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DOCTORAL THESIS

Physical Activity and Motor Proficiency in Learning Contexts of Primary School Children: Relationships with Academic Performance.

Macdonald, Kirstin

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Physical Activity and Motor Proficiency in Learning Contexts of Primary School Children: Relationships with Academic Performance

Kirstin Andrea Macdonald

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Faculty of Health Sciences and Medicine

Associate Professor Robin Orr, Associate Professor Nikki Milne and Professor Rodney Pope

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Abstract

Levels of physical activity, physical fitness and motor skill proficiency in Australian primary school children are concerningly low and emerging evidence suggests that academic outcomes may be correlated with these factors. In children and adolescents, there is strong evidence to suggest that motor skill proficiency is favourably associated with health-related outcomes, including cardiorespiratory fitness, weight status and participation in physical activity. Thus, developing children's motor proficiency may not only improve health outcomes, but also those of an academic nature.

Primary school-aged children spend a considerable amount of their time at school. The primary school setting therefore presents an opportune environment through which to support the ongoing physical development of children, particularly their motor skill development. However, further knowledge is needed regarding the specific relationships between motor proficiency and academic outcomes in children in the early years of primary school in Australia. The frequency, type and exact context of children's physical activity occurring in early primary school classrooms must also be ascertained, along with the barriers and facilitators to increasing physical activity during school class time. Finally, it is necessary to explore the feasibility of implementing classroom-based motor skill programs to children in the early years of primary school.

Therefore, the overall objectives of this doctoral program of research were to (i) investigate relationships between motor proficiency and academic performance in mathematics and reading in children in the early years of primary school in Australia; and (ii) explore whether early primary school classrooms in Australia are feasible settings to implement physical activity, particularly motor skill programs, as a strategy to promote children's motor proficiency and academic outcomes. To meet these objectives, a progressive three-stage framework, drawn from a model for the development and evaluation of health promotion programs was employed.

Stage 1 of the thesis framework involved defining the problem and included a narrative review of the literature and a systematic review. Findings from the **Narrative review (Chapter 2)** revealed that Australian children are currently demonstrating low levels of physical activity, aerobic and muscular fitness and proficiency in motor skills. The need to explore strategies to support the physical development of Australian children, particularly within the school setting, was identified. Positive relationships between

physical activity, cognition and academic performance in children and adolescents were consistently reported in the literature. However, there is currently inconclusive evidence to support a beneficial effect of physical activity interventions on children's cognition and overall academic performance. Several key gaps in the literature were evident, including a lack of systematic reviews examining relationships between motor proficiency and specific academic outcomes in school-aged children and adolescents. Furthermore, a limited number of studies had previously examined the impact of school-based motor skill interventions, including classroom-based motor skill interventions, on children's motor proficiency and academic outcomes.

To address these gaps in the literature, a **Systematic review (Chapter 3)** was conducted to identify, critically appraise, and synthesise the findings of studies examining the relationship between motor proficiency and academic performance in mathematics and reading in typically developing school-aged children and adolescents. Eligible studies were identified and critically appraised using a modified Downs and Black checklist. A total of 55 studies (51 observational, four experimental) of low to moderate methodological quality were eligible for inclusion. Key findings from observational studies included in the review revealed significant positive associations between both fine motor skills (specifically fine motor integration and total fine motor scores) and gross motor skills (specifically upper limb coordination, speed and agility and total gross motor scores) and mathematical and reading outcomes. However, the strength of the association was highest between fine motor skills and mathematical outcomes. Findings from four experimental studies examining the impact of school-based motor skill interventions on academic and motor proficiency outcomes revealed predominantly significant intervention effects on academic and motor proficiency outcomes. However, due to limitations in the methodological quality, this systematic review concluded that studies with more robust designs are required to evaluate these findings further.

Stage 2 of the thesis framework encompassed generating solutions and was informed by three studies. The first study **(Study 1, Chapter 4)** investigated associations between fine and gross motor proficiency and academic performance in mathematics and reading in a cohort of Year 1 children in Australia. The cross-sectional study included 55 Year 1 children (25 boys, 30 girls, mean age = 6.77 ± 0.40 years) from two primary schools in New South Wales, Australia. Motor proficiency and academic performance were assessed using standardised tests, including the Bruininks-Oserestsky Test of Motor Proficiency – 2nd Edition and the Wechsler Individual Achievement Test – 2nd Edition – Australian Standardised Edition, respectively. Pearson's and/or Spearman's correlation analyses revealed total motor composite scores were significantly associated with mathematics composite scores (r = .466, p < .001). Hierarchical multiple linear regression analyses revealed that after controlling for age, fine motor precision and fine motor integration together explained 27% and 21% of the observed variance in mathematics and reading composite scores, respectively. Overall findings suggest that Year 1 children's motor proficiency was positively associated with their mathematical skills; however, it was children's fine motor integration skills that were most predictive of mathematics and reading ability.

Study 2 (Chapter 5) began to explore the feasibility of implementing physical activity, particularly motor skill programs, into early primary school classrooms in Australia by investigating existing levels of Year 1 children's physical activity and the context of this physical activity during school class time. Future opportunities to incorporate physical activity, including motor skill activities, into the Year 1 class schedule were also identified. A cross-sectional classroom observation study was thus conducted with 34 Year 1 children (20 boys, 14 girls; mean age = 6.36 ± 0.34 years) from one primary school in Queensland, Australia. A modified version of the direct observation tool, the Observational System for Recording Physical Activity in Children – Elementary School was used to record Year 1 children's physical activity and the context of this physical activity during school class time. Analysis of 44 h of observation (i.e., 5305 30 s observation intervals) revealed that Year 1 children were sedentary for the majority (86%) of observed intervals during class time. Levels of light (12% of intervals) and moderate to vigorous (2% of intervals) physical activity were observed infrequently. Organised physical activity (i.e., physical education/school sport) and classroom-based physical activity (i.e., incorporating movement into academic lessons and/or during transitions between lessons) were seldom observed (5.9% and 2.8% of intervals, respectively). Classroom-based physical activity was identified as a potential strategy to encourage children to be more active during class time.

Study 3 (Chapter 6) sought to further explore the feasibility of implementing classroom-based physical activity into early primary school classrooms. A cross-sectional survey was designed to explore the factors that may influence the provision of classroom-based physical activity to students in the early years of primary school, from the perspective of educators and school principals in Australia. A 45-item online questionnaire was administered to Australian classroom teachers and assistant, deputy and school principals working with students in Prep/Kindergarten to Year 2. Responses to closed and open-ended responses were analysed using a social ecological approach. A total of 34 of 75 participants responded to the survey (response rate 22%). Identified barriers to classroom-based physical activity included insufficient time, limited training opportunities and resources as well as educator attitudes towards physical activity and their confidence to implement physical activity programs within the school setting. Proposed solutions to overcome these barriers included the provision of training and resources, including education about the potential benefits of classroom-based physical activity for children's health and academic outcomes. Overall, multiple strategies, targeting both educators and the school, at an organisational level, were determined as being required to overcome the perceived barriers to providing classroom-based physical activity to students in the early years of school in Australia.

Having defined the problem in *Stage 1* of the thesis framework and investigated means of generating solutions in *Stage 2*, *Stage 3* of the thesis framework sought to test proposed solutions. Given the scarcity of literature evaluating outcomes of school-based motor skill interventions on children's motor proficiency and academic performance, an exploratory pilot study was conducted alongside a school-based participatory action project, to investigate whether Year 1 children exposed to a 12-week classroom-based gross motor program progressed differently to Year 1 children undertaking their regular school program in motor proficiency, mathematics and reading outcomes **(Study 4, Chapter 7)**. Fifty-five Year 1 school children in Australia (25 boys, 30 girls, mean age = 6.77 ± 0.40 years) were exposed to either (i) their normal school program or (ii) a 12-week program comprised of gross motor circuits and physically active: a) reading lessons or b) mathematics lessons. The program was designed and delivered by a registered physiotherapist, with assistance from physiotherapy and exercise science university students. The Bruininks-Oseretsky Test of Motor Proficiency – 2nd Edition and the Wechsler Individual Achievement Test – 2nd Edition – Australian Standardised Edition were used to assess motor proficiency and academic performance in mathematics and reading, respectively. Findings revealed mean change scores for the mathematics composite were significantly greater for participants exposed to active reading lessons (9.61 ± 5.62, p = .001) and active mathematics lessons (7.57 ± 5.79, p = .019) than for participants undertaking their normal Year 1 school program (0.76 ± 8.00). Mean change scores for reading (11.54 ± 7.51, p = .017) and total motor composites (6.12 ± 5.07, p = .034) were also significantly greater for participants exposed to active mathematics lessons than those undertaking their regular school program (4.47 ± 3.50 and 0.82 ± 4.38 respectively). Overall, participation in a 12-week classroom-based gross motor program, specifically a combination of gross motor circuit training and physically active mathematics lessons, was associated with improvements in motor proficiency and academic outcomes for Year 1 school children. The benefits and constraints of conducting this pilot evaluation under "real world" conditions, alongside a school-based participatory action project, were also acknowledged and discussed.

Overall findings from this doctoral program of research reveal that in Australia, Year 1 children's motor proficiency, particularly fine motor integration, was positively associated with their mathematics and reading skills. Observation of Year 1 children's existing levels of physical activity revealed they engaged in predominantly sedentary activities during school class time, thus implementing classroom-based physical activity was identified as a potential strategy to encourage children to be more active during class time. Participation in a 12-week classroom-based gross motor program, particularly a combination of gross motor circuit training and physically active mathematics lessons, was associated with improvements in motor proficiency and academic outcomes for a cohort of Year 1 school children in Australia. On this basis, early primary school classrooms in Australia may indeed be appropriate and feasible settings to implement physical activity, particularly motor skill programs, as a strategy to promote children's motor proficiency and academic outcomes. However, multiple strategies need to be employed to support school staff to trial such programs. More rigorous outcome and process evaluations are required to confirm findings from the exploratory work conducted as part of this program of research. Collectively, the results from this doctoral program of research will inform educators, schools and caregivers about relationships between motor proficiency and academic outcomes, as well as the opportunities and barriers to providing physical activity, particularly motor skill programs, to children in the early years of school during class time. Findings also highlight a potential partnership that schools could forge with allied health professionals who are qualified to assess and facilitate children's motor proficiency and promote children's health and wellbeing, as they may be able to support educators to implement these practices.

Keywords

Physical activity, motor proficiency, fine and gross motor skills, academic performance, mathematics, reading, classroom-based physical activity, primary school children

Declaration by Author

This thesis is submitted to Bond University in fulfilment of the requirements of the degree of Doctor of Philosophy by Research.

I declare that the research presented within this thesis is a product of my own original ideas and work and contains no material which has previously been submitted for a degree at this university or any other institution, except where due acknowledgement has been made.

Name: Kirstin Andrea Macdonald

Date: 18th May 2021

Declaration by Co-authors

Macdonald K, Milne N, Orr R, Pope R. Relationships between motor proficiency and academic performance in mathematics and reading in school-aged children and adolescents: a systematic review. *Int J of Environ Res and Public Health*. 2018; 15(8): 1603. doi: 10.3390/ijerph15081603 (Chapter 3)

Author contribution	Concept and design	Conducted systematic search	Critical appraisal	Data extraction and synthesis	Drafting of initial manuscript	Review of draft and final manuscripts
Kirstin Macdonald	√	√	√	√	√	√
Nikki Milne	√		√			√
Robin Orr	√		√ (kappa analysis)			√
Rodney Pope	√			√ (reviewed data extraction tables)		√

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Kirstin Macdonald	√	√	√	√	√	√
Nikki Milne	√	√ (reviewed)		√ (reviewed)		√
Robin Orr	√	√ (reviewed)				√
Rodney Pope	√	√ (reviewed)		√ (reviewed)		√

Macdonald K, Milne N, Pope R, Orr R. Directly observed physical activity of year 1 children during school class time: a cross-sectional study. *Int J of Environ Res and Public Health.* 2021; 18, 3676. doi: 10.3390/ijerph18073676 (Chapter 5)						
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Robin Orr	√	√ (reviewed)		√ (reviewed)		√
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Rodney Pope	√	√ (reviewed)		√ (reviewed)		√

Research Outputs

Peer-reviewed publications

Macdonald K, Milne N, Orr R, Pope R. Relationships between motor proficiency and academic performance in mathematics and reading in school-aged children and adolescents: a systematic review. *Int J of Environ Res and Public Health*. 2018; 15(8): 1603. doi: 10.3390/ijerph15081603

Macdonald K, Milne N, Orr R, Pope R. Associations between motor proficiency and academic performance in mathematics and reading in year 1 school children: a cross-sectional study. *BMC Pediatr.* 2020; 20: 69. doi: 10.1186/s12887-020-1967-8

Macdonald K, Milne N, Pope R, Orr R. Directly observed physical activity of year 1 children during school class time: a cross-sectional study. *Int J of Environ Res and Public Health.* 2021; 18, 3676. doi: 10.3390/ijerph18073676

Macdonald K, Milne N, Pope R, Orr R. Factors influencing the provision of classroom-based physical activity to students in the early years of primary school: a survey of educators. *Early Child Educ J.* 2020; 1-13. doi: 10.1007/s10643-020-01076-y

Macdonald K, Milne N, Pope R, Orr R. Evaluation of a 12-week classroom-based gross motor program designed to enhance motor proficiency, mathematics and reading outcomes of year 1 school children: a pilot study. *Early Child Educ J.* 2021; 1-12. doi: 10.1007/s10643-021-01199-w

Presented conference abstracts

Podium presentations (presenting author underlined):

Macdonald K, Milne N, Orr R, Pope R. Associations between motor proficiency and academic performance in mathematics and reading in year 1 school children: a cross-sectional study. 15-minute oral presentation presented at: Australian Physiotherapy Association National Conference; October 17, 2017; Sydney, Australia.

Macdonald K, Milne N, Orr R, Pope, R. Impact of a 12-week classroom-based gross motor program on motor proficiency, mathematics and reading performance of year 1 school children. 8-minute oral presentation presented at: World Confederation for Physical Therapy Congress; May 11, 2019; Geneva, Switzerland.

Macdonald K, Milne N, Orr R, Pope R. Relationships between motor proficiency and academic performance in mathematics and reading in school-aged children and adolescents: a systematic review. 8-minute oral presentation presented at: World Confederation for Physical Therapy Congress; May 12, 2019; Geneva, Switzerland.

Macdonald K, Milne N, Pope R, Orr R. Year 1 children are sedentary during school class time and can move more. 15-minute oral presentation presented at: Australian Physiotherapy Association National Conference; October 19, 2019; Adelaide, Australia.

e-Poster presentations

Macdonald K, Milne N, Pope R, Orr R. Facilitators and barriers for providing classroom-based physical activity to students in the early years of primary school: a pilot survey. 10-minute e-Poster oral presentation presented at: Australian Physiotherapy Association National Conference; October 19, 2019; Adelaide, Australia.

Please see Appendix E and Appendix F for a copy of the certificate of presentation received for presenting at the World Confederation for Physical Therapy Congress in Geneva, Switzerland in May 2019.

Ethics Declaration

The research associated with this thesis received ethics approval from the Bond University Human Research Ethics Committee. As this research also involved school student and staff participants, in order to conduct research in selected schools, research approval was obtained from several school jurisdictions in Australia.

Bond University Human Research Ethics Committee Application Number	**Research approval from selected school jurisdictions in Australia**
RO1836	1. State Education Research Approval Process in New South Wales, Australia (Reference number: 2014075)
15547	1. Queensland Department of Education (Reference number: 17/77163) 2. State Education Research Approval Process in New South Wales, Australia (Reference number: 2017031) 3. Brisbane Catholic Education Research Committee (Reference number: 242)
KM03093	1. State Education Research Approval Process in New South Wales, Australia (Reference number: 2019177) 2. Queensland Department of Education (Reference number: 550/27/2157) 3. ACT Education Directorate Research Services (Reference number: RES-1910)

Ethics and research approval letters as well as participant information sheets and consent forms for each study included in this doctoral program of research are available upon request.

Copyright Declaration

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Chapter 3: https://www.mdpi.com/1660-4601/15/8/1603

Macdonald K, Milne N, Orr R, Pope R. Relationships between motor proficiency and academic performance in mathematics and reading in school-aged children and adolescents: a systematic review. *Int J of Environ Res and Public Health*. 2018; 15(8): 1603. doi: 10.3390/ijerph15081603 under Creative Commons Attribution Licence (CC BY 4.0)

Chapter 4: https://bmcpediatr.biomedcentral.com/articles/10.1186/s12887-020-1967-8

Macdonald K, Milne N, Orr R, Pope R. Associations between motor proficiency and academic performance in mathematics and reading in year 1 school children: a cross-sectional study. *BMC Pediatr.* 2020; 20: 69. doi: 10.1186/s12887-020-1967-8 under Creative Commons Attribution Licence (CC BY 4.0)

Chapter 5: https://www.mdpi.com/1660-4601/18/7/3676.

Macdonald K, Milne N, Pope R, Orr R. Directly observed physical activity of year 1 children during school class time: a cross-sectional study. *Int J of Environ Res and Public Health.* 2021; 18, 3676. doi: 10.3390/ijerph18073676 under Creative Commons Attribution Licence (CC BY 4.0)

Chapter 6: https://link.springer.com/article/10.1007%2Fs10643-020-01076-y#citeas

Macdonald K, Milne N, Pope R, Orr R. Factors influencing the provision of classroom-based physical activity to students in the early years of primary school: a survey of educators. *Early Child Educ J.* 2020; 1-13. doi: 10.1007/s10643-020-01076-y under Creative Commons Attribution Licence (CC BY 4.0)

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Chapter 7: http://link.springer.com/article/10.1007/s10643-021-01199-w

Macdonald K, Milne N, Pope R, Orr R. Evaluation of a 12-week classroom-based gross motor program designed to enhance motor proficiency, mathematics and reading outcomes of year 1 school children: a pilot study. *Early Child Educ J.* 2021; 1-12. doi: 10.1007/s10643-021-01199-w Copyright © 2021. Reproduced with permission from Springer Nature.

Acknowledgements

As a registered physiotherapist of 16 years, I have always been passionate about health and fitness and encouraging others to lead a healthy lifestyle. I was fortunate to have an active childhood and I feel this early exposure to physical activity and participation in sport helped shape my interest and lifelong commitment to leading an active lifestyle. Throughout my career as a physiotherapist, I have been a strong advocate for preventative health, as I believe that everyone deserves to be educated on how they can look after themselves to stave off future illness.

