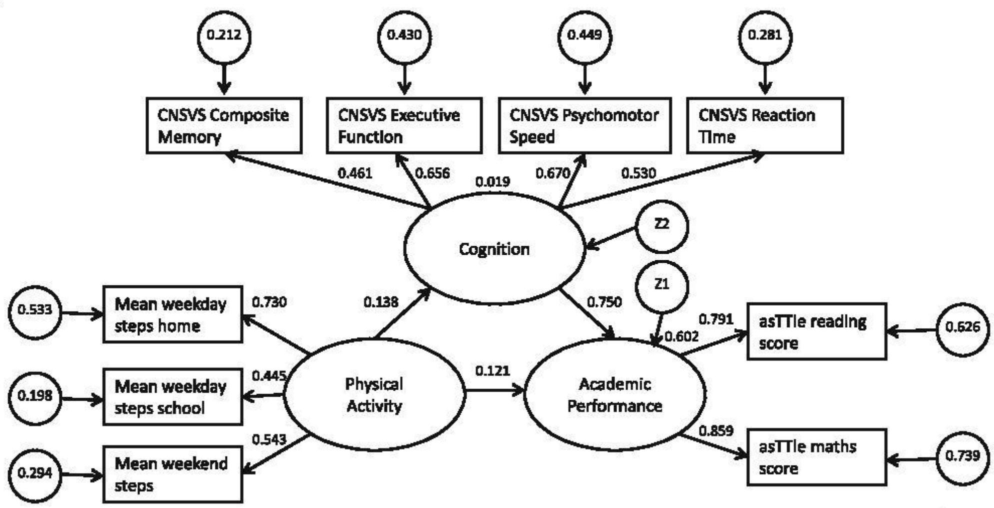

Fig. 2 Structured Equation Model explaining the relationship between physical activity, cognition and academic achievement (Model 2), χ^2 (24) = 67.6, p = .000, RMSEA = 0.055, CFI = 0.963, TLI = 0.944, PNFI = 0.628. Three variable model explaining the relationships between physical activity, cognition and academic performance

Table 2 Significance outputs and 95% Bias-corrected confidence intervals from SEM models

	Sample Size	Model 1				Model 2											
		PA-AP: Direct				PA-AP: Direct				PA-Cognition: Indirect				Cognition-AP			
		β	LCL	UCL	*P*	β	LCL	UCL	*P*	β	LCL	UCL	*P*	B	LCL	UCL	*P*
Full sample	601	.225	.129	.310	< .01	.121	.008	.197	< .05	.138	.010	.274	< .05	.750	.659	.828	< .05
Male	300	.191	.044	.355	< .05	.087	−.037	.231	.181	.163	−.094	.352	.181	.716	.600	.856	< .01
Female	301	.277	.120	.460	< .01	.169	.055	.338	< .05	.147	−.046	.317	.096	.778	.664	.906	< .01
NZEuro	419	.214	.100	.352	< .01	.083	−.039	.187	.243	.177	.022	.321	< .05	.730	.620	.835	< .05
NonNZEuro	182	.189	.000	.335	.071	.179	−.002	.340	.052	.049	−.233	.272	.752	.818	.649	.939	< .05
Decile 1–5	108	.351	.086	.554	< .05	−.018	−.970	.287	.909	.398	−.076	.718	.069	.869	.521	1.496	.094
Decile 6–8	284	.146	−.094	.278	.222	.152	−.019	.278	.071	−.011	−.193	.167	.977	.706	.552	.826	< .05
Decile 9–10	209;	.198	.060	.338	< .05	.009	−.156	.182	.730	.253	.032	.448	< .05	.813	.000	.920	.056