Over the last eight years I have developed a particular interest in preventative health for children and young people. I have been able to pursue my passion for promoting the health and wellbeing of children and young people through my appointment of two positions that involved coordinating health promotion projects in the early childcare setting (the *Kids at Play* project), as well as the primary and secondary school settings (the *Tweed Healthy Schools* project). These unique experiences consolidated my special interest in children's health and learning and inspired me to undertake a PhD in this field. Therefore, I feel very fortunate to have had the opportunity to complete a doctoral program of research on a topic that is so meaningful to me and I would like to acknowledge those around me who have supported me along the way.

The African proverb '*it takes a village'* is often used to refer to the collective effort required by members of the community to successfully support children to grow and prosper. I believe this phrase also encapsulates what is required to successfully undertake and complete a PhD. The support that I have received from my research supervision team, my peers (both work colleagues and fellow HDR students) and especially my family, has enabled me to achieve this milestone of submitting my thesis for examination.

It is important to acknowledge that I endured a steep learning curve during the first few years of my candidature. Although supported by my research supervision team, Nikki, Rob and Rod, the autonomy that postgraduate research afforded me meant that I was often pushed outside my comfort zone and I had to learn how to navigate the challenges that arose throughout my candidature. However, without facing challenges, I don't believe I would have grown as much as a person and as a researcher. Thus, as I reflect upon the last seven years of my candidature, I am able to truly appreciate all the lessons that I have learned along the way. Therefore, I would like to thank my research supervision team for allowing me to grow as a researcher by encouraging me to be autonomous whilst also providing me with enough support and guidance. I am particularly grateful for how responsive my supervision team has always been in providing feedback to ensure that deadlines and milestones were met. Rob – thank you for taking on the important role as my primary supervisor and for your ongoing encouragement particularly during the final, crucial stages of my candidature. Thank you also for your generosity and encouraging me to attend conferences and submit my work for peer-review so that I could share my work with like-minded researchers and clinicians. Nikki – thank you for the invaluable role you have played in this supervision team; our shared vision and passion for children's health and development has kept me motivated and inspired. Thank you for sharing your expertise as a paediatric physiotherapist and researcher with me and for your invaluable contribution to various components of this program of research. Rod – thank you for sharing your incredible wisdom and research expertise with me – you have been an important role model to me throughout my candidature and I feel fortunate to have had this opportunity to work with you and learn from you. Throughout my candidature, I have often found it challenging to juggle being a PhD candidate whilst also being employed full-time as a Senior Teaching Fellow with the Doctor of Physiotherapy program at Bond University. However, I was always encouraged by my team to maintain focus and momentum, whilst still acknowledging the importance of trying to maintain a balanced life outside of work/study. Overall, Rob, Nikki and Rod, thank you for sharing your unique strengths with me – I have learned a considerable amount through working with you and I appreciate this immensely.

I would also like to acknowledge and thank the staff and children from the primary schools who participated in the studies. It was a privilege to spend time immersed within the primary school environment to gain a deeper understanding of the school culture and routines, as well as the Year 1 Australian Curriculum. I was fortunate to work with several school principals and Year 1 classroom teachers who taught me so much through their ability to be role models to their students and wear many 'hats' as educators. In 2013, I was appointed as the Clinical Coordinator of the *Tweed Healthy Schools Project* (THSP), a school-based, interprofessional clinical placement program for university health professional students. Through this role I had the opportunity to

supervise, support and mentor 44 university health professional students from different disciplines including physiotherapy, exercise science, nutrition and dietetics, occupational therapy, speech-language pathology, and public health. The university health professional students, particularly the physiotherapy and exercise science students, were instrumental in assisting with the assessment of children's motor proficiency, as well assisting with the delivery of the 12-week classroom-based gross motor program with Year 1 children under my supervision so a big thank you to them too.

Given the part-time nature of my candidature, I have proudly watched many of my HDR peers successfully complete their PhDs and hoped that one day I could join them. I have often felt moved by the support that my peers have offered me and each other as they have understood perfectly what it is like to go through this research journey. I would like to thank many of the HDR students I have been lucky to cross paths with for the impromptu chats and debriefs. However, to my dear friends Jess and Damon in particular – you have been an incredible support and I cannot thank you enough for your wonderful friendship.

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partner and best friend Matt, thank you for standing by my side through the good times and the challenging times. Your ongoing encouragement, support and belief in me has made it all the more possible to achieve this lifelong goal.

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List of Abbreviations

Australian Curriculum, Assessment and Reporting Authority	ACARA
Australian Early Development Census	AEDC
Australian Early Development Instrument	AEDI
Analysis of Variance statistic	ANOVA
Bruininks-Oseretsky Test of Motor Proficiency – 2nd Edition	BOT-2
Bond University Human Research Ethics Committee	BUHREC
Classroom-based Physical Activity	CBPA
Cardiorespiratory Fitness	CRF
Comprehensive School Physical Activity Program	CSPAP
Fundamental Movement Skills	FMS
Health and Physical Education	HPE
Health Promoting School	HPS
Index of Community Socio-Educational Advantage	ICSEA
Moderate to Vigorous Physical Activity	MVPA
Observation System for Recording Physical Activity in Children – Elementary School	OSRAC-E
Physical Activity	PA
Professional Development	PD
Physical Education	PE
Randomised Controlled Trial	RCT
Socioeconomic Status	SES
Standard Deviation	SD
Tweed Healthy Schools Project	THSP
Wechsler Individual Achievement Test – 2nd Edition – Australian Standardised Edition	WIAT-II Australian

Chapter 1: Introduction

1.1 Background

Experiences during the early childhood period are crucial for children's physical, cognitive, social and emotional development and are closely linked to health, education and social outcomes during adulthood.[1] Consequently, in Australia, early childhood educators employ holistic approaches to teaching and learning that aim to promote advancement across multiple domains of children's development.[2] However, upon entry to primary school, the main focus of learning is for children to develop skills in numeracy and literacy.[3] As a result, less time may be allocated in the school curriculum to target children's ongoing physical development, particularly their motor development, given competing academic demands.

Prioritising the ongoing physical development of Australian children in the early years of primary school is imperative, given findings from the Australian Early Development Census (AEDC) that one in five children in their first year of full-time school are considered either developmentally at risk or developmentally vulnerable on the physical health and wellbeing domain.[4] The physical health and wellbeing domain assesses the development of a child's fine and gross motor skills, along with their physical independence and physical readiness for the school day. Poor or delayed motor skill development may be attributed to biological factors, for example, a motor impairment due to an underlying developmental condition such as Cerebral Palsy or Developmental Coordination Disorder.[5] However, environmental and sociocultural factors such as a lack of exposure to, and/or practice of, motor skills may also lead to a child having poor or delayed motor skill development.[5] The development of motor skills during the early childhood period is considered critical for promoting other areas of development, including cognitive and social emotional development.[6,7] Therefore, it is essential that children in the early years of primary school are provided opportunities to practice and refine their motor skills and that educators identify early any children presenting to school with poor or delayed motor skill development.[5]

The development of motor skill proficiency may also influence a child's ability to participate in physical activity (PA), both directly and indirectly, across the lifespan.[8] For example, in children and adolescents, there is strong evidence to support that motor skill proficiency is favourably associated with health-related outcomes, including cardiorespiratory fitness (CRF), weight status,[9,10] as well as participation in PA.[9,11,12]

Therefore, one potential strategy to further promote the physical development of children, beyond the regular primary school physical education (PE) program, may be through the implementation of school-based motor skill programs.[13-15] School-based motor skill programs aim to improve children's motor proficiency through the delivery of structured motor skill activities that are developmentally appropriate.[13,14] Identifying novel strategies such as these in Australia are becoming increasingly important, as national statistics suggest that children and young people are not active enough and overall, they are failing to meet the recommended 60 minutes of moderate to vigorous physical activity (MVPA) each day.[16] Similar trends are evident in children's aerobic and muscular fitness and proficiency in movement skills.[16] In fact, a decline in the muscular fitness of Australian children (as measured by standing long jump distance) over the last 30 years has recently been reported.[16-18] Similarly, Australian boys and girls are demonstrating low levels of mastery of fundamental movement skills, specifically object control and locomotor skills, as assessed in Grade 6 (i.e., at 11 or 12 years of age) when ideally they should have achieved competency of these movement skills by this year level.[19] Collectively, these trends are concerning, given that physical inactivity has been identified globally as the fourth leading cause of death due to non-communicable diseases[20] and, specifically in children and young people, physical inactivity is associated with adverse physical, mental, social-emotional and cognitive outcomes.[21]

Global figures estimate that 90% of children are enrolled in primary school.[22,23] Given that healthy habits and behaviours are formed during the early childhood period,[24] and that children spend a considerable amount of their time attending school, primary schools are ideally placed to positively influence the physical development and PA behaviour of children as they transition to the school setting. On this basis, there is a need to identify how schools can facilitate the ongoing physical development of children in the early years of primary school. However, as the priority for schools is to foster the educational outcomes of students, it is essential that strategies to promote children's physical development do not adversely impact educational outcomes.[24,25]

To advocate to schools and educators for the importance of prioritising time during the school day to provide students with opportunities to move and be active, a rapidly expanding body of research has examined relationships between PA, cognition and academic performance in children and adolescents. The term physical activity (PA) is commonly defined as '*any bodily movement produced by skeletal muscles that requires energy expenditure'*.[26] Therefore, in this body of literature, PA has been described as a broad umbrella term that encompasses the independent variables examined in studies on this topic, for example, objectively/subjectively measured PA, physical fitness, sports participation and school physical education programs.[27] Similarly, cognitive function (e.g., executive functions, attention, memory) and academic performance (e.g., results from academic achievement tests, school grades and classroom behaviour) are umbrella terms that encompass the dependent variables examined in studies. Observational studies have investigated cross-sectional and longitudinal relationships between various PA-related variables (independent variables) and cognition and academic performance (dependent variables).[28-30] Experimental studies have sought to investigate causality, by examining the effect of PA interventions on children's cognition and academic performance, and in some cases, children's PA-related outcomes.[28-34] Each of these terms will be defined more comprehensively in Chapter 2 (Sections 2.3 and 2.4).

A review of the empirical literature to date suggests that significant, positive relationships exist between PA, cognition and academic performance in children and adolescents. However, despite favourable findings from experimental studies reporting beneficial effects of PA interventions on children's cognition and academic performance, collectively, results are mixed and appear to be inconclusive.[28-35] Furthermore, it has been suggested that health-related physical fitness (e.g., CRF) and proficiency in complex motor skills (e.g., bilateral limb coordination) may differ in the way they relate to cognition and academic performance.[36,37] In fact, several recently published systematic reviews have suggested that PA interventions utilising cognitively engaging types of PA (i.e., PA which involves complex motor and cognitively challenging tasks that require problem solving) may be more beneficial for children's cognition and academic outcomes than PA interventions focussing on purely aerobic types of PA.[33,34] Hypotheses regarding the mechanisms that may underpin the PA-cognition relationship continue to be tested and stem from research conducted by multiple disciplines including exercise and cognition, developmental neuroscience, motor development, motor learning and motor control.[38-41] Each of these mechanisms will be discussed in further detail in Chapter 2 (Section 2.5).

The effectiveness of school-based PA interventions, particularly classroom-based PA interventions, for influencing children's health and educational outcomes has also been evaluated with keen interest over the last decade.[42-46] Classroom-based PA involves incorporating PA into academic lessons (i.e., physically active academic lessons) and/or scheduling PA breaks during the school day (with or without an academic focus).[46] Findings reveal promising preliminary evidence of higher levels of PA, improved on-task behaviour, and academic outcomes in children following classroom-based PA interventions; particularly physically active academic lessons, compared to the regular academic program.[43,44] However, due to limitations in the methodological quality of studies included in previous reviews, further research has been recommended to investigate more extensively the design and parameters of effective classroom-based PA interventions.[44-46]

Despite the volume of research examining relationships between PA, cognition and academic performance, it remains unclear which independent variables relating to PA (i.e., objectively and subjectively measured PA, components of health-related physical fitness, motor proficiency, physical education, sports participation, etc.) and their associated parameters (i.e., intensity, duration, frequency etc.) are most strongly associated with cognition and academic performance in school-aged children and adolescents. To investigate relationships between PA, cognition and academic performance, the independent variables that studies have predominantly examined include objectively or subjectively measured PA and/or the components of health-related physical fitness (e.g., CRF, muscular strength/endurance).[30] Fewer studies examining this broad topic have evaluated the performance-related (or skill-related) components of physical fitness, or motor proficiency (e.g., coordination, balance, speed and agility) as an independent variable in observational studies, or evaluated motor proficiency as an outcome (in addition to academic and cognitive outcomes) in experimental studies following school-based motor skill interventions.[37] In fact, systematic and narrative reviews examining the relationship between motor proficiency, cognition and academic performance are limited.[37,47] Furthermore, previous reviews have not explored relationships between motor proficiency and specific domains of academic performance (e.g., mathematics and reading) in children and adolescents.[47] Distinctions between specific academic domains such as mathematics and reading are of importance given that numeracy and literacy are considered priority areas of the

Australian primary school curriculum. In order to design and evaluate effective classroom-based PA interventions to investigate whether they enhance both academic and PA-related outcomes, it is also important to ascertain the most effective types of PA to utilise in interventions (e.g., aerobic, motor skills, resistance, flexibility or a combination).[32] For example, to date, the majority of studies have included aerobic activities as part of their classroom-based PA interventions with fewer studies including gross motor skill activities as part of their intervention.[48] Knowledge of other effective parameters of classroom-based PA interventions (e.g., intensity, duration, frequency, the degree of cognitive engagement involved in active lessons or breaks) is also required.

For educators in Australia to consider prioritising time during the school day to provide opportunities for children in the early years of primary school to further develop and refine their motor skills and to be active, two key lines of enquiry are warranted. Firstly, there is a need to advance understanding regarding the relationship between motor proficiency and academic outcomes, particularly numeracy and literacy, which are considered priority areas of the Foundation to Year 2 Australian Curriculum.[3] This area of focus differs from previous research that has primarily investigated CRF or levels of PA as the core aspects of children's physical development to target within the school setting. If motor proficiency is positively associated with both health-related (i.e., CRF and PA levels) and academic outcomes (e.g., mathematics and reading), the early years of primary school may represent an ideal time to support children to further develop and refine their motor skills within the school setting. This is particularly important given that children's motor skill development is crucial for other areas of their development, including cognitive and social emotional development, during the early childhood period (i.e., up to 8 years of age).[6,7,49,50]

Secondly, there is a need to explore whether early primary school classrooms are feasible settings to implement PA, particularly motor skill programs, as a strategy to promote children's motor proficiency and academic outcomes. To do this, it is necessary to establish existing practices in Australia regarding the frequency, type and context of PA opportunities being provided to students in the early years of primary school during class time. To successfully implement, reproduce and sustain school-based PA interventions under 'real-world' conditions, it is also important to identify which PA opportunities may be the most realistic and practical for educators in

Australia to incorporate into an already busy classroom schedule.[51] Further, it is essential to examine the factors (barriers and facilitators) which may influence the provision of PA opportunities to students in the early years of school, specifically from the perspective of educators and school principals in Australia. Finally, given the scarcity of literature examining the effectiveness of school-based motor skill interventions on children's motor proficiency and academic outcomes, further knowledge of the potential outcomes of implementing a 12-week classroom-based gross motor program during the early years of primary school is also warranted. Therefore, this doctoral program of research was designed to address these key gaps in knowledge, as outlined in the following section.

1.2 Overview of the doctoral program of research

The overall objectives of this doctoral program of research were to (i) investigate the relationship between motor proficiency and academic performance in mathematics and reading in children in the early years of primary school in Australia; and (ii) explore whether early primary school classrooms in Australia are feasible settings to implement physical activity, particularly motor skill programs, as a strategy to promote children's motor proficiency and academic outcomes.

1.2.1 Framework utilised to describe the stages of this doctoral program of research

A public health model, specifically a health promotion model, was used as the overarching framework to describe the three stages of this doctoral program of research. The first three of these stages arise from the six stages of research required to develop and evaluate a health promotion program, as proposed by Nutbeam[52] in 1998 (Figure 1).

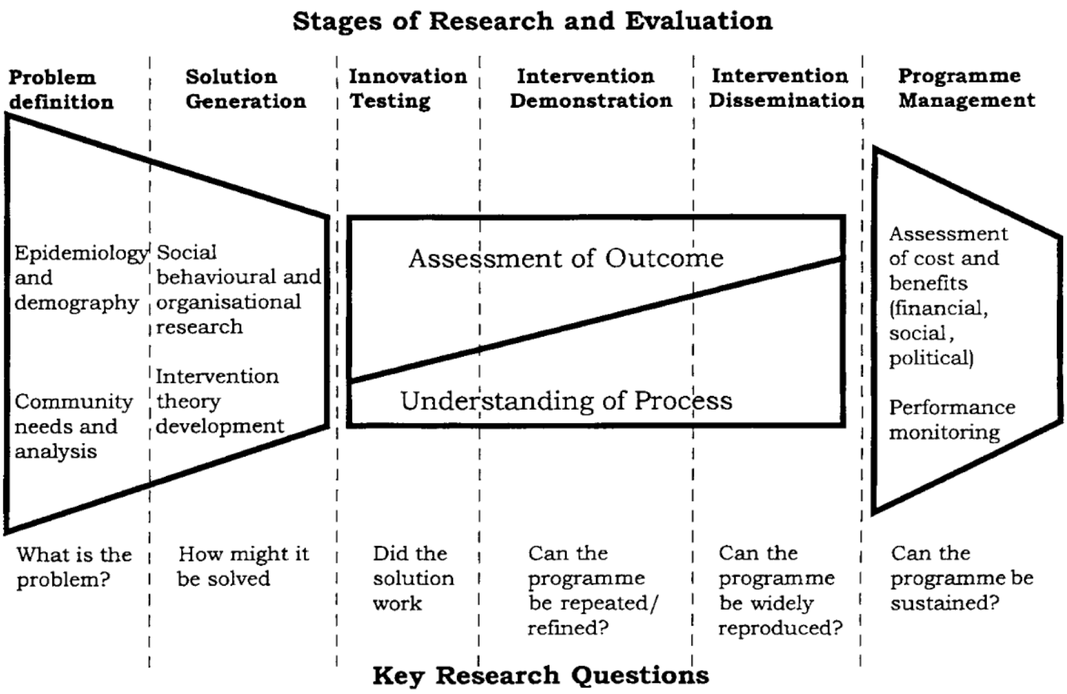

Figure 1: Six-stage development model for the evaluation of health promotion programs. Nutbeam, D. Evaluating health promotion—progress, problems and solutions. Health Promot Int, 1998, *13*, 27-44, p8, by permission of Oxford University Press.[52]

A number of stages are involved in developing and implementing a health promotion program, including (i) stage one: defining the problem within a target population and identifying the potential causes of the problem; (ii) stage two: generating a potential solution to address the problem; (iii) stage three: testing a solution to address the problem (i.e. outcome evaluation); (iv) stage four: identifying conditions for success and testing the solution in circumstances which are closer to 'real-life' (i.e., process evaluation); (v) stage five: widespread dissemination of the successful solution; and (vi) stage six: program management and sustainability.[52]

1.2.2 Stages, aims and hypotheses of this doctoral program of research

The studies and chapters of this doctoral program of research are derived from stages one to three of the six stages involved in developing a health promotion solution (i.e., the provision of classroom-based gross motor programs to children in the early years of primary school as a strategy to promote children's motor proficiency and academic outcomes). The following research aims were thus pursued across these three progressive stages.[52]

1.2.2.1 Stage 1: Defining the problem

The focus, under this stage of the program of research, was to:

1. Summarise existing trends in Australian children's levels of physical activity, physical fitness, and motor proficiency; to examine and discuss key theoretical and empirical concepts relating to early childhood development; and to summarise existing literature examining relationships between PA, cognition, and academic performance **(Narrative review, Chapter 2)**.
2. Identify, critically appraise, and synthesise the findings of studies examining the relationship between motor proficiency and academic performance in mathematics and reading in typically developing school-aged children and adolescents **(Systematic review, Chapter 3)**.

1.2.2.2 Stage 2: Generating solutions

The focus, under this stage of the program of research, was to explore solutions to the problem identified in Stage 1 and thus:

3. Examine associations between fine and gross motor proficiency and academic performance in mathematics and reading in Year 1 children **(Study 1, Chapter 4)**.
4. Directly observe Year 1 children's physical activity and the context of their physical activity during school class time and identify opportunities to incorporate additional activity **(Study 2, Chapter 5)**.
5. Examine the factors that influence the provision of classroom-based physical activity to students in the early years of primary school in Australia, within a social ecological framework **(Study 3, Chapter 6)**.

1.2.2.3 Stage 3: Testing proposed solutions

The focus, under this stage of the program of research, was to test a proposed solution and thus:

6. Explore whether Year 1 school children exposed to a 12-week classroom-based gross motor program, comprised of gross motor circuit training and physically active reading or mathematics lessons, progressed differently to Year 1 children undertaking their regular school program in motor proficiency, mathematics and reading outcomes **(Study 4, Chapter 7)**.

1.2.2.4 Hypotheses

The following hypotheses were proposed for Studies 1 to 4 that were conducted as part of this program of research:

I. Motor proficiency will be positively related to academic performance in mathematics and reading. However, it was anticipated that the components of fine motor proficiency will be more strongly related to mathematics and reading outcomes than the components of gross motor proficiency **(Study 1, Chapter 4)**.

II. Year 1 children will be predominantly sedentary during school class time, with limited opportunities to engage in active lessons and active breaks **(Study 2, Chapter 5).**

III. Multiple individual and organisation level factors, particularly time, will be identified as influencing the provision of classroom-based physical activity to students in the early years of primary school in Australia **(Study 3, Chapter 6).**

IV. Year 1 children who participate in a 12-week classroom-based gross motor program will demonstrate greater improvements in academic outcomes, particularly mathematics, and motor proficiency outcomes, when compared to the Year 1 children undertaking their regular school program **(Study 4, Chapter 7).**

Figure 2 provides an overview of this doctoral program of research for ease of navigation through the thesis. Together, the collective findings from the systematic review and four studies included in this doctoral program of research will elucidate in more detail than previously reported, relationships between motor proficiency and academic performance (in reading and mathematics) of children in the early years of primary school. Findings will also shed light upon whether early primary school classrooms are feasible settings to implement PA, particularly motor skill programs, as a strategy to promote children's motor proficiency and academic outcomes. Key results from this doctoral program of research will be applicable to children enrolled in the early years of primary school in Australia and will thus be relevant to schools, educators and caregivers, as well as allied health professionals working in schools who are qualified to assess and facilitate children's motor proficiency and promote children's health and wellbeing. Crucial lessons learned whilst conducting research in schools will also be outlined, which will be useful in guiding future investigations on this topic.[1]

[1] Please note that all references in this chapter are presented in the References section of the thesis

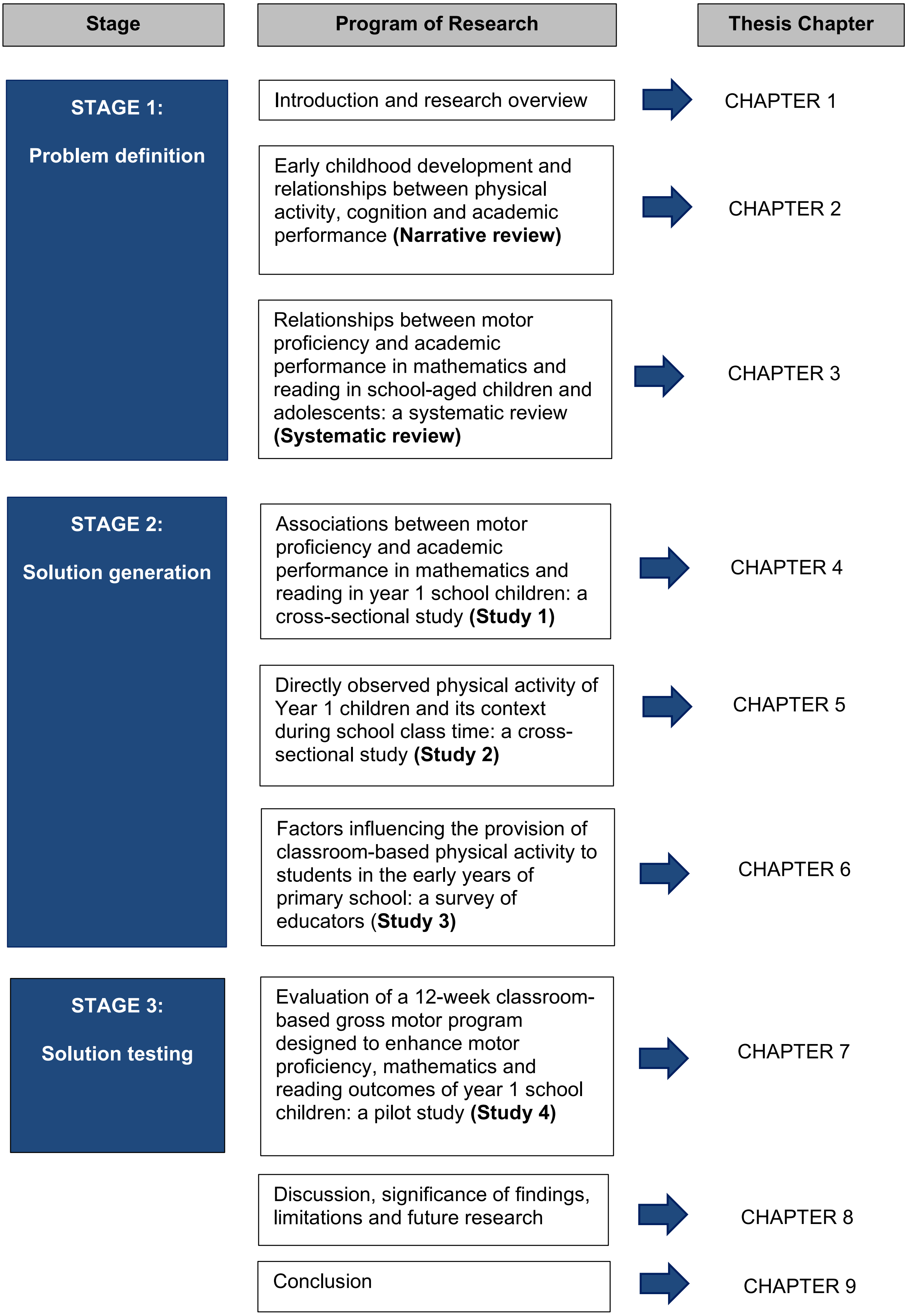

Figure 2: Overview of the proposed doctoral program of research.

Chapter 2: Narrative Review of the Literature

2.1 Preface

The following chapter provides the rationale and relevant context that informed the development of the objectives and study aims for this doctoral program of research and forms part of *Stage 1* of the thesis framework, *defining the problem*. To clearly highlight the importance of undertaking this program of research, existing trends in the physical development of Australian children are outlined. Evidence to support the relationship between motor skill proficiency, health-related physical fitness and participation in physical activity (PA) is also presented, providing the justification for focussing on motor proficiency as a core aspect of children's physical development to promote within the early years of primary school. Given that motor skill development is crucial for other areas of children's development, relationships specifically between motor and cognitive development are discussed as a possible origin for the proposed PA-cognition link. Findings from research investigating relationships between PA, cognition and academic performance in children and adolescents are summarised, identifying gaps in the literature that require further examination. Finally, a rationale is provided for exploring early primary school classrooms in Australia as potentially feasible settings to implement PA, particularly motor skill programs, as a strategy to promote children's motor proficiency and academic outcomes.

2.2 Introduction

To address the first stage of this program of research, *defining the problem*, a thorough narrative review of the literature has been undertaken. The aims of this narrative review were to summarise existing trends in Australian children's levels of PA, physical fitness and motor proficiency; to examine and discuss the key theoretical and empirical concepts relating to early childhood development; and to summarise existing literature examining relationships between PA, cognition and academic performance. Specifically, this narrative review: (i) provides an overview of childhood development in Australia, including a description of how children in their first year of full-time school are progressing in two key developmental domains; physical health and wellbeing, and language and cognitive skills; (ii) outlines trends in Australian children's PA levels, aerobic and muscular fitness, and movement skills, based on data collected through state and national surveys and studies; (iii) describes known relationships between motor skill proficiency, health-related physical fitness, and PA; (iv) examines theories that underpin early childhood development, highlighting how each theory contributes to the pedagogy utilised today by educators to promote children's learning and development – theories of motor and cognitive development are specifically discussed, followed by an overview of research examining the relationship between motor and cognitive development; (v) summarises existing literature on the broad topic of the relationship between PA, cognition and academic performance, (vi) explores the school as a setting for health and PA promotion; and (vii) provides an overview of the literature examining the effectiveness of classroom-based PA interventions within the school setting.

2.3 Childhood development in Australia

2.3.1 A snapshot of early childhood development in Australia

Early childhood development encompasses the period from conception to eight years of age and refers to the process of cognitive, physical, language, temperament, socioemotional and motor development of children.[49,50] Evidence suggests that fostering the physical, cognitive, emotional and social development of children in their early years is imperative for successful health, education and social outcomes during adulthood.[4,53] The Australian Early Development Census (AEDC) was introduced in 2009 and provides information about how well children in their first year of full-time school in Australia are developing across five developmental domains that have been shown to predict later health, wellbeing, and academic outcomes (Table 1).[4]

Table 1: Descriptions of the five key developmental domains of the Australian Early Development Census.[4(p8)] Reprinted by permission Commonwealth of Australia, *Australian Early Development Census National Report 2018: A snapshot of early childhood development in Australia*. Department of Education, Skills and Employment: Canberra © 2019

Domain	Description
Physical health and wellbeing	This domain assesses the development of a child's gross and fine motor skills, along with their physical independence and physical readiness for the school day.
Social competence	This domain measures a child's ability to engage with others, including developing an understanding of their responsibilities and respect for those they interact with. A child's approach and readiness to learn is also assessed within this domain.
Emotional maturity	This domain assesses a child's behaviour and how they relate to others. It measures the presence of pro-social and helping behaviours, anxiety, fearful or aggressive behaviour, or hyperactivity and inattentive behaviour.
Language and cognitive skills (school-based)	This domain measures the way in which a child organises information through school-based literacy and numeracy skills as well as their interest in literacy, numeracy and memory.
Communication skills and general knowledge	This domain assesses a child's communication skills and general knowledge. This is based on broad developmental skills and competencies.

The Australian Early Development Instrument (AEDI) is the tool used to collect data as part of the census and was adapted from the Early Development Instrument originally developed in Canada. The AEDI is comprised of 100 questions relating to the five developmental domains. Classroom teachers participating in the census are required to complete the AEDI for each child in their class. Responses from questions in the AEDI are used to calculate a score for each domain. The number and percentage of children considered to be "developmentally on track", "developmentally at risk" or "developmentally vulnerable" for each of the domains is reported on a community, state/territory and national level and presented in an AEDC National Report.[4] Results from the AEDC National Report highlight the frequency and geographical location of children who are considered developmentally vulnerable in different communities across Australia. Findings are subsequently used to guide the allocation of resources and early intervention support, particularly within the school setting, as it is recognised that investing during the early years is important given the rapid brain development that occurs during this period.[4]

To date, AEDC data has been collected over four time points, these being in 2009, 2012, 2015 and 2018. The 2018 AEDC National Report provides the most recent snapshot of early childhood development. Data were collected for approximately 96.4% (n = 308953) of Australian children in their first year of full-time school (51.4% boys, 48.6% girls; mean age = 5 years, 7 months).[4] Findings revealed that approximately 21.7% (n = 63448) of Australian children were considered developmentally vulnerable in one or more domains, and 11% (n = 32434) of children were considered developmentally vulnerable in two or more domains.[4] Notably, 45.5% of children who resided in very remote Australia, compared to 20.8% of children from major cities, were considered developmentally vulnerable in one or more domains. Additionally, 32.3% of children living in the most socio-economically disadvantaged areas were considered developmentally vulnerable in one domain, compared to 14.7% of children living in the least disadvantaged communities. Approximately 4.6% of Australian children were also identified as having chronic medical, physical or intellectual needs and 13.3% of all children were identified as requiring further assessment of their learning needs.[4]

The two developmental domains of the AEDC most relevant to this doctoral program of research include the *physical health and wellbeing* domain and the *language and cognitive skills (school-based)* domain. A summary of the characteristics of these two domains from the 2018 AEDC National Report[4] is provided in Table 2. Whilst it is acknowledged that the other three domains of the AEDC regarding children's social and emotional development and communication skills are equally important for children's development, a detailed summary of findings for these domains is not provided here but may be found in the original document.[4]

Table 2: Characteristics of the physical health and wellbeing domain and the language and cognitive skills (school-based) domain.[4(pp17,32)] Reprinted by permission Commonwealth of Australia, *Australian Early Development Census National Report 2018: A snapshot of early childhood development in Australia*. Department of Education, Skills and Employment: Canberra © 2019

Developmental domain	Developmentally on track	Developmentally at risk	Developmentally vulnerable
Physical health and wellbeing	Almost never have problems that interfere with their ability to physically cope with the school day. These children are generally independent, have excellent motor skills, and have energy levels that can get them through the school day.	Experience some challenges that interfere with their ability to physically cope with the school day. These may include being dressed inappropriately, frequently late, hungry or tired. Children may also show poor coordination skills, have poor fine and gross motor skills, or show poor to average energy levels during the school day.	Experience a number of challenges that interfere with their ability to physically cope with the school day. These may include being dressed inappropriately, frequently late, hungry or tired. Children are usually clumsy and may have fading energy levels.
Language and cognitive (school-based)	Children will be interested in books, reading and writing, and basic maths; capable of reading and writing simple sentences and complex words. Will be able to count and recognise numbers and shapes.	Have mastered some but not all of the following literacy and numeracy skills: being able to identify some letters and attach sounds to some letters, show awareness of rhyming words, know writing directions, being able to write their own name, count to 20, recognise shapes and numbers, compare numbers, sort and classify, and understand simple time concepts. Children may have difficulty remembering things, and show a lack of interest in books, reading, maths and numbers, and may not have mastered more advanced literacy skills such as reading and writing simple words or sentences.	Experience a number of challenges in reading/writing and with numbers; unable to read and write simple words, will be uninterested in trying, and often unable to attach sounds to letters. Children will have difficulty remembering things, counting to 20, and recognising and comparing numbers; and are usually not interested in numbers.

Findings from the 2018 AEDC National Report[4] reveal that upon entry to primary school, whilst 78.1% (n = 229542) of children were considered developmentally on track in the physical health and wellbeing domain, 21.9% of children were considered either developmentally at risk (12.3%; n = 36105) or developmentally vulnerable (9.6%; n = 28247). Furthermore, there was a significant increase in the percentage of children considered developmentally vulnerable in the physical health and wellbeing domain in 2018 (9.6%), when compared to baseline values collected in 2009 (9.3%).[4] In relation to the language and cognitive skills domain, in 2018, 84.4% (*n* = 247870) of children were considered developmentally on track, 9.0% (*n* = 26291) of children were considered developmentally at risk and 6.6% (*n* = 19417) of children were considered developmentally vulnerable.[4] A significant decrease was evident in the percentage of children considered developmentally vulnerable in the language and cognitive skills domain in 2018 (6.6%), when compared to baseline values collected in 2009 (8.9%).[4]

Overall, whilst trends in the AEDC National Report from 2009 to 2018 demonstrate improvements in the number of Australian children considered developmentally vulnerable in the language and cognitive skills domain in their first year of full-time school, these improvements are not evident in trends for children considered developmentally vulnerable in the physical health and wellbeing domain.[4] These trends in the physical health and wellbeing domain highlight the ongoing need for schools to ensure they support children's physical health and wellbeing in the early years of primary school.

2.3.2 A snapshot of Australian children's physical activity, physical fitness, and motor skill development

2.3.2.1 Key definitions

Key terms and definitions commonly used throughout this program of research are discussed in this section prior to providing a snapshot of Australian children's PA, physical fitness and motor skill development. **Physical activity (PA)** is commonly defined as *'any bodily movement produced by skeletal muscles that requires energy expenditure'*.[26] PA has also been described as a complex and multi-faceted behaviour,[54] comprised of several dimensions including duration, frequency, intensity, type (or mode) and domain.[55,56] **Exercise** is '*physical activity that is planned and structured and aims to improve or maintain physical fitness*'[26] and is considered a subset of PA. **Physical fitness** is defined as '*a set of inherent or achieved personal attributes that relate to the ability to perform physical activity',*[26] and can be separated into health-related components and performance/skill-related components.[56] **Motor skills** are defined as '*activities or tasks that require voluntary control over movements of the joints and body segments to achieve a goal*'.[57] **Gross motor skills** are '*motor *skills that require the use of large musculature to achieve the goal of the skill'*, whereas **fine motor skills** are '*motor skills that require control of small muscles to achieve the goal of the skill; typically involves eye-hand coordination and requires a high degree of precision of hand and finger movement*'.[57] **Fundamental movement skills (FMS)** are described as '*the building blocks of more advanced, complex movements required to participate in games, sports or other context specific physical activity'.*[58] More recently, the term foundational movement skills has been proposed as a more suitable term than FMS as it considers a broader range of activities that will have relevance across the lifespan.[16] **Foundational movement skills** are defined as '*goal-directed movement patterns that directly and indirectly impact an individual's capability to be physically active and that can continue to be developed to enhance physical activity participation and promote health across the lifespan'.*[8] **Motor proficiency** refers to the '*motor control and movement patterns required to perform complex fine and gross motor skills*.'[59] Finally, **motor competence** is '*the degree to which an individual can perform goal-directed human movement'*.[8] An overview of the definitions of the different foundations of physical movement can be found in Table 3, as can common outcome measures used to assess these different types of physical movement.