PA = Physical Activity; AP = Academic Performance; NZEuro = New Zealand European ethnicity; NonNZEuro = Non New Zealand European ethnicity;
β = standardised coefficient; LCL = lower 95% confidence limit, UCL = upper 95% confidence limit using bias-corrected bootstrapping

significant relationship between PA and academic performance (standardised coefficient = 0.351, $p < 0.05$ and standardised coefficient = 0.198, $p < 0.05$, respectively). The relationship was not significant for students in the mid socioeconomic decile schools (standardised coefficient = 0.146, $p = 0.167$). For students from low socioeconomic decile schools, Model 2 showed no significant relationship between PA and academic performance (standardised coefficient = 0.018, $p = 0.909$), or between PA and cognition (standardised coefficient = 0.398, $p =$ 0.141). For students from mid socioeconomic decile schools, Model 2 shows a small significant relationship between PA and academic performance (standardised coefficient = 0.152, $p < 0.05$), but not between PA and cognition (standardised coefficient = − 0.011, $p = 0.904$). Lastly, students from high socioeconomic decile schools showed no significant relationship between PA and academic performance in Model 2 (standardised coefficient = 0.009, $p = 0.887$); however, there was a small significant relationship between PA and cognition (standardised coefficient = 0.253, $p < 0.01$).

Discussion

One of the key outstanding questions in the PA-cognition-academic performance relationship is whether the association between PA and academic performance relationship is independent or if it is mediated by cognitive ability. This study explains three aspects to the relationships: (1) the individual relationships PA has with cognition and academic performance; (2) the mediating effect of cognition on the PA-academic performance relationship; and (3) the overall relationship between PA, cognition and academic performance.

This cross-sectional study supports the growing body of research showing consistent positive relationships between PA and cognition [2, 4, 14], and between PA and academic performance [7, 24, 25]. A key focus of this study was to examine those relationships further, to determine whether the association between PA and academic performance remained after considering cognition. As hypothesized for the full sample, cognition was shown to reduce the strength of association between PA and academic performance. Further, the mediating effect of cognition on the association between PA and academic performance is only partial as a small significant relationship between PA and academic performance remained. Additionally, when considering the positive association between PA and cognition, the total association between PA and academic performance is greater in Model 2 than Model 1.

The present findings differ from a similar model tested by van der Niet et al., that characterised the relationship between physical fitness, executive function and academic achievement in 263 children (145 boys, 118 girls) aged 7–12 years in the Netherlands [26]. In their two-variable model of physical fitness and academic achievement, the relationship was slightly greater than the equivalent PA-academic performance relationship for Model 1 in this study. When adding executive function to their model, they also found a stronger relationship in the physical fitness-executive function than PA-cognition for Model 2 in this study. However, the main difference was in considering mediating effects. By adding executive function, the physical fitness-academic achievement relationship dropped completely, showing a complete mediating effect of executive function [26]. Model 2 in this study, however, only found a partial mediating effect of cognition. In other words, van der Niet et al., found that executive function explained all of the variance in academic achievement, whereas the present study identified PA and cognition had independent relationships with academic performance. The differences between the two studies may be due to a number of factors including indicator measures used in assessment and participant differences. The key for both studies is they further help explain essential considerations in the PA cognition field by demonstrating the different level executive function and cognition affect the PA-academic performance relationship and the importance of considering independent and mediating effects of variables.

The present study also considered whether the hypothesized models were equivalent for demographic sub-groups (gender, age, ethnicity and school socioeconomic decile). However, due to small sub-group sample sizes, a lack of statistically significant results across the multigroup analyses precludes robust conclusions across all groups. Research in larger samples may improve the power to detect differences between groups. Previous research has shown that the relationships between PA, cognition and academic performance may differ by gender. For example, in a retrospective analysis of 5316 children, Carlson et al., found that girls in a high activity group performed better academically than those in medium and low activity groups [27]. No differences between groups were noted for boys [27]. Other studies have identified PA-cognition and PA-academic performance relationships for children of many different ethnic origins including US [27], Dutch [26], French [10], Australian [28], and Taiwanese [29], but none were identified that consider differences in the relationship on the basis of ethnicity. SES or school socioeconomic decile is the last confounding variable this study considered. Although SES is recognised as one of the main influences on children's academic success [7, 24, 30], none of the papers reviewed for this study were shown to adjust or consider for SES. Also, this study's use of a school-level socioeconomic decile as a measure of SES may not fully elucidate the effect of this confounding indicator. Future studies should incorporate the two important confounders of an individual-level SES indicator and the educational level of parents.