Table 3: Definitions of the foundations of physical movement and how they are commonly assessed.

Type of physical movement	Description	Examples of outcome measures
Physical activity	'Any bodily movement produced by skeletal muscles that requires energy expenditure.'[26(p126)] Dimensions of PA include:[56] • **Duration:** units of time – e.g., number of minutes per session • **Frequency:** e.g., number of sessions, bouts or days • **Intensity:** effort associated with PA – e.g., commonly expressed as metabolic equivalent multiples of resting metabolic equivalent (MET) (light = 1.8–2.9, moderate = 3.0‑5.9, vigorous ≥ 6.0) • **Mode:** the type of physical activity behaviour – e.g., bicycling, walking, football • **Domain:** the context or reason for the PA – e.g., household chores, transport, leisure, physical education, occupation	Objective measures and their outputs include:[55,60] • **Heart rate monitors:** measures duration, frequency, intensity of PA and estimate of energy expenditure. • **Accelerometers**: measures duration, frequency, intensity of PA, estimate of energy expenditure, total movement counts/minute, minutes of specific intensities of PA • **Direct (or systematic) observation**: measures the type, duration, frequency, intensity and context of PA; estimate of energy expenditure. • **Pedometers:** step counts per day Subjective measures (parent-rated, teacher-rated, self-report if > 10 years) include:[55,60] • **Questionnaires/survey:** measures type, frequency, duration and context of PA • **Diary/log**
Sport	'Physical activities performed individually or in teams and may involve some form of competition.'[56,61]	
Exercise	'Exercise is physical activity that is planned, structured, repetitive, and purposive in the sense that improvement or maintenance of one or more components of physical fitness is an objective.'[26(p128)]	
Physical fitness	'A set of inherent or achieved personal attributes that relate to the ability to perform physical activity.'[26(128)]	Physical fitness assessments including the Eurofit physical fitness test (standing broad jump, sit-ups, 10x5m shuttle run).[62] The FitnessGram[63] measures health-related fitness

Type of physical movement	Description	Examples of outcome measures
a) **Health-related fitness**[26,61]	These factors are usually associated with disease prevention and health promotion and include:	
	• **Cardiorespiratory endurance (or cardiovascular /aerobic fitness):** the ability of the circulatory and respiratory systems to supply oxygen during sustained PA.	• Cardiorespiratory endurance may be assessed by field or lab tests including the 20m shuttle run field test, or the VO_{2max} laboratory test.
	• **Muscular strength:** relates to the amount of external force that a muscle can exert.	• Muscular strength may involve the assessment of one repetition maximum of a major muscle group.
	• **Muscular endurance:** the ability of muscle groups to exert external force for many repetitions or successive exertions.	• Muscular endurance may be assessed by measuring the number of repetitions of push-ups or sit ups.
	• **Body composition:** the relative amounts of muscle, fat, bone and other vital parts of the body.	• Skinfold callipers may be used to assess the percentage of body fat.
	• **Flexibility:** the range of motion available at a joint.	• Flexibility may be measured by the sit and reach test.
b) **Performance (or skill) related fitness**[26,56,61]	These factors reflect the skill-related aspect of physical fitness and include:	
	• **Balance:** the maintenance of equilibrium while stationary or moving.	• Static (e.g., flamingo balance test) and dynamic balance assessment
	• **Coordination:** the ability to use the senses, together with body parts in performing motor tasks smoothly and accurately.	• Tests of hand-eye or foot-eye coordination may include dribbling a ball or throwing to a target.
	• **Speed:** ability to perform a movement within a short period of time.	• Speed and agility may be assessed by a 10 x 5m shuttle run test.
	• **Agility:** the ability to rapidly change the position of the entire body in space with speed and accuracy.	
	• **Power:** relates to the rate at which one can perform work	• Power may be assessed by the standing broad jump field test or vertical jump
	• **Reaction time:** related to the time elapsed between stimulation and the beginning of the reaction to it.	

Type of physical movement	Description	Examples of outcome measures
Motor development	'Human development from infancy to old age with specific interest in issues related to either motor learning or motor control.'[57] 'The continuous, age-related process of change in movements as well as the interacting constraints (or factors) in the individual, environment and task that drive these changes.'[64]	
Motor learning	'The acquisition of motor skills, the performance enhancement of learned or highly experienced motor skills, or the reacquisition of skills that are difficult to perform or cannot be performed because of injury or disease.'[57] 'The relatively permanent gains in motor skill capability associated with practice or experience.'[64]	
Motor control	'How our neuromuscular system functions to activate and coordinate the muscles and limbs involved in the performance of a motor skill.'[57] 'The study of the neural, physical and behavioural aspects of movement.'[64]	
Motor skills[57] a) **Gross motor skills** b) **Fine motor skills**	'Activities or tasks that require voluntary control over movements of the joints and body segments to achieve a goal.' Motor skills that require the use of large musculature to achieve the goal of the skill. Motor skills that require control of small muscles to achieve the goal of the skill; typically involves eye-hand coordination and requires a high degree of precision of hand and finger movement.	Common standardised motor assessment tools include: • Bruininks-Oseretsky Test of Motor Proficiency – 2nd Edition:[59] Assesses fine and gross motor skills • Movement Assessment Battery for Children – 2nd Edition:[65] Assesses fine (manual dexterity) and gross motor skills (aiming and catching, balance) • Test of Gross Motor Development – 2nd or 3rd Editions:[66] Assessment of FMS including locomotor and object control skills. • Beery Buktenica Developmental Test of Visual Motor Integration:[67] Assessment of visual motor skills.
Motor competence	'The degree to which an individual can perform goal-directed human movement.'[8]	

Type of physical movement	Description	Examples of outcome measures
Motor proficiency[59]	'Motor control and movement patterns required to perform complex fine and gross motor skills.' • **Fine motor precision:** activities that require precise control of finger and hand movement. • **Fine motor integration (visual motor integration):** measures the ability to integrate visual stimuli with motor control. • **Manual dexterity:** activities that involve reaching, grasping and bimanual coordination with small objects. • **Upper limb coordination:** activities designed to measure visual tracking with coordinated arm and hand movement. • **Bilateral coordination:** tasks require body control, and sequential and simultaneous coordination of the upper and lower limbs. • **Balance:** motor control skills that are integral for maintaining posture when standing, walking or performing other common activities (e.g., stability of trunk, stasis and movement, use of visual cues). • **Running speed and agility:** control and coordination of the large musculature involved in locomotion. • **Strength:** trunk and upper and lower body strength and is a component that is essential in many daily activities.	• Bruininks-Oseretsky Test of Motor Proficiency – 2nd Edition)[59]
Fundamental movement (or motor) skills	'The building blocks of more advanced, complex movements required to participate in games, sports or other context specific physical activity'.[58,68] Consist of: • **Locomotor skills** that are used to propel a human body through space (e.g., running, jumping, hopping).[66] • **Object control skills** which include manipulating an object in action situations (e.g., throwing, catching, kicking).[66] • **Balance/stability skills**	Process-oriented measures (i.e., skill-specific performance criteria – how the movement was performed): • Test of Gross Motor Development – 2nd or 3rd Editions[66,69] • Get Skilled, Get Active process-oriented checklist[70] Product-oriented measures (i.e., outcome or performance: time or quantity of the motor skills measured) • Bruininks-Oseretsky Test of Motor Proficiency – 2nd Edition[59] • Movement Assessment Battery for Children – 2nd Edition[65]

Type of physical movement	Description	Examples of outcome measures
Foundational movement skills[8]	'Goal-directed movement patterns that directly and indirectly impact an individual's capability to be physically active and that can continue to be developed to enhance physical activity participation and promote health across the lifespan.' Consist of: Locomotor and object control skills with the addition of cycling, aquatic skills (freestyle swimming, treading water), scootering and resistance training skills (lunge, overhead press, push-up, squat)	

2.3.2.2 Outcome measures used to assess children's PA, physical fitness and motor performance

Physical activity

Children's PA is commonly assessed using objective and/or subjective measures (Table 3)[60] with these measures used to quantify the frequency, duration, intensity and type of movement undertaken.[54,55] Different measures provide information related to various dimensions of PA, including global estimates (e.g., pedometer step counts per day, minutes of moderate to vigorous physical activity (MVPA) per day) or specific details such as the type, frequency, intensity and context of PA.[60] Objective measures of PA include (i) *heart rate monitoring* which provides an estimate of energy expenditure, as well as the duration, frequency and intensity of PA; (ii) *direct (or systematic) observation* assesses PA behaviour (type, context), the frequency and intensity of PA and can be used to estimate energy expenditure; (iii) *accelerometers* provide an estimate of the duration, frequency and intensity of PA and produce an output of total movement counts which may be converted using cut-off points to different intensities of PA, including minutes of MVPA (Note: An estimate of energy expenditure may also be calculated); and (iv) *pedometers* which register steps taken during walking or running (i.e. step counts per day).[54,60] Subjective measures of PA include the use of a *diary/log* or *questionnaire/survey* which may be self-reported (valid for children over 10 years) or completed by a parent or teacher for younger children.[60] Subjective measures often rely on the recollection of PA and can provide information about different dimensions of PA including type, frequency, duration and context.[54,60]

Choosing the most appropriate instrument to assess children's PA requires careful consideration of the validity and reliability of the tool, the type of data collected, the population group of interest and the cost.[60] Several narrative and systematic reviews have been conducted to guide researchers on selecting the most valid and reliable measures to assess children's PA.[54,55,60,71,72] Research suggests that adopting multiple simultaneous approaches to measuring PA may lead to a more complete profile of children's PA.[54,60] However, to obtain information about the frequency, type and intensity of PA, whilst simultaneously collecting information about the physical and social environment in which the PA occurs, direct observation may be the most suitable method to employ, given that accelerometers and pedometers are limited in their ability to capture information regarding the type and context of PA.[60,73] As such, direct observation has been suggested as an ideal method for researchers using a social ecological framework to better understand the individual, social and environmental factors that may positively or negatively influence PA behaviour.[73]

Physical fitness

As physical fitness is a multi-faceted construct, the components of health-related physical fitness (e.g., CRF) or performance/skill-related physical fitness (e.g., coordination, balance and agility) or a combination of both may be assessed.[56] For example, a battery of tests such as the Eurofit physical fitness test[62] measures the components of both health-related and performance-related fitness (Table 3). Alternatively, a single test, such as the 20m shuttle run or a graded exercise test (e.g., VO_{2max} test)[37] may be used to assess CRF, a component of health-related physical fitness. However, a battery of tests, such as the FitnessGram,[63] may also be used to assess the different components of health-related physical fitness and provide an overall score for health-related physical fitness.

Motor performance

A range of instruments have been developed to assess children's motor performance, including standardised motor assessment tools, standardised developmental assessments or tests that assess individual motor skills (Table 3).[74] Varying definitions have been used to describe, and thus assess, motor proficiency and/or motor competence in the literature. The majority of reviews examining relationships between motor proficiency, health-related physical fitness and PA have measured motor performance using both process and product-oriented measures. For example, FMS are often evaluated using a process-oriented approach which assesses how a movement is performed (e.g., how a child's movement compares to that of an expert performer). FMS are comprised of locomotor skills (e.g., gross motor skills of running, jumping and hopping), object control skills (e.g., gross motor skills of catching, throwing and kicking)[66] and balance/stability skills.[58] The Test for Gross Motor Development – 2nd Edition (TGMD-2) or 3rd Edition (TGMD-3) is most commonly used in research evaluating the quality of gross motor skill performance.[66,69] However, a product-oriented approach, where the outcome of the assessment relates to the performance or outcome (i.e., time or quantity) of motor skills may also be used to assess motor performance. Standardised motor assessments such as the Movement Assessment

Battery for Children – 2nd Edition (MABC-2)[65] and the Bruininks-Oseretsky Test of Motor Proficiency – 2nd Edition (BOT-2)[59] employ a product-oriented approach for assessing motor performance of both fine and gross motor skills. A reliable and valid test battery that addresses broader foundational movement skills is yet to be developed.[16]

A systematic review by Griffiths et al.[74] published in 2018 evaluated the psychometric properties and clinical utility of seven gross motor assessment tools for children aged 2 to 12 years, including the BOT-2, MABC-2 and TGMD-2. The BOT-2 was considered to have the strongest evidence for internal consistency and test-retest reliability with excellent methodological quality reported by studies included in the review. Internal consistency and test-retest reliability for the MABC-2 and TGMD-2 was considered good to excellent, based on good methodological quality. Inter-rater reliability was supported in the TGMD-2, MABC-2 and BOT-2. Overall, the content and construct validity for the majority of gross motor assessment tools evaluated in the review were considered good to excellent. Evidence for the ability to discriminate between particular age or diagnosis groups was found for the BOT-2, MABC-2 and TGMD-2. Finally, the BOT-2 and MABC-2 are the standardised measures most often used clinically by health professionals or for research purposes to quantify difficulties in motor performance, and are recommended for use children with coordination difficulties, at risk for or diagnosed with conditions such as Developmental Coordination Disorder.[75]

2.3.2.3 Relationships between motor proficiency, health-related physical fitness and physical activity[2]

Studies examining the determinants of children's PA suggest that children's PA behaviour is influenced by factors at multiple levels of a social ecological model, including factors at the individual, interpersonal, organisational, community and public policy levels.[76] For example, research suggests that children's PA is influenced by a combination of biological/physiological factors (e.g., genetics, sex) and psychological factors (e.g., self-efficacy, perceived competence) that are relevant to an individual as

[2] It is important to note that within this body of literature, there is considerable variability in the terminology used to define children's motor skills (e.g., fundamental movement or motor skills, motor development, motor proficiency, motor competence, motor ability, motor coordination). The measurement of children's motor skills is equally variable with both process and product-oriented approaches employed to assess children's motor skills. Therefore, the relevant motor skill constructs and the outcome measures used to assess each motor skill will be outlined as described by different authors within their studies.

well as social/cultural factors (e.g., socioeconomic status, influence from peers/parents) and environmental factors (e.g., built environment, access to facilities).[77,78]

2.3.2.3.1 Conceptual models explaining relationships between motor skill development and PA

Several conceptual models have been proposed to explain how motor skill competence (i.e., the ability to perform goal-directed human movement) may be related to lifelong engagement in PA.[8,79,80] It has been suggested that developing proficiency in motor skills during childhood may equip children with a repertoire of skills that may facilitate and motivate them to engage in PA throughout their lives.[79] One of the earliest models describing relationships between motor skill development and PA was proposed by Seefeldt[80] in 1980. Seefeldt[80] hypothesised that when examining the link between children's motor skill development and engagement in PA across the lifespan, a proficiency barrier may exist, such that if children do not acquire a certain level of proficiency in their fundamental motor skills, they may be less likely to engage in PA.

In their conceptual model published in 2008, Stodden et al.[79] hypothesised that the relationship between motor competence and PA may be reciprocal, and the strength of the relationship may change throughout different stages of childhood and adolescence (Figure 3). Stodden et al.[79] defined motor competence in terms of proficiency in common FMS including object control and locomotor skill development which differs to the definition recently proposed by Hulteen et al.[8] in 2018.

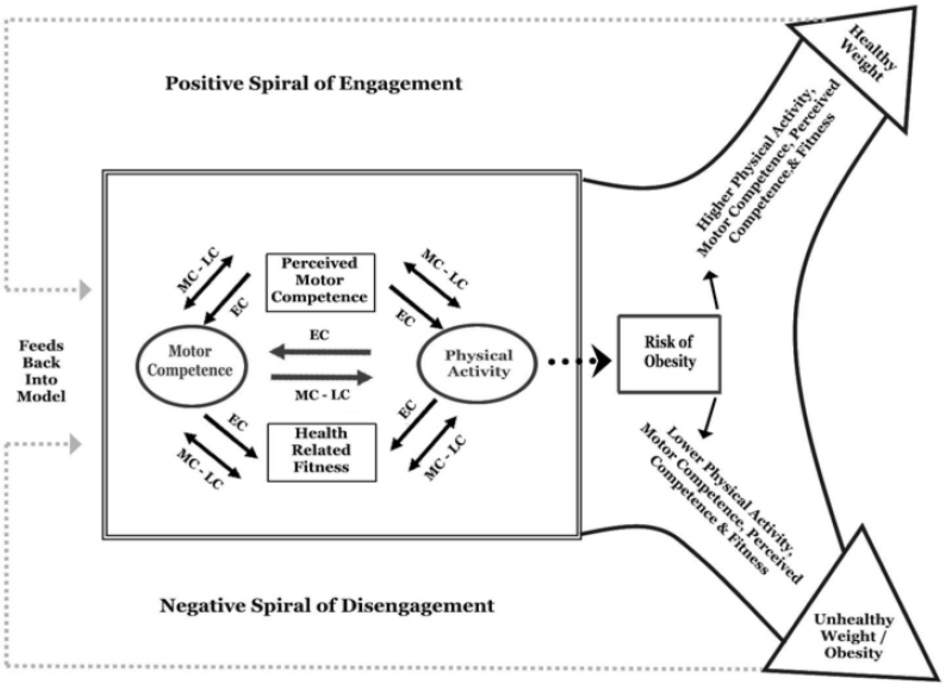

Figure 3: Conceptual model hypothesising relationships between motor competence, health related fitness and physical activity proposed by Stodden et al.[79] Reproduced with permission by Taylor & Francis.

Stodden et al.[79] proposed that the strength of the relationship between motor competence and PA may be weak during early childhood (EC) as a child's exposure to movement opportunities is largely influenced by contextual factors such as the physical and social/cultural environment (e.g., parental influence).[6,79] However, the relationship between motor competence and PA may strengthen by middle childhood (MC) to late childhood (LC) and continue to do so into adolescence. This may occur as children who demonstrate greater proficiency in motor skills may have higher levels of health-related fitness and perceived competence in their motor skills (i.e., perception of their actual movement capabilities[81]), which may enable them to participate in a wider range of games and sports leading to higher levels of engagement in PA. Conversely, children who demonstrate poor proficiency in motor skills may be less likely to engage in games and sports and consequently undertake lower levels of PA.[79]

The conceptual model developed by Hulteen and colleagues[8] in 2018 (Figure 4) builds upon the earlier models proposed by Seefeldt[80] and Stodden et al.[79] and depicts the evolution of motor development from reflexive movements observed during infancy to the development of more specialised movement skills (e.g., tennis backhand, baseball pitch) which may be used across the lifespan to engage in PA.

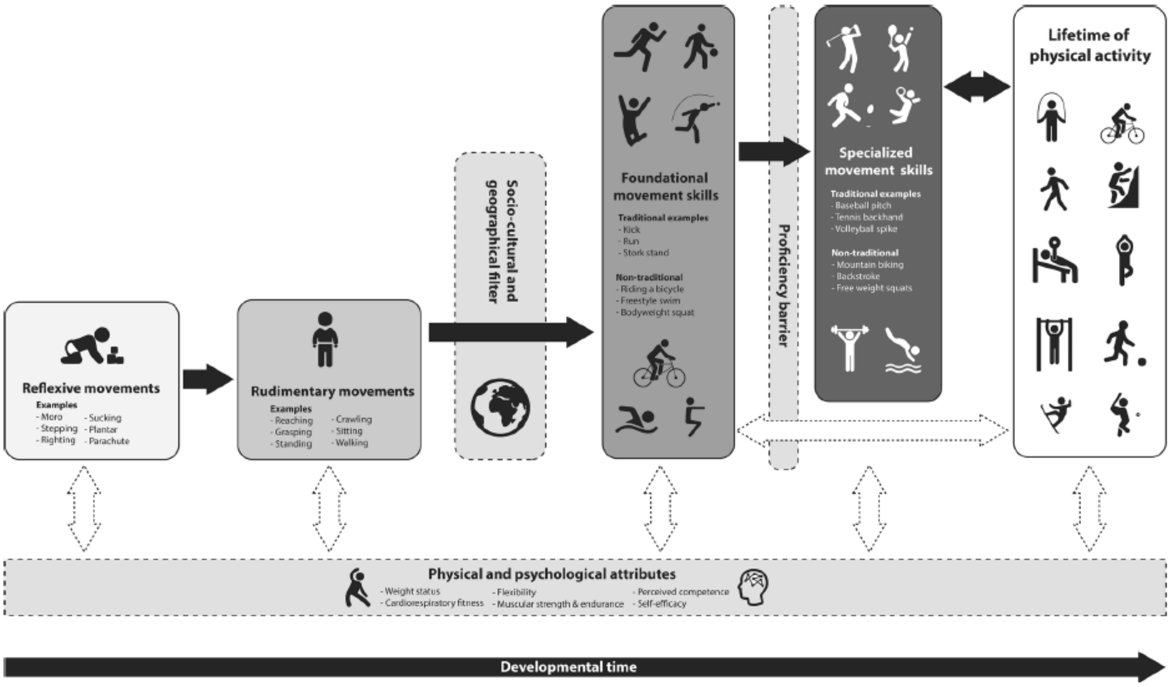

Figure 4: Conceptual model summarising the development of foundational movement skills to promote physical activity across the lifespan proposed by Hulteen et al.[8] Black arrows indicate previously hypothesised pathways; white arrows and dotted boxes indicate newly hypothesised pathways/components unique to this conceptual model. Reprinted by permission Springer Nature, Sports Medicine. Hulteen, R. M., Morgan, P. J., Barnett, L. M., Stodden, D. F., & Lubans, D. R. Development of foundational movement skills: a conceptual model for physical activity across the lifespan. *Sports Medicine, 48*(7), 1533-1540 © 2018

The conceptual model by Hulteen et al.[8] supports the hypothesis proposed by Seefeldt[80] regarding the existence of a 'proficiency barrier' whereby '*individuals who do not develop sufficient competence in foundational movement skills will have greater difficulty developing and maintaining health-enhancing physical activity habits across the lifespan.*[8(p5)]' The potential existence of a proficiency barrier reinforces the importance of identifying early, any children who commence primary school with poor or delayed motor skills so they can be supported in developing and refining these skills.

Finally, as previously stated, children's PA behaviour is complex and the physical (i.e., health-related fitness, weight status) and psychological (i.e., perceived motor competence, self-efficacy) attributes of the individual as well as environmental and social/cultural factors may also influence the relationship between children's motor development and PA.[10] These social ecological factors are acknowledged in the model proposed by Hulteen et al.[8] and summarised below in Figure 5.

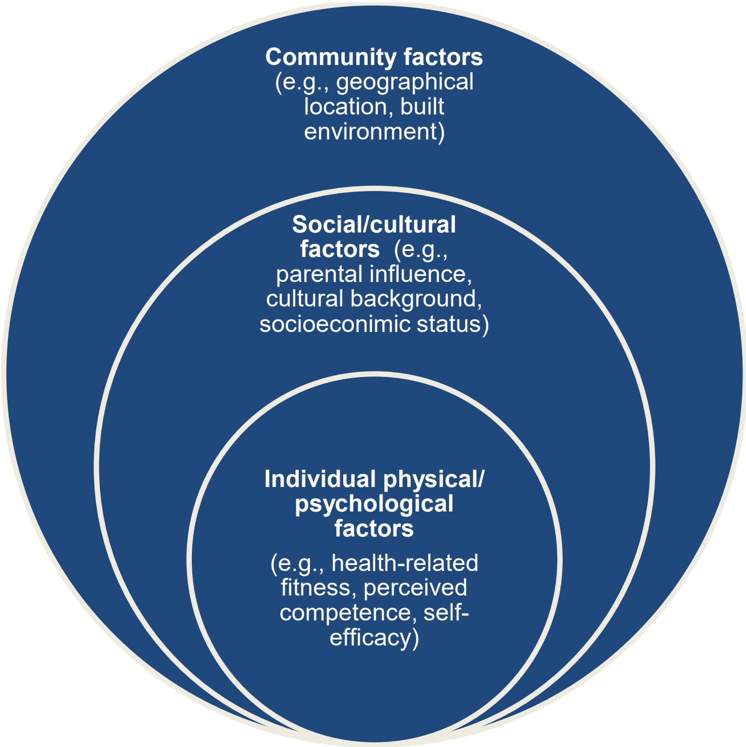

Figure 5: Social ecological factors that may influence children's motor development and physical activity behaviour.[8] Created by the author.

2.3.2.3.2 Relationships between motor proficiency and PA

Several reviews have investigated the relationship between motor skill proficiency and PA in children and adolescents and provided evidence to support the conceptual model proposed by Stodden et al.[9,11,81] A systematic review by Lubans et al.[9] published in 2010 synthesised the findings of 21 studies (*n* = 15 cross-sectional, *n* = 4 longitudinal, *n* = 2 experimental) and found strong evidence from cross-sectional studies to support positive associations between FMS (assessed using process and product-oriented outcome measures) and PA (assessed using self-report measures and pedometers). A few years later, Holfelder and Schott[11] conducted a systematic review of 23 studies (*n* = 15 cross-sectional, *n* = 8 longitudinal), further evaluating the relationship in children and adolescents between FMS (assessed via both product and process-oriented outcome measures) and PA (assessed using self-report questionnaires, accelerometers and pedometers). Findings revealed strong evidence of a positive relationship between FMS and organised PA, consistent with findings from the earlier review by Lubans et al.[9] The authors suggested that higher levels of FMS competency may be associated with an increase of PA and vice versa. However, the results of the review by Holfelder and Schott[11] suggested that a cause and effect relationship between FMS and PA has yet to be validated. In their systematic review conducted in 2015, Logan et al.[12] shed light on the strength of the relationship, reporting strong evidence (12/13 observational studies) for a positive low to high (r = .16-.55) relationship between FMS competence (evaluated by process-oriented measures only) and PA (assessed using self-report measures, accelerometers, pedometers and direct observation). The strength of the relationship differed between age groups with low to moderate relationships reported during early childhood (r = .16-.48), low to high relationships reported during middle to late childhood (r = .24-.55) and low to moderate relationships reported during adolescence (r = .14-.35).

A systematic review by Poitras et al.[82] in 2016 investigated the relationship between objectively measured PA and a number of primary and secondary health indicators. Motor skill development (measured using a standardised assessment or a single test) was evaluated as an important secondary health indicator in only seven of the 162 studies included in the review. Findings revealed evidence to support a positive relationship between objectively measured PA and motor skill development; however, there were differences in findings between experimental (n = 2 studies) (i.e., no between group effects following PA intervention) and cross-sectional studies (i.e., favourable associations reported). Furthermore, the quality of available evidence ranged from very low to low. The authors concluded there was a paucity of data regarding the relationship between motor skill development and PA, with a need for further high-quality studies to be conducted.[82]

Overall, findings suggest there is strong evidence from observational studies to support a positive relationship between motor proficiency and PA; however, there is insufficient evidence from experimental studies to confirm a causal relationship.

2.3.2.3.3 Relationships between motor proficiency and health-related physical fitness

The conceptual model by Stodden et al.[79] also proposes that a relationship may exist between motor skill proficiency and health-related physical fitness. For example, it has been hypothesised that health-related physical fitness may mediate the relationship between motor skill competence and PA, with the strength of association increasing from childhood to adolescence.[79,81] A longitudinal study published by Barnett et al.[83] in 2008 investigated the relationship between childhood motor skill proficiency (measuring three object control and four locomotor skills) and adolescent cardiorespiratory fitness (CRF) (assessed using a multistage fitness test). Findings revealed that children's proficiency in object control skills, assessed in primary school (Grade 4/5) predicted their CRF, assessed six years later (Grade 10/11). A systematic review by Cattuzzo et al.[10] published in 2016 investigated the relationship between motor competence (as measured by product and process-oriented motor assessments) and the components of health-related physical fitness (body weight status, cardiorespiratory and musculoskeletal fitness and flexibility) in children and adolescents. A total of 44 studies (*n* = 82% cross-sectional, *n* = 18% longitudinal studies) were included in the review. The authors[10] reported a strong level of evidence to support positive associations between motor competence and CRF (12/12 studies) and between motor competence and musculoskeletal fitness (7/11 studies). A strong level of evidence was also found to support an inverse association between motor competence and body weight (27/33 studies). These findings were consistent with the previously published systematic review by Lubans et al.[9] who found evidence to support positive associations between FMS and CRF (4/4 studies) and an inverse association between FMS and body mass index (5/8 studies).[10] Overall, there appears to be a growing body of evidence to support a strong relationship between motor skill proficiency and the components of health-related fitness, particularly CRF. However, the notion that health-related fitness mediates the relationship between motor competence and PA has yet to be validated.

Collectively, this body of literature provides promising evidence to support the notion that children's motor proficiency is favourably associated with both health-related physical fitness and PA; however, more experimental studies are required to further determine causality.

2.3.2.4 National physical activity guidelines and associated benefits – How much should children and youth be moving?

At the commencement of this program of research in 2014, the Australian Physical Activity and Sedentary Behaviour Guidelines for Children (5-12 years) and Young People (13-17 years) was the key source of information outlining recommendations for the amount, intensity and type of PA required for optimal health.[84] According to these national guidelines, Australian children and young people should accumulate at least 60 minutes of moderate (e.g., brisk walking, riding a bike) to vigorous intensity (e.g., running, playing sport) of PA every day. Muscle and bone strengthening activities are also recommended on at least three days of the week. Screen time (i.e., time spent using electronic media such as television, seated electronic games, portable electronic devices or computers for entertainment) should also be limited to no more than two hours per day. Finally, children are encouraged to engage in up to several hours of activity per day to achieve additional health benefits.[84]

However, the Australian 24-hour Movement Guidelines for Children (5-12 years) and Young People (13-17 years): An Integration of Physical Activity, Sedentary Behaviour and Sleep were subsequently introduced in 2019.[85] These new guidelines shifted the focus from time requirements for PA and screen time to recommending a combination of movement behaviours across a 24-hour day. Children and young people are still encouraged to accumulate 60 minutes or more of MVPA per day and muscle strengthening activities should also be performed at least three days per week. Screen time recommendations remain limited to two hours per day. Newly featured in the guidelines is the recommendation that over a 24-hour period children and young people should also undertake several hours of light PA, break up long periods of sitting and achieve sufficient sleep (5-13 years: 9-11 hours uninterrupted sleep; 14-17 years: 8-10 hours uninterrupted sleep).[85]

These national guidelines were informed by systematic reviews that investigated the relationships between PA, sedentary behaviour and, more recently, sleep hygiene, and health outcomes.[82] For example, participation in regular PA, particularly at moderate-to-vigorous intensities, is positively associated with numerous physical health indicators including body composition, cardiovascular and metabolic health biomarkers, cardiorespiratory and muscular fitness, and bone health.[82,86] However, participation in regular PA is also positively associated with academic achievement and cognition, as well as socio-emotional and mental health outcomes (e.g., emotional regulation and pro-social behaviour).[82]

2.3.2.5 National physical activity surveillance in Australia – How much are children and youth actually moving?

To monitor how well Australian children and young people are adhering to the national PA guidelines, the inaugural Active Healthy Kids Australia (AHKA) PA Report Card for Children and Young People was published in 2014 by a collaboration of Australian PA researchers.[87] The AHKA PA Report Card synthesises data from national and state/territory surveys and studies to provide a grade for common PA-related indicators, including children's individual traits, along with other sources of influence including families and peers, the school setting, the built environment and strategies and investments at the government level. Findings from the 2014 Report Card revealed that only 19% of Australian children and young people aged 5-17 years performed sufficient levels of PA to meet the recommended 60 minutes of MVPA each day.[87] Children's aerobic fitness was considered below average, ranked in the 31st percentile relative to age- and sex-matched international peers.[87] Nationally representative data in relation to children's movement skills was not available; however, state-based survey data suggested that girls and boys in Grade 6 (i.e., 11 or 12 years of age) were demonstrating poor mastery of locomotor skills (e.g., run, vertical jump, side gallop, leap) and object control skills (e.g., kick, overarm throw, catch) as objectively measured using a movement skill competency assessment.[88] Ideally, by Grade 4 (i.e., 9 or 10 years of age) children should demonstrate mastery of less complex FMS, including locomotor skills such as the sprint run, vertical jump and side gallop and object control skills such as the catch and overarm throw.[19] Mastery of more complex FMS, including the leap and kick should be achieved by the end of Grade 5 (i.e., 10 or 11 years of age).[19] Finally, in relation to the school setting, only 64% of Australian primary schools reported providing at least 120 minutes of physical education (PE) to students per week.[87]

The most recent AHKA PA Report Card was published in 2018 and reported there was insufficient evidence to suggest there had been any change in children's overall PA levels since 2014.[16] It also highlighted that there is a need to collect nationally representative data on children's overall PA levels as this is currently lacking.[16] In relation to children's aerobic and muscular fitness, objectively measured data revealed that young Australians aged 9-15 years ranked in the 35th percentile for both aerobic (assessed by 20m shuttle run) and muscular fitness (assessed by standing long jump), relative to age- and sex-matched international peers.[16] According to state/territory data, low levels of mastery continued to be demonstrated in object control and locomotor movement skills by boys and girls by Grade 6.[16] The following proportion of girls in Grade 6 showed mastery in locomotor skills - run: 30%; vertical jump: 33%; side gallop: 71%; leap: 31%; and object control skills - kick: 13%; overarm throw: 14%; catch: 29%.[19] The following proportion of boys in Grade 6 showed mastery in locomotor skills - run: 32%; vertical jump: 32%; side gallop: 68%; leap: 13%; and object control skills - kick: 50%; overarm throw: 53%; catch: 59%.[19] It was apparent that boys appeared to demonstrate a higher proportion of mastery in object control skills than girls.[19] Finally, in relation to the school setting, national data collected from school staff revealed that 66% of primary school students were receiving at least 120 minutes of PE each week, suggesting there had been minimal change in this indicator since 2014.[16]

Collectively, these trends demonstrate a clear need to improve Australian children's motor proficiency, physical fitness and overall levels of PA. Ideally, children should demonstrate mastery of object control and locomotor skills by Grade 6;[19] however, current trends suggest that Australian boys and girls are only achieving low levels of FMS competency by this year level. It has been suggested that focussing on improving children's motor proficiency during the early years of primary school may result in more permanent changes in their capability, consistent with the principles of motor learning.[81,83] This is in contrast to children's PA levels and other aspects of children's physical development, including health-related physical fitness and weight status, where changes appear to fluctuate more often. Given strong evidence reported in the literature to support the relationship between children's motor proficiency, health-related physical fitness and PA and that low levels of motor proficiency among school students is associated with low CRF, low PA levels, and being overweight or obese,[89] the aspect of children's physical development that schools may be able to prioritise during the early years of primary school is their motor skill development. However, this would need to be communicated to schools and implemented in such a way as not to compete, but rather align, with the development of children's literacy and numeracy skills.

To provide schools with a rationale for exploring early primary school classrooms in Australia as feasible settings to implement PA, particularly motor skill programs, as a strategy to promote children's motor proficiency and academic outcomes, an in depth understanding of early childhood development, the link between motor and cognitive development and the relationship between PA, cognition and academic performance is required and will be described in the following section.

2.4 Early childhood development

Early childhood education involves teaching young children up to eight years of age;[50] ages inclusive of Prep/Kindergarten to Year 2 in primary school. It has been proposed that the origins of the link between PA, cognition, and academic performance may stem from the relationship between motor and cognitive development during early childhood.[38] Therefore, a theoretical perspective on early childhood development is necessary and will be summarised first.

2.4.1 Developmental theories

Holistic approaches to teaching and learning during the early years recognise children's learning as integrated and interconnected across multiple developmental domains.[2] These approaches are informed by developmental theories that attempt to explain behaviour and development during the early childhood period.[2] Several developmental theories exist and key examples include the psychoanalytic, behavioural (or learning), cognitive, sociocultural and epigenetic theories.[90] An overview of each theory is provided in Table 4, describing the key theorists, their proposed theories and a summary of how the theory has contributed to modern early childhood pedagogy.

Each of these theories have their strengths and limitations and are useful in assisting early childhood educators in their role by providing a framework that allows them to better understand children's development. Each theory has made a valuable contribution to shaping overall understanding of development across the lifespan. Knowledge of these theories also encourages educators to consider the impact of early childhood experiences on children's subsequent development.[2] Consideration of specific theories builds awareness of the importance of social interaction within the family and community, how learning processes influence behaviour, and the effect that genetic and environmental factors may have on children's development.[2]

Table 4: Theories of childhood development.