The measures used in this study have potential limitations. Pedometers give a valid and reliable indicator of overall volume of physical activity and have been used widely among student populations [16], but do not consider the intensity of the steps or time of day. High intensity aerobic activity and activity immediately prior cognitive assessment have been linked to greater cognitive function and academic performance [2, 4, 8]. Furthermore, pedometers do not monitor other aspects of fitness that have been linked to cognitive function such as acute effects of activity, cardiorespiratory fitness, resistance exercise, or combinations of exercise and activity [8, 24, 29]. Similarly, the two e-asTTle measures are well researched and robust, but additional school-based assessments such as writing could provide greater insights to children's academic performance. Although CNSVS showed consistent strong relationships between its different measures and with academic measures both at bivariate and SEM analysis stages, the CNSVS measures used in this study do not consider all areas of cognition. Students were not familiar with the CNSVS assessment and thus results may reflect this unfamiliarity rather than difficulty with the cognitive demands and content. Differences in PA, cognition and academic performance due to age is an important potentially confounding factor for analysis [8, 12]. Accordingly, this study aimed to analyse children by school year. However, the school year multigroup analysis was not able to proceed due to a lack of measurement equivalence. Also, classroom behaviour is also shown to have a strong influence on a child's cognition and academic performance [7, 10, 25, 28]. Initially behaviour was considered for the model, however the behaviour indicator variables had a high degree of missing values and were thus removed from the model. A final limitation is that while this study concludes a positive association between PA and cognition, and PA and academic performance, it cannot ascribe direction in those relationships. Although the theoretical assumption is that increased PA leads to better cognition and academic performance as indicated in the models, bidirectional relationships are possible, and high levels of cognition and academic performance may lead to increased PA. One of the key questions in the PA/cognition field is: are smart children active or does being active make children smart? Future studies need to ensure enough participants to enable subgroup analysis to consider confounding factors. Furthermore, longitudinal research is needed to examine PA, cognitive and academic changes over time which will provide clearer understanding to possible causal relationships.

Conclusions

This study shows a positive association between PA and academic performance for the whole study cohort. Importantly, this study further shows that relationship remains when considering the mediating effect of cognition. Thus, the model tested identifies PA is associated with academic performance directly and indirectly through cognition. Studies with larger sample sizes are needed to investigate important confounding factors such as gender, age, SES and ethnicity.

Abbreviations

CFA: Confirmatory Factor Analysis; CFI: Comparative Fit Index; CNSVS: CNS Vital Signs; EM: Estimation maximization; MAR: Missing at random; MCAR: Missing completely at random; MNAR: Missing not at random; MVA: Missing values analysis; NonNZEuro: Non-New Zealand European ethnicity; NZEuro: New Zealand European ethnicity; PA: Physical Activity; PE: Physical education; PNFI: Parsimonious Normed Fit Index; RMSEA: Root mean square error of approximation; SEM: Structured Equation Modelling; SES: Socio-economic status; TLI: Tucker-Lewis Index

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Availability of data and materials
The datasets generated and/or analysed during the current study are not publicly available due to confidentiality but are available from the corresponding author on reasonable request.

Authors' contributions
AM Study design, analysis and manuscript preparation. SD Study design, data curation, and manuscript review. LM Contribution to analysis and manuscript review. JK Study design, data collection, and manuscript review. All authors read and approved the final manuscript.

Ethics approval and consent to participate
Written informed parental consent and personal assent was obtained from each participant for the collection and use of the data in future publication. Ethical approval for the study was obtained from the Auckland University of Technology Ethics Committee (10/159).

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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