Theory	Key theorists and proposed theory	Application to early childhood pedagogy
Psychoanalytic Theory[90]	• Sigmund Freud[91] and Erik Erikson[92] proposed that the development of irrational, unconscious drives and motives during childhood shapes behaviour throughout adulthood.	• Psychoanalytic theories highlight the need to consider the impact that early childhood experiences may have on a child's subsequent development.
Behavioural (or Learning) Theory[90]	• Ivan Pavlov and Burrhus Frederic Skinner[93] described the laws and processes by which behaviour is learned. **Laws of Behaviour** • *Classical conditioning:* the learning process whereby a person associates a meaningful stimulus with a neutral stimulus that had no special meaning before they became conditioned. • *Operant conditioning:* a particular action is followed by either something desired or undesired. The consequence will influence whether the person will repeat the action again, depending on whether they received positive or negative reinforcement. **Social Learning Theory** • Albert Bandura[94] proposed that learning can also occur by observing the behaviours of others and subsequently modelling that behaviour.	• Behavioural (or learning) theories highlight the role that experiences play in shaping children's behaviour.[2] For example, positive reinforcement may be used with children to encourage good behaviour. **Implications** • Early childhood educators and caregivers may apply the principles of classical and operant conditioning as part of behaviour management strategies in the classroom or at home by coupling activities with rewards and reinforcements based on the behaviour observed.
Cognitive Theory[90]	• Jean Piaget[95] proposed that thought processes are dependent on the development of cognition through four, age-related stages: - *Sensorimotor stage (0-2 years):* Infants experience the world primarily through movement and their five senses. Infants are considered to be 'egocentric'. - *Preoperational stage (2-7 years):* The young child is not yet able to understand concrete logic and is unable to mentally manipulate information. - *Concrete operational stage (7-11 years):* Children can think logically, and they are no longer egocentric.	• Cognitive theories prompt educators to consider how the processes of children's learning and development can change over time. For example, during infancy, thought processes may be shaped by movement experiences. **Implications** • Early childhood activities should be planned in relation to the developmental stage of the child.[2]

Theory	Key theorists and proposed theory	Application to early childhood pedagogy
	- *Formal operational stage (11-16+ years):* Marked by the development of abstract thought. • Jerome Bruner[96] considered development to be a continuous process, not a series of stages. He proposed three modes of representation in his research on the cognitive development of children: - *Enactive (action-based) (0-1 years):* Infants encode action-based information and store it in their memory. - *Iconic (image-based) (1-6 years):* Information is stored visually in the form of images. - *Symbolic (language-based) (7 years onwards):* Information is stored in the form of a code or symbol, and is flexible in that it can be manipulated, ordered and classified (e.g., words, mathematical symbols)	
Socio-cultural Theory[90]	• Leo Vygotsky[97] postulated that novices learn the skills and values of society through the guidance of skilled mentors. • Children's knowledge and acquisition of knowledge is tied to exposure to social settings (zone of proximal development). • Children develop skills through the process of scaffolding (supportive, structured interaction between an adult and a child with the aim of helping the child achieve a specific goal), • Jerome Bruner[96] supports this theory in that he emphasises the role of education and the adult (self-directed learning). The main difference with Vygotsky is around 'assisted learning.'	• Socio-cultural theories provide insight into the social and cultural contexts of children's learning and development by emphasising the important influence that families and cultural groups have upon a child's learning and the importance of developing relationships with others living within their community.[2] **Implications** • In response to children's prior knowledge, educators and skilled mentors can scaffold and transform their learning.
Epigenetic Theory[90]	• This theory considers an individual's genes and the environmental factors that directly affect the expression of those genes.[98] • The experiences children have early in life, and the environments in which they have them, shape the structure and function of the developing brain.[99]	**Implications** • Epigenetic theories emphasise the importance of providing supportive and nurturing experiences for young children during early childhood as this is when brain development is most rapid.

2.4.2 Theories of motor development

Motor development is defined as *'the continuous, age-related process of change in movements as well as the interacting constraints (or factors) in the individual, environment and task that drive these changes'.*[64(p5)] Developmental theories relating to motor development encompass several different perspectives including the neural-maturationist theory, cognitive theory, and the dynamic systems theory.[90,100,101] The neural-maturationist theory was pioneered by Arnold Gesell[102] and proposes that it is the maturation of the central nervous system that is primarily responsible for motor development.[64,101] The cognitive theory proposed by Jean Piaget[95] suggests that cognitive development occurs across four age-related stages. For example, during the first sensorimotor stage from birth to two years, infants experience the world primarily through movement and their five senses. It is proposed that this interaction with the environment assists infants to make sense of the world around them and provides the foundation of thought.[101] Burrhus Frederic Skinner[103] described a more behavioural approach to development proposing that development occurs through an individual's interaction with their environment and the reinforcement they receive.[101] Finally, the dynamic systems theory described by Esther Thelen and colleagues[104] provides a more holistic perspective, proposing that motor development is influenced by the interaction of intrinsic (i.e., mechanical, neurological, cognitive, perceptual) and extrinsic (environmental) factors.[100,101]

Overall, it is evident that theories of motor development have evolved over time. Contemporary perspectives employ an ecological approach which acknowledge that motor development involves a complex interplay between multiple factors including the individual (e.g., the child), the task (e.g., type of activity) and the environment (e.g., the school or home setting).[105]

2.4.2.1 Motor learning theories

Insight into how children learn motor skills can be gained by examining motor learning theories. Motor learning is defined as *'the relatively permanent gains in motor skill capability associated with practice or experience'*.[64(p5)] Fitts and Posner[106] proposed that the acquisition of motor skills occurs across three distinct stages. The first 'cognitive' stage is considered to require a high cognitive demand, as new learners (e.g., school children) try to understand the different components that make up that skill (e.g., learning how to throw a ball). New learners consequently rely on instructions and feedback from an external instructor (e.g., physical education or classroom teacher) to help improve their performance. Once the learner masters the basic form of the motor skill, the second, 'associative' stage involves refining their motor skill performance. Consequently, the cognitive demand of the task begins to decline during this second stage. When learners reach the final 'autonomous' stage, their motor skill performance becomes more automatic and they no longer need to allocate conscious attention to performing the motor skill and thus they can shift their attention to being more strategic when performing the skill, for example, in a game or sport situation.[106]

Contemporary motor learning research suggests the process of learning a motor skill is influenced by the individual, the task (e.g., motor skill/activity) and the environmental context in which the person performs the task (e.g., the school setting).[107] As learning a new motor skill requires practice, it is also important to consider how different practice conditions affect motor learning. As such, an instructor may modify the practice conditions depending on the individual's stage of motor learning. For example, an instructor may modify the type of instructions they provide (e.g., whole, part or mental practice), the type of practice schedule (i.e., constant vs varied practice) and the type of feedback they provide to the learner (e.g., knowledge of results about the outcome of motor performance or knowledge of performance – i.e., how the person moved).

Collectively, knowledge of the developmental theories discussed in the preceding sections provides the foundation for understanding the empirical literature examining relationships between motor and cognitive development, which is presented in the following section.

2.4.3 Brain development

The body of literature examining relationships between motor and cognitive development uses neurodevelopmental terminology, including anatomical and physiological terminology.[35,108] As such, relevant terms, definitions and concepts are discussed in this section prior to presenting the findings from research investigating these relationships.

During infancy and early childhood, there is rapid growth in the axons, dendrites and synapses of neurones within the brain. During the early childhood period and through to adolescence, ongoing myelination occurs.[90] Myelination is the process by which axons become coated with myelin, a fatty substance which facilitates the speed with which neurones communicate messages with each other.[90] Maturation of the corpus callosum and prefrontal cortex is enhanced through improved myelination, leading to refinement of both mental processing and motor skills. Growth of the corpus callosum enables communication between the two sides of the brain to be more efficient whereas growth of the prefrontal cortex helps to fine-tune emerging higher-order cognitive functions, referred to collectively as executive functions.[109] In addition to the refinement of executive processing skills through to adolescence, motor development also continues into adolescence.[108]

2.4.3.1 Key definitions relating to cognition and academic performance

Cognition is a general term that describes a number of different mental processes including executive function, intelligence and perception.[35,36] **Executive functions** encompass several top-down mental processes, with core executive functions including inhibitory control, cognitive flexibility, and working memory.[35] Reasoning, problem solving, and planning are considered higher order executive functions that build upon the core executive functions.[36] Executive functions are involved when making decisions, solving problems, adapting to changes, and resisting temptation. In contrast, **academic performance** (or academic achievement) is defined by success or performance at school, with assessments typically measuring student knowledge and/or classroom behaviour.[27] Table 5 provides an overview of the definitions for intelligence, cognition, executive function and academic performance.

Table 5: Definitions of intelligence, cognition, executive function and academic performance**.**

	Definition	
Intelligence[110]	'The ability to derive information, learn from experience, adapt to the environment, understand, and correctly utilise thought and reason.'	
Cognition[111]	'All forms of knowing and awareness, such as perceiving, conceiving, remembering, reasoning, judging, imagining, and problem solving.'	
Executive Function[36]	'A collection of top-down control processes used when going on automatic or relying on instinct or intuition would be ill-advised, insufficient or impossible.'	
	Inhibitory control: Inhibition	'Controlling one's attention, behaviour, thoughts, and emotions to override a strong internal predisposition or external lure.'
	Inhibitory control: Self-control	'The aspect of inhibitory control that involves resisting temptations and not acting impulsively or prematurely.'
	Working memory	'Holding information in mind and mentally working with it (e.g., relating one thing to another, using information to solve a problem). Includes verbal and non-verbal working memory.'
	Cognitive flexibility	'Changing perspectives or approaches to a problem, flexibly adjusting to new demands, rules, or priorities (as in switching between tasks).'
	Fluid intelligence	'Ability to reason, problem solve and see patterns or relations among items.'
Metacognition[90]	'Thinking about thinking' or the ability to evaluate a cognitive task to determine how best to accomplish it, monitor it and adjust one's performance on that task.'	
Academic performance[27]	Success or performance at school, commonly measured by examinations or continuous assessment (e.g., standardised academic achievement tests, grade point average, teacher-reported academic reports, observation/report of classroom behaviour).	
Reading composite[112]	Word reading	Assesses pre-reading (phonological awareness) and 'decoding skills'
	Reading comprehension	Reflects reading instruction in the classroom
	Pseudoword decoding	Assesses the ability to apply phonetic decoding skills
Mathematics composite[112]	Numerical operations	Evaluates the ability to identify and write numbers
	Maths reasoning	Assesses the ability to reason mathematically
Literacy[113]	According to the Australian Curriculum, Assessment and Reporting Authority (ACARA), 'literacy involves students listening to, reading, viewing, speaking, writing and creating oral, print, visual and digital texts, and using and modifying language for different purposes in a range of contexts.'	
Numeracy[114]	According to ACARA, 'numeracy encompasses the knowledge, skills, behaviours and dispositions that students need to use mathematics in a wide range of situations.'	

There is evidence to suggest that cognitive functions, particularly executive functions, are related to academic performance.[36,115] Research suggests that executive functions assessed early in life are predictive of lifelong achievement, health, wealth, and quality of life.[36] Ineffective executive function (or executive dysfunction) may result in children having difficulty inhibiting inappropriate behaviour, which may affect their ability to concentrate and complete tasks within the classroom setting.[35]

2.4.4 Relationship between motor and cognitive development

As stated previously, the dynamic systems perspective proposes that development occurs through a complex interplay between multiple systems, including body systems, the physical environment and social/cultural influences.[6] During infancy, it is suggested that the development of each motor skill (e.g., lying, rolling, sitting, crawling, walking) allows an infant to gain further independence, enabling them to explore more of their environment, which, in turn, provides a new opportunity to learn. Thus, the development of cognition may be linked to these early movement experiences. For example, infants learn how to problem solve when they encounter novel and complex situations through early exploratory motor behaviour. This, in turn, may lay the foundation for the development of higher order cognitive functions.[6,38]

In a seminal review published in 2000, Diamond[108] summarised evidence from the empirical literature describing the potential role the dorsolateral prefrontal cortex and cerebellum may both play in cognitive and motor performance. Diamond described findings from functional neuroimaging studies that reported co-activation of the prefrontal cortex and cerebellum during particular cognitive tasks.[108] For example, during tasks that were novel or more complex (i.e., when conditions changed or a quick response was required), functional neuroimaging studies showed increased activation in the dorsolateral prefrontal cortex and neocerebellum.[108] This is consistent with the first, cognitive stage of motor skill acquisition described in motor learning theories.[106] Table 6 summarises the regions of the brain that are crucial for motor and cognitive development, along with their functions as outlined by Diamond.[108]

Table 6: Key areas of the brain crucial for motor and cognitive development during childhood and adolescence as proposed by Diamond.[108] Reprinted by permission John Wiley and Sons, Child Development. Diamond, A. Close interrelation of motor development and cognitive development and of the cerebellum and prefrontal cortex. *Child Dev* 2000, *71*, 44-56. © 2000

Region of the Brain	Function	Description
Prefrontal cortex (dorsolateral prefrontal cortex)	Executive function	• Includes inhibitory control, working memory, cognitive flexibility.
Cerebellum (neocerebellum)	Motor learning	• Neurons are most active during the early stages of learning a task or when conditions change. • Potential role in error detection.
Basal Ganglia (caudate nucleus)	Movement control	• Includes balance, posture and coordination. • Involves selecting proper movements, muscles and forces.
Premotor cortex		• Planning, preparation and sensory guidance of movement.
Supplementary motor area		• Bimanual coordination, generation and execution of sequences.

Research investigating the effect of dysfunction of the motor system on cognition may provide additional support for the interconnected nature of motor and cognitive systems.[108] For example, abnormalities have been reported in both the cerebellum and prefrontal cortex in children with neurodevelopmental disorders including Attention Deficit Hyperactivity Disorder (ADHD), Autism Spectrum Disorder (ASD) and Specific Language Disorder. Executive dysfunction, including a lack of behavioural control (i.e., failure to inhibit behaviour) and attention is a key characteristic observed in children with ADHD, Specific Language Disorder and ASD;[116] however, concomitant problems with motor coordination are also often observed in children with these conditions.[108]

A longitudinal study conducted in 2008 by Piek et al.[117] also provided evidence to support a relationship between early motor development and later cognitive ability. The Ages and Stages Questionnaire (ASQ) was used to assess the fine and gross motor skills of 33 children (16 girls, 17 boys) aged 4 months to 4 years of age. Fine and gross motor performance and cognitive development were then reassessed when children were 6 to 12 years using the McCarron Assessment of Neuromuscular Development and Wechsler Intelligence Scale for Children – 4th Edition, respectively. Findings revealed that after controlling for socioeconomic status (SES), gross motor trajectory information (assessed by the ASQ) significantly predicted cognitive performance – specifically working memory and processing speed. However, fine motor trajectory information did not predict cognitive performance after controlling for SES.

A few years later in 2011, a cross-sectional study by Davis et al.[118] provided insight into the strength of the relationship between motor proficiency and cognition across development. The motor and cognitive ability of 248 typically developing children, 4 to 11 years of age, was assessed using the Bruininks-Oseretsky Test of Motor Proficiency – 2nd Edition and the Kaufman Assessment Battery for Children – 2nd Edition, respectively. A significant moderate correlation was found between overall motor and cognitive scores (r = .515, p < .0001), which was consistent across the entire sample. Fine manual control (fine motor precision and fine motor integration) and visual processing were found to underpin this relationship. The authors concluded that as the strength of the correlation between fine manual control and visual processing was consistent in children across different age groups, this supported the notion that motor and cognitive skills may be interrelated across development.[118]

Finally, in 2015, a systematic review by van der Fels et al.[47] synthesised the findings of studies published between 2000 to 2013 that investigated the relationship between motor and cognitive skills in typically developing school-aged children. A total of 21 observational studies with good to high methodological quality were included in the review. Motor skills were grouped into six categories including gross motor skills, fine motor skills, bilateral body coordination, timed performance in movements, object control and total motor score. Key cognitive skills included the components of executive function, IQ, memory, attention and academic skills. Overall findings revealed either no correlation or insufficient evidence to support a relationship between many motor and cognitive variables (including academic skills). However, notably, fine motor skills, bilateral body coordination and timed performance in movements had the strongest correlations with cognitive skills. The authors suggested that these more complex motor skills may involve a higher cognitive demand, supporting the notion that co-activation of the cerebellum and prefrontal cortex may occur with more complex motor tasks.[47]

Overall findings from cross-sectional and longitudinal studies reveal there is preliminary evidence to suggest that motor skills are positively associated with cognitive skills, particularly when more complex motor skills are assessed. However, there appears to be insufficient evidence from experimental studies to suggest that motor skill interventions are beneficial for improving children's cognitive skills. Knowledge of the literature examining relationships between motor and cognitive development provides a foundation for understanding the relationship between PA, cognition and academic performance.[38]

2.5 Relationships between physical activity, cognition and academic performance

Several models have been proposed to conceptualise the relationship between PA, cognition and academic performance.[27,39] In the conceptual model presented in their review published in 2012, Howie and Pate[27] hypothesised that PA (i.e., the broad term used to encompass PA, physical fitness and sports participation) may firstly modify children's cognition (i.e., the broad term used to encompass executive function, attention, memory and IQ), and, secondly, that improvements in cognition may underlie improvements in academic performance (i.e., the broad term to encompass grades, standardised tests and classroom behaviour). The model proposed by Tomporowski et al.[39(p51)] three years later in 2015 (Figure 6) suggested that including the construct of metacognition in this pathway, which is defined as '*an individual's understanding of what they know and how to use that knowledge to regulate behaviour*', situated between cognition and academic performance, could improve understanding of the relationship between PA and children's academic performance.

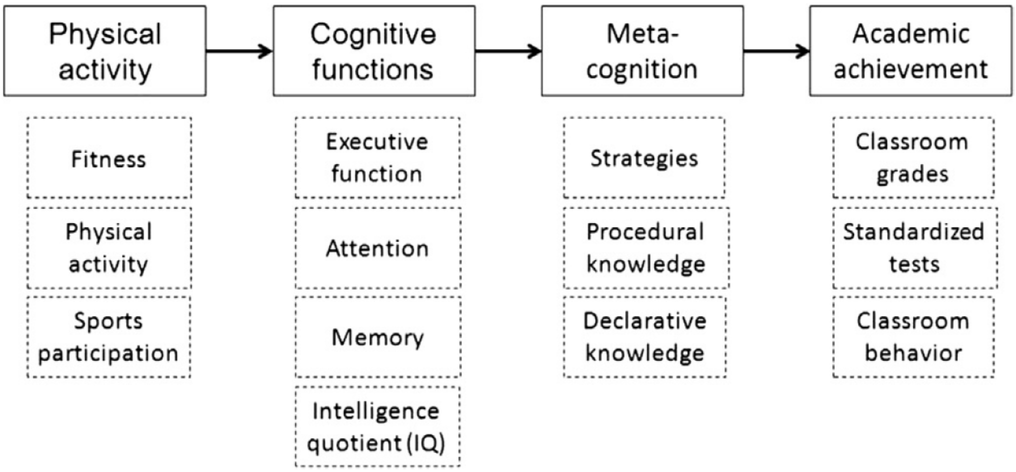

Figure 6: Relationship among physical activity, cognition, metacognition, and academic achievement as proposed by Tomporowski et al.[39] This figure is from the article by Tomporowski et al.[39] published under a Creative Commons Attribution NonCommercial NoDerivitives 4.0 International Licence.

For example, it has been suggested that the development of children's procedural learning during complex motor tasks may lead to the development of declarative (or semantic) knowledge (i.e., information that can be thought about and talked about without engaging in a specific activity) which is necessary for thinking, planning and anticipating.[119] Tomporowski et al.[39(p53)] summarised this concept stating that '*mental strategies that children acquire in a physical activity training environment to problem solve can influence how they deal with tasks that involve executive control in academic conditions*'. Notably, motor proficiency has yet to be included in these conceptual models.

2.5.1 Hypotheses regarding the mechanisms that may underlie relationships between PA, cognition and academic performance

Researchers from various disciplines have proposed several hypotheses regarding the underlying mechanisms that may explain the relationship between PA, cognition and academic performance.[38,39,41,48,109] For example, biological and psychosocial mechanisms as well as mechanisms relating to the context in which children learn have been proposed.[38,40] Biological mechanisms refer to the cellular changes that occur in response to short-term participation in PA, including increased cerebral blood volume, upregulation of growth factors and neurotrophins (e.g., brain-derived neurotrophic factor) and alterations in brain neurotransmitters (e.g., noradrenaline, dopamine).[28,35,120] Chronic or long-term participation in PA is thought to result in the development of new blood vessels (angiogenesis), nerve growth (neurogenesis) and increased formation of synapses (synaptogenesis). It has been proposed that these changes in brain structure and function may underlie observed changes in cognitive function (i.e., learning and memory processes) that are associated with participation in PA.[30]

Research investigating the relationship between PA and/or health-related physical fitness to brain structure in children and adolescents is still in its infancy.[30] However, several cross-sectional studies[121-123] have examined the relationship between aerobic fitness and brain structure reporting changes in grey matter volume in the basal ganglia and hippocampus on Magnetic Resonance Imaging (MRI).[30] Initial findings suggest that aerobic fitness is associated with the volume of these subcortical structures, with larger volumes evident in higher-fit children compared to lower-fit children.[30] Additional findings from two RCT pilot studies[124,125] demonstrated increased white matter (or structural) integrity on diffusion tensor imaging in children participating in an 8-month after school PA intervention compared to children in the control group.[30]

Children's brain function is typically assessed using functional MRI and/or electroencephalography (EEG) – a measure of neural activity in response to, or in preparation for, a stimulus or response (event-related brain potentials).[30] A systematic review by Donnelly et al.[30] found evidence from nine cross-sectional studies to support a relationship between aerobic fitness and neuroelectric indices during cognitive tasks (e.g., attention, inhibition, cognitive flexibility, academic). Notably, a cross-sectional study by Hillman et al[126] found that children with higher levels of fitness demonstrated greater allocation of attentional resources and faster cognitive processing speed than children with lower levels of fitness. Results from several RCTs[127,128] have demonstrated similar findings on EEG in children participating in a daily PA intervention compared to children on the waitlist.[30] Finally, the review by Donnelly et al.[30] also summarised findings from several cross-sectional studies and RCTs reporting increased recruitment and activation on functional MRI in the frontal and parietal regions of the brain during cognitive tasks in children with higher levels of fitness.

The underlying mechanisms relating to the context in which children learn stem from research examining motor development and motor learning research and its link to cognition.[38,48,108,129] For example, increased activation of the pre-frontal cortex and cerebellum during the skill acquisition phase of learning a motor task highlights the cognitive demand inherent in complex motor skill acquisition.[108,129] Several researchers have described how many forms of exercise, particularly group activities or games, can be considered as cognitively engaging.[38,39,48] For example, complex cognitive processes are required during group games in order for individuals to cooperate with others, anticipate each other's behaviour, employ strategies during the game and adapt to changing task demands and novel situations.[38] It is hypothesised that employing these complex mental processes during cognitively engaging forms of exercise may transfer to other learning environments, such as the classroom.[39] Furthermore, modifying the practice environment during motor learning by applying principles of variability of practice to the tasks may optimise motor and cognitive processes.[48]

Finally, developmental neuroscientists have argued in favour of a more holistic explanation for observed changes in executive function and academic performance brought about by PA interventions, particularly highlighting that psychosocial factors (e.g., improvements in self-confidence, experiencing a sense of belonging during group games) may mediate this relationship.[40] For example, it has been highlighted that stress, feeling sad or lonely, being sleep deprived or physically unfit leads to deleterious effects on executive function, and impaired reasoning, problem solving, concentration and self-control. Diamond[40] hypothesised that improvements in executive function may also occur by reducing stress, providing an individual with a sense of belonging or social inclusion, improving sleep or improving fitness.

2.5.2 Review of literature examining relationships between PA, cognition and academic performance

Overall, a variety of terminologies have been used in the literature examining relationships between PA, cognition and academic performance in children and adolescents (refer to sections 2.3.2.1 and 2.4.3.1). Observational studies (e.g., cross-sectional and longitudinal studies) have commonly examined relationships between independent variables such as objectively/subjectively measured PA, health-related physical fitness, sports participation, or physical education and dependent variables measuring cognition and/or academic performance.[28-30] In contrast, experimental studies have typically examined the effect of different types of PA interventions on cognitive and academic outcomes, as well as PA-related outcomes.[28-34]

Historically, researchers have predominantly examined the relationship between PA (as measured objectively/subjectively) and/or the components of health-related physical fitness (specifically CRF), and cognition and academic performance employing cross-sectional study designs.[28-30] Similarly, studies evaluating the effect of PA interventions on cognition and academic performance have largely measured or manipulated the quantitative dimensions of PA such as the intensity, duration, frequency and type (or mode) of PA undertaken in the intervention.[32,41] This may be due to the fact that PA and exercise prescription guidelines provide recommendations based upon the dose-response relationship between PA and health outcomes. It has been noted that a gap in the literature exists in relation to examining the impact of the 'qualitative' characteristics of PA interventions on cognition and academic performance, which encompass dimensions including the degree of cognitive and motor coordination demands within an activity, along with the social and emotional demands of the activity.[41] Although early research examining this broad topic dates back to the 1940s,[29,31] there has been rapid growth of research in this field within the last decade with increasing numbers of narrative and systematic reviews published examining the relationship between PA, cognition and academic performance in children and adolescents.[28-32,34,35,120]

Sibley and Etnier[28] conducted one of the earliest meta-analyses on this topic in 2003. Their meta-analysis included 44 studies (n = 9 peer-reviewed true experimental studies) and overall findings supported a positive relationship between PA and cognition in children, reporting an overall effect size of 0.32 (SD = 0.27). Moderator variables examined in the review included study design (true, quasi-experimental, cross-sectional), participant characteristics (healthy, mentally impaired, physically disabled, year level at school), acute and chronic PA interventions (e.g., resistance/circuit training, perceptual-motor training, PE program, aerobic), activity assessment (e.g., overall fitness, motor ability) and type of cognitive assessment (e.g. perceptual skills, developmental level/academic readiness, IQ, achievement, maths tests, verbal tests, memory). Results revealed a positive relationship between PA and cognition across all study design types, for all participants and for all types of PA interventions.[28] However, larger effect sizes were reported for children in middle school (11-13 years), and children in early elementary school (4-7 years), and for relationships between PA and IQ (ES = 0.34; SD = 0.28) and academic achievement (ES = 0.30; SD = 0.22).

A meta-analysis by Fedewa and Ahn[29] published in 2011 built upon the findings reported by Sibley and Etnier.[28] The authors quantitatively synthesised the results of 59 studies conducted over the period between 1947 to 2009. Studies were categorised as either (i) experimental studies examining the effect of PA interventions on cognitive outcomes (*n* = 39); or (ii) cross-sectional studies examining the relationship between level of physical fitness and cognitive outcomes (*n* = 20). Fedewa and Ahn[29] found evidence to support a significant and positive association between PA and children's cognitive outcomes, reporting a combined overall effect size of 0.28 (SE = 0.04; 95% CI: 0.20, 0.37), which was similar to the overall effect size reported by Sibley and Etnier.[28] The effect size differed only slightly between studies with experimental designs (d = 0.35, SE = 0.04, 95% CI: 0.27, 0.43) and cross-sectional designs (d = 0.32, SE = 0.03, 95% CI: 0.26, 0.37). Collective findings from experimental studies suggested PA interventions had a significant positive effect on children's cognitive and academic outcomes. Collective findings from cross-sectional studies suggested that children with higher levels of physical fitness achieved higher performance on cognitive and academic outcomes. Larger effect sizes were found for PA interventions with aerobic training (d = 0.35, SE = 0.07, 95% CI:0.21, 0.48), followed by regular PE programs (d = 0.20, SE = 0.06, 95% CI: 0.09, 0.32) and perceptual motor training (d = 0.15, SE = 0.06, 95% CI: 0.04, 0.26). Furthermore, children appeared to benefit from PA interventions regardless of who delivered them (i.e., teachers, researchers, PE specialist). In relation to the cognitive status of participants, significant effect sizes were reported for all children, including children who were cognitively impaired or children with a learning disability. In relation to cognitive and academic outcomes, the largest effect size was found for mathematics (d = 0.44, SE = 0.09, 95% CI: 0.27, 0.61), IQ (d = 0.39, SE = 0.06, 95% CI: 0.27, 0.52) and reading (d = 0.36, SE = 0.11, 95% CI: 0.14, 0.58) achievement. Finally, largest effect sizes were found for participants in elementary school (K-5; or approx. 5 to 11 years).

A few years later in 2014, Castelli et al.[31] conducted a systematic review and meta-analysis of studies examining the relationship between PA, physical fitness and academic performance over the period between 1967 and 2013, a similar time frame used in the meta-analysis by Fedewa and Ahn.[29] Although 215 studies met the inclusion criteria, only 20 experimental studies were included in the meta-analysis. Findings revealed that children who participated in PA interventions demonstrated significant improvements in academic performance (inclusive of school attendance, on-task behaviour, standardised tests, attention, memory and executive/cognitive control), with an overall effect size of 0.383 (SE = 0.078). This effect size was slightly higher than the effect sizes reported for experimental studies in the reviews by Sibley and Etnier[28] and Fedewa and Ahn.[29] A subgroup analysis was conducted on the different time periods in which studies were published (1967 to 1999; 2000 to 2009; 2010 to 2013). Studies published after 2010 (*n* = 7) showed larger effect sizes (ES = 0.564, 95% CI: 0.421, 0.707) than studies published between 2000 to 2009 (*n* = 5) (ES = 0.496, 95% CI: 0.119, 0.872) and studies published before 2000 (*n* = 8) (ES = 0.212, 95% CI: 0.025, 0.400). The authors concluded that differences in results between the time periods may be attributed to the rapid growth in the body of literature on this topic with changes evident in the terminology and outcomes used within studies, the methodological quality of studies and the hypotheses regarding the proposed mediating and moderating factors.

A systematic review and meta-analysis by Vazou et al.[32] published in 2016 sought to identify the qualitative aspects (e.g., cognitive, motor coordination, emotional and social demands) or common factors shared by the most effective types of chronic PA interventions. In this regard, the line of enquiry shifted from examining the impact of the more traditional quantitative characteristics of PA interventions (e.g., duration, frequency, intensity) to exploring the impact of PA interventions that included qualitatively different types of movement. A total of 28 experimental studies published between 1986 and 2016 were included in the review. Types of PA interventions were classified into seven categories, including aerobic, motor skill or cognitively engaging interventions and their combinations. PA interventions were conducted within the school setting (*n* = 11 during PE; *n* = 10 classroom-based PA, *n* = 1 during recess), after school (*n* = 4) and during a summer camp (*n* = 2). Comparison groups included no PA intervention, academic, traditional PE and aerobic PA. Cognitive outcomes were diverse and included inhibition, working memory, cognitive flexibility, planning, fluid intelligence, attention and other indicators of information processing. The overall effect size based on 28 comparisons was 0.46 (95% CI: 0.28, 0.64; $p < .001$). This suggested that compared to all comparison groups, PA interventions had a significant, medium effect on measures of cognitive function. In relation to specific comparison groups, significant positive effects were identified when all PA interventions were compared to no PA intervention (ES = 0.86, 95% CI: 0.18, 1.55; $p = .01$; $n = 5$; $I^2 = 93\%$) or academic instruction (ES = 0.57; 95% CI: 0.32, 0.86; $p < .001$; $n = 10$; $I^2 = 81\%$). The strongest effects were observed for PA interventions that involved aerobic exercise, aerobic and cognitively engaging exercise, motor skills or low-intensity, cognitively engaging exercise (e.g., yoga and meditation/stretching). However, high heterogeneity was reported suggesting considerable variability in the types of PA interventions and comparison interventions, study methodology and participant characteristics across studies. The authors therefore concluded that results should be interpreted with caution.[32]

One of the largest systematic reviews to date was conducted by Donnelly et al.[30] in 2016 and involved investigating, firstly, whether PA and physical fitness were associated with cognition, learning, brain structure and brain function (n = 64 studies) and, secondly, whether PA participation (including PE and sports programs) and fitness were associated with academic achievement and concentration/attention (n = 73 studies), in children five to 13 years of age. Results from 11 cross-sectional studies provided support for a positive relationship between objectively measured PA or aerobic fitness and cognitive performance. Results suggested that children with higher levels of aerobic fitness demonstrated significantly better cognitive performance when compared to children with lower levels of fitness. A total of 14 experimental studies examined the effect of PA interventions on cognition. A positive improvement in at least one measure of cognition was found in seven out of the 10 RCTs following participation in a PA intervention. The types of PA interventions included after-school programs involving aerobic PA (n = 9), with only one program administered during the school day. A total of 27 cross-sectional and longitudinal studies examined the relationship between health-related physical fitness and academic achievement with fairly consistent findings that fitness was positively associated with academic achievement. However, there was variability in how the fitness and academic measures were used and categorised and several limitations were noted in relation to study quality and reporting. Findings from 10 cross-sectional studies examining the relationship between objectively or subjectively measured PA and academic achievement were inconsistent and thus it was difficult to draw conclusions. Results from PA intervention studies were also mixed, with eight of 14 studies finding clear improvements in either overall academic achievement or in specific aspects of academic achievement. Types of PA interventions included physically active classroom lessons, classroom PA breaks, additional school PA (e.g., specialised programs) and an after-school fitness program. Interestingly, three of four studies examining physically active academic lessons as the PA intervention reported improvements in children's mathematics scores following the intervention. Overall, there was considerable heterogeneity in the study parameters and outcome measures used in the review, making it difficult to draw clear conclusions, though on balance a positive relationship between PA, fitness, cognition and academic achievement appears likely.[30]

A meta-analysis published in 2018 by de Greeff et al.[33] investigated the effect of acute and longitudinal PA interventions on executive function, attention and academic performance in pre-adolescent children. A total of 31 intervention studies published between 2000 and 2017 met the inclusion criteria. Key outcomes included executive function (inhibition, working memory, cognitive flexibility, planning), attention (selective, divided, sustained) and academic performance (mathematics, spelling, reading). Interventions included aerobic or cognitively engaging types of PA. Both acute and longitudinal PA interventions were examined. A total of 14 studies implemented longitudinal PA interventions and examined the effects on children's cognitive function. Overall, a small to moderate positive effect of longitudinal PA interventions on cognitive function was found (Hedges' g = 0.37; 95% CI: 0.20, 0.55; $p \leq .001$). Only three studies examined the effect of longitudinal PA interventions on academic performance reporting an overall small to moderate positive effect (Hedges' g = 0.26; 95% CI: 0.02, 0.49; $p = .032$). In relation to the type of PA intervention (e.g., $n = 11$ aerobic PA, $n = 5$ cognitively engaging PA), an overall small to moderate positive effect was found for aerobic types of PA interventions (Hedges' g = 0.29; 95% CI: 0.13, 0.45; $p = .001$); however, an overall moderate to large positive effect was found for cognitively engaging PA interventions (Hedges' g = 0.53; 95% CI: 0.14, 0.92; $p = .008$).[33]

Finally, another systematic review examining the effect of PA interventions on cognitive and academic performance in children and adolescents was published in 2019 by Singh et al.[34] A total of 58 studies met the inclusion criteria, including 27 RCT or cluster-RCT studies. Types of PA interventions included aerobic PA ($n = 34$), cognitively engaging PA (e.g., coordinative exercise, skill-based training, motor skill training, gesturing physical exercise, perceptual motor training and motor-enriched learning activities), motor demanding or cognitively engaging activities. A total of 14 studies delivered physically active academic lessons. The authors[34] synthesised the findings from the 11 studies rated as having high methodological quality. For cognitive performance, 10 of 21 (48%) analyses showed a statistically significant beneficial effect of PA interventions. For academic performance, 15 of 25 (60%) analyses found a beneficial effect of PA interventions. Interestingly, beneficial effects of PA interventions were reported in six out of seven analyses (86%) for children’s mathematical outcomes. The authors concluded that whilst there is currently inconclusive evidence for a beneficial effect of PA interventions on cognition and overall academic performance, there appears to be strong evidence for beneficial effects of PA interventions on mathematical performance.[34]

2.5.2.1 Summary of the empirical evidence

From the volume of evidence presented in the systematic reviews and meta-analyses conducted on this topic to date, it is evident that there is considerable variability across studies included within the reviews, along with notable methodological limitations in study quality and reporting thus making it difficult to draw firm conclusions about the relationship between PA, cognition and academic performance in children and adolescents. For example, the preceding narrative synthesis highlighted differences between studies in relation to their (i) study design (experimental vs observational); (ii) PA interventions (iii) comparison groups (e.g., no treatment, academic only, traditional PE, aerobic PA group); and (iv) outcome measures used (e.g., cognitive function, academic performance, PA). In relation to PA interventions, differences were apparent in relation to the context (e.g., before school, during school – adapted school curriculum or additional PA, after school) and parameters of the PA intervention, including the type of PA (e.g., aerobic, motor skill, resistance, cognitively engaging) and other quantitative vs qualitative characteristics. A summary of the different types of PA interventions reported in experimental studies included in the review by Vazou et al.[32] is provided in Table 7.

Table 7: Summary of the type of physical activity interventions and associated description examined in experimental studies included in the review by Vazou et al.[32] Reproduced with permission Taylor & Francis.

Type of PA intervention	Description
Aerobic	Examples of activities include running, skipping and physical education (PE) games.
Motor skill	Examples include: (i) balance and coordination tasks (ii) training object control skills; or (iii) PE class with an emphasis on developing children's fundamental motor skills
Cognitively engaging	Examples include PA that involves mindful behaviour (e.g., yoga, meditation, and breathing exercises).
Motor skill and aerobic	Examples include team games such as soccer practice.
Motor skill and cognitively engaging	Examples include: (i) enhanced PE programmes with sports, such as tennis, basketball, soccer games and dancing that require remembering rules and constantly thinking of action plans (ii) mindful Martial Arts (iii) complex motor and cognitively challenging tasks (e.g., constantly changing the rules of a game; or motor tasks integrated with social and emotional skills)
Aerobic and cognitively engaging	Examples include: (i) physically active academic lessons (e.g., students complete mathematics and/or language arts with aerobic activities such as jumping, hopping, walking, crab walking, or skipping; or running games, circuit training, relay games with letters, rope skipping and sit-ups with the focus of the lesson being on moderate-to-vigorous PA levels). (ii) aerobic activities with purposeful cognitive engagement such as team games with frequent rule changes
Aerobic, motor skill and cognitively engaging	Examples include: (i) aerobic, motor skill and cognitively engaging enriched environment in which students learn complex motor and cognitively challenging tasks of moderate exercise intensity (ii) variability of coordinative demands while also staying aerobically active

In reviews that conducted meta-analyses, the overall effect size reported was considered small (range = 0.28 to 0.46).[28,29,31-33] As this field of research has evolved, there have also been changes in the terminology used to describe the type of PA intervention, with earlier studies differentiating between aerobic, PE, perceptual-motor and resistance types of activities included in interventions. More recently published reviews have used terminology classifying PA interventions as involving cognitively engaging types of PA.[32-34] This makes it difficult to draw conclusions between the effectiveness of different types of PA interventions. However, there appears to be preliminary support in the literature that cognitively engaging types of PA interventions may be more beneficial than aerobic PA interventions.[34] Similarly, in relation to academic outcomes, there appears to be consistent findings to suggest that PA interventions are beneficial specifically for children's mathematics outcomes.[34]

As one of the objectives of this doctoral program of research is to explore whether early primary school classrooms are feasible settings to implement PA, particularly motor skill programs, as a strategy to promote children's motor proficiency and academic outcomes, the following section will discuss relationships between PA, cognition and academic performance within the context of the school setting and more specifically summarise literature examining the effectiveness of classroom-based PA interventions (i.e. physically active academic lessons and/or PA breaks).

2.6 The school as a setting for health and physical activity promotion

Healthy habits and behaviours are formed during the early childhood period, with evidence to suggest that attitudes, beliefs and behaviours learned during the early years track into adulthood.[24] Therefore primary schools are in an ideal position to positively influence children's PA behaviour as they transition to primary school, by promoting healthy lifestyles and equipping children with the knowledge and skills needed to make healthy choices.[20,130]

The Melbourne Declaration on Educational Goals for Young Australians acknowledges the importance of health and wellbeing for young Australians, indicating that to become confident and creative individuals, they will need to '*have the knowledge, skills, understanding and values to establish and maintain healthy, satisfying lives.'* [3(p9)] The importance of young Australians developing skills in literacy and numeracy has also been acknowledged. These educational goals for young Australians emphasise the need for the school curriculum to support the development of the student as a whole person.

Despite this recommended holistic approach to teaching and learning, findings from the 2014 and 2018 Active Healthy Kids Australia (AHKA) Report Cards revealed that only two thirds of primary school students receive the recommended 120 minutes of physical education (PE) each week.[16] A number of major barriers to improving the quantity and quality of PE in some states and territories in Australia, for example, in New South Wales (NSW) government primary schools, have been previously identified.[130,131] In 2013, an audit of physical activity practices in NSW government primary schools revealed that the classroom teachers responsible for delivering PE lessons felt their knowledge and skills were limited.[130] Furthermore, classroom teachers reported difficulty finding time to prioritise PE in a crowded curriculum due to the emphasis on numeracy and literacy, particularly with the introduction of national testing in 2008 through the National Assessment Program – Literacy And Numeracy.[130]

Concerning trends from state/territory-based surveys and studies in Australia highlight the need to improve children's motor skill proficiency, physical fitness and overall PA levels (Section 2.3.2.5). Consequently, the 2018 AHKA report outlined several strategies to support schools to overcome the barriers to delivering movement opportunities to children throughout the school day.[16] To summarise these recommendations, the following section commences with an overview of several frameworks that have been previously recommended for schools to employ to promote health and PA within the school setting. Secondly, research examining the effectiveness of classroom-based PA interventions (i.e., physically active lessons and/or PA breaks) on children's health and educational outcomes will be synthesised to reveal several gaps that will be investigated further through this doctoral program of research.

2.6.1 Health promoting schools framework

The health promoting schools (HPS) framework was developed in the late 1980s by the World Health Organisation (WHO) to describe a holistic approach to health promotion in schools and to highlight the importance of fostering both children's health and learning.[24] By adopting the philosophy of a HPS, schools have the ability to positively influence children's health behaviour.[24,132] The philosophy of a health promoting school recognises that different factors influence health behaviour at multiple levels, including the individual, organisational (school environment) and community levels.[24] In Australia, the HPS framework is comprised of three interrelated components, including (i) curriculum, teaching and learning, (ii) school organisation, ethos and environment; and (iii) engagement with community and partnerships (Figure 7).[24,133]

Figure 7: Components of the health promoting schools framework used in Australia.

A health promoting school aims to deliver a health education program that equips students with the knowledge and skills to establish positive attitudes to PA and health behaviours. A school that has an ethos and provides a school environment that supports healthy behaviours is also recognised as an essential component of an HPS. Finally, schools that foster community links and partnerships acknowledge the influence that families and communities have on children's health and the integral role they also play in reinforcing children's health behaviour.

A Cochrane review published in 2014 by Langford et al.[24] synthesised the findings from studies investigating the effectiveness of schools employing the HPS framework in enhancing the health and wellbeing of students and their academic achievement. A total of 67 studies utilising a cluster RCT design were included in the review. The overall quality of evidence in studies ranged from low to moderate. Health outcomes were diverse but those relating primarily to PA and fitness included body mass index, PA/sedentary behaviour (assessed using accelerometers and self-report measures) and physical fitness (assessed by 20m shuttle run and the step test). Academic outcomes included standardised test scores, IQ and school grades. Interventions were required to address all three components of the HPS framework, including the inclusion of health education in the curriculum, changes to the physical and/or social environment of the school and engagement with families and/or the local community. Findings from the meta-analysis conducted revealed that interventions using the HPS approach were able to increase PA (~ 3 min of PA per day) and fitness levels, along with several other health outcomes relating to nutrition and substance use. Notably, there was insufficient evidence to determine the effectiveness of the HPS approach for improving children's academic outcomes. The authors[24] concluded that despite the known links between health and education, a gap exists in the literature regarding the benefits of the HPS approach for children's educational outcomes.

Given the reported links between children's health and education, it is imperative that the health and education sectors work together to support schools to become health promoting schools.[25] In Australia, there is evidence of this partnership between sectors already occurring as children may be eligible to access allied health services within the school setting including physiotherapy, occupational therapy and speech language pathology.[134] As part of their service delivery, allied health professionals aim to build the capacity of school staff through the provision of professional development and training that helps to meet the needs of school students.[134]

2.6.2 Current role of allied health professionals working within the school setting in Australia

In Australia, school students with physical, vision, hearing, speech-language impairments, an intellectual disability and/or Autism Spectrum Disorder may be eligible to access allied health services within the school setting.[134] However, eligibility criteria to access these services differs between states and territories. As such, the role of allied health professionals working within the school setting may also vary between each state/territory and school sector (i.e. public/government, independent or Catholic).[134] In Australia, Queensland is considered a leading state for providing school-based therapy services as the Department of Education employs allied health professionals including physiotherapists, occupational therapists and speech-language pathologists to support students enrolled in government schools to access and participate at school and to facilitate their achievement of educational goals.[134] Although allied health professionals may not be employed in this capacity in other states and territories, students may be able to access allied health services within the school setting that are either privately funded by caregivers or through the National Disability Insurance Scheme or in some instances the school may initiate and fund selected services.[135] Table 8 summarises the role of key allied health professionals currently working within the school setting in Australia.

Table 8: Role of allied health professionals working in schools in Australia.

Health profession	Existing role within the school setting
Physiotherapy	'Physiotherapists use specialised knowledge of the body's movement abilities, senses, endurance and fitness to promote student health, well-being, self-management and physical activity. This is achieved through targeted assessment and the provision of recommendations for education adjustments, equipment advice and/or environmental adaptations to enhance students' access, participation and achievement of educational outcomes.'[134]
Occupational therapy	'Occupational therapists use specialised knowledge of the skills and abilities required for learning and occupational performance at school (including movement and sensory, cognitive and psychosocial skills), along with expertise in the design of tasks, environments and equipment to deliver evidence-informed strategies for occupational success. Services are delivered through collaboration and embedding advice in curriculum activities and classroom routines to enhance learning engagement and achievement.'[134]
Speech-language pathologist	'Speech-language pathologists study, identify and treat communication disorders including difficulties with speaking, listening, understanding language, reading, writing, social skills, stuttering and using voice. They work with people who have difficulty communicating and/or who experience difficulties swallowing food and drinks. Speech language therapy services assist schools with identifying and addressing barriers to learning. These services support students with speech, language and communication needs, or with eating and drinking difficulties, to achieve in education.'[136]
Accredited exercise physiologist	'Exercise physiologists specialise in clinical exercise interventions for people with a wide range of conditions and injuries. Exercise physiologists prescribe effective exercise programs that help to prevent or manage acute, subacute or chronic disease or injury as well as assisting in rehabilitating people's physical and mental health and wellness.'[137]

2.6.3 Comprehensive school physical activity programs

Schools can establish health-promoting environments that support children's PA behaviour by providing multiple opportunities for students to be active each day, including before school, during school class time, during recess and lunch breaks; and after school, in addition to the regular physical education program.[16,138,139] This whole-of-school approach to PA promotion is known in the public health literature as a comprehensive school physical activity program (CSPAP) and should ideally involve engagement with school staff, families and the wider community.[16,138]

A Cochrane review published in 2013 by Dobbins et al.[78] synthesised the findings from studies investigating the effectiveness of school-based PA interventions in promoting children's PA and physical fitness. A total of 44 studies with RCT designs were included in the review and, overall, studies were deemed to have a moderate risk of bias. Primary outcomes included rate and duration of moderate to vigorous physical activity (MVPA) (assessed using accelerometers or self-report measures) and time spent watching television (self-report or parent report). Secondary outcomes included blood pressure, blood cholesterol, body mass index, maximal oxygen consumption (VO_{2max}) and heart rate. For studies to be included in the review, PA interventions had to be implemented for a minimum of 12 weeks, with examples including changes to school curriculum and school routines, increasing levels of MVPA during PE classes and the provision of teacher training (e.g., providing educational materials and equipment). Other interventions included strategies involving engagement with parents and the community. Based on the findings from the review, the authors suggested that children and adolescents exposed to school-based PA interventions were three times more likely to spend time engaged in MVPA than those not exposed. Time spent engaged in MVPA following interventions reported in studies ranged from five to 45 min more per day and improvements in VO_{2max} ranged from 1.6 to 3.7mL/kg per min. However, despite emerging evidence to support the link between children's motor proficiency, health-related fitness and PA, children's motor skills were not assessed as a primary or secondary outcome in this review.[78]

2.6.3.1 Effectiveness of school-based motor skill interventions for improving children's motor proficiency

The effectiveness of school-based motor skill interventions for improving children's motor proficiency has also been investigated[13-15] In 2012, Logan et al.[13] published a meta-analysis regarding the effectiveness of motor skill interventions for improving children's FMS competency (as measured by a process-oriented motor assessment). A total of 11 studies were included in the review (*n* = 6 controlled experimental studies). Findings revealed a significant positive effect of motor skill interventions for improving children's FMS (d = 0.39, 95% CI: 0.23, 0.51; $p < .001$), including both object control skills (d = 0.41, 95% CI: 0.27, 0.55, $p < .001$) and locomotor skills (d = 0.45, 95% CI: 0.20, 0.70, $p < .001$). Notably, the majority of studies included in the meta-analysis described interventions with children who were either developmentally delayed or at risk of delay in developing FMS competence due to environmental or biological factors.[13]

A systematic review and meta-analysis conducted in 2013 by Morgan et al.[15] also evaluated the effectiveness of FMS interventions designed to improve children's FMS proficiency (as measured by product and process-oriented motor assessments). A total of 22 experimental studies (*n* = 6 RCTs) were eligible for inclusion. Evidence was found to support a positive influence of enhanced physical education (PE) programs (i.e., focussing on optimal FMS development to improve children's FMS proficiency). All 12 studies included in the meta-analysis reported significant effects of motor skill interventions on children's overall motor skill competency (standardised mean difference (SMD) = 1.42, 95% CI: 0.68, 2.16, z = 3.77; $p < .0002$; $I^2 = 93\%$). Similar to the review by Logan et al.,[13] significant intervention effects were also reported for locomotor skill competency (SMD = 1.42, 95% CI: 0.56, 2.27, z = 3.25; $p = .001$; $I^2 = 94\%$) and object control skill competency (SMD = 0.63, 95% CI: 0.28, 0.98, z = 3.53, $p = .0004$; $I^2 = 87\%$). The majority of interventions were delivered in the primary school setting by PE teachers, coaches or trained classroom teachers. The authors noted that findings should be treated with caution as there was a high risk of bias identified in many studies appraised in the review as well as considerable heterogeneity among FMS interventions.[15]

Finally, a recently published systematic review by Eddy et al.[14] in 2019 investigated the effectiveness of school-based motor skill interventions for improving the motor skills of children aged three to 12 years. Motor skill interventions targeted training of children's FMS (*n* = 12), handwriting (*n* = 7), fine motor skills (*n* = 2) and global motor skills (*n* = 2). Motor skills had to be objectively measured as an outcome. A total of 23 studies (48% RCT, 52% case-controlled studies) were included in the review with five studies including samples of children with motor skill deficits or delays. Significant benefits were reported at post-test for FMS interventions (10/12 studies), object manipulation skills (9/10 studies) and gross motor skills (4/6 studies). The majority of interventions were teacher led; however, there was evidence in some studies of interdisciplinary methods being trialled, including embedding health professionals (e.g., occupational therapists) within the classroom to assist children with the development of fine motor and handwriting skills. The authors noted that results should be interpreted with caution due to limitations in the methodological quality of the included studies (e.g., risk of bias was deemed 'unclear' in 54% of studies).[14]

Collectively, there is emerging evidence to suggest that school-based motor skill interventions may be beneficial for improving children's motor proficiency. This includes populations of typically developing children as well as children who have, or are at risk of, motor skill delays or deficits (e.g., children with neurodevelopmental conditions).

2.6.4 Social ecological approaches to implementing school-based physical activity programs

Current literature offers strong empirical evidence that multiple social ecological factors affect the implementation process of health promotion and preventive interventions.[51,140] A social ecological model may be used to gain a comprehensive understanding of the factors that influence health at the individual, interpersonal, organisation, community and systems levels.[141,142] Figure 8 outlines the five, interdependent levels of this model which emphasises that not only can an individual's personal attributes (i.e., attitudes, knowledge, beliefs) facilitate or inhibit their health behaviour but so can the social and environmental contexts within which they live.[76,143]

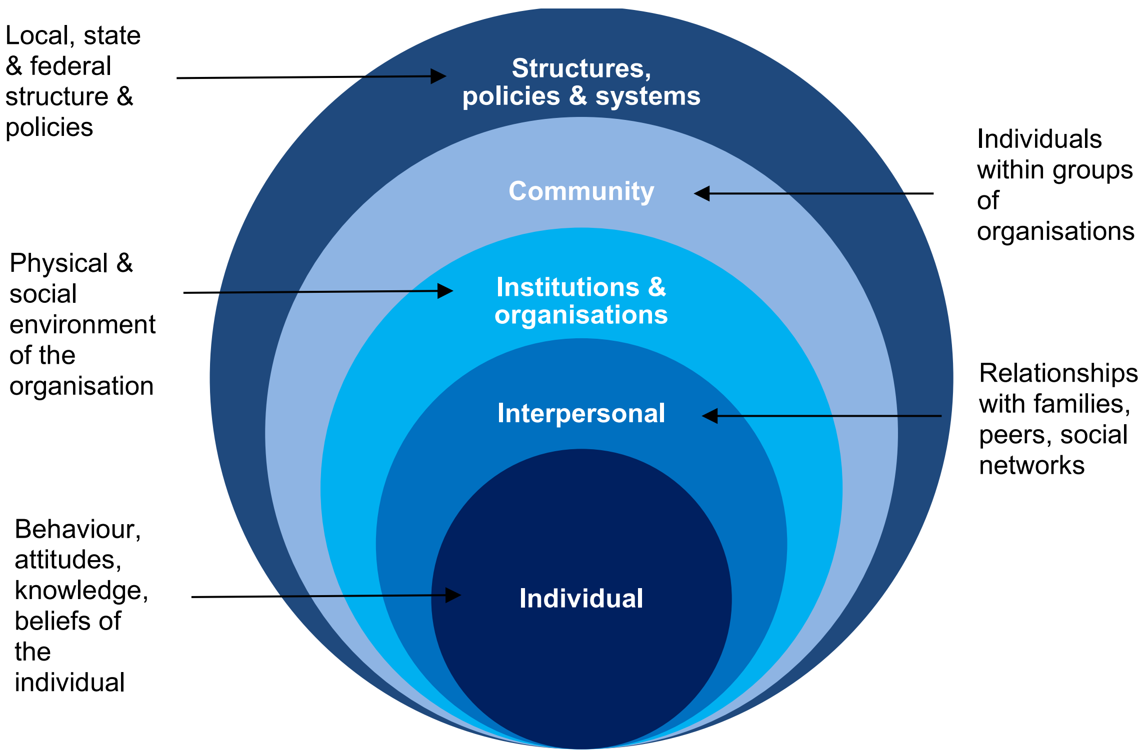

Figure 8: Social ecological model.[76,142,144] Created by the author.

Implementation science research has identified that whilst outcome evaluations of school-based PA interventions delivered in controlled settings are essential for determining efficacy, research suggests that when these interventions are subsequently delivered under real world conditions, in a less controlled environment, their success appears to be limited.[145] A systematic review by Naylor et al.[51] sought to better understand how school-based PA interventions could be successfully translated into real world settings. One of the key objectives of the review was to identify factors that influenced implementation of school-based PA interventions. Factors were categorised using the framework described by Durlak and Dupre.[140] The most commonly cited categories related to characteristics of the provider (e.g., self-efficacy, skill proficiency of the person implementing the intervention), characteristics of the innovation (e.g., the compatibility/contextual appropriateness, availability of quality resources), factors relating to the delivery system (e.g., presence of a supportive school climate) and the support system (e.g., provision of training and support). Time was also the factor most consistently reported as a barrier to implementation of school-based PA interventions. The authors concluded that a multi-level ecological framework for understanding implementation may be necessary and that studies should consider conducting process evaluations to better assess implementation.[51]

2.6.5 Classroom-based physical activity

Rising numbers of school-based PA interventions have been described in the literature which have aimed to promote children's PA-related outcomes as well as their educational outcomes.[46] Examples of school-based PA interventions include augmented PE lessons, recess and lunch time PA programs, physically active lessons (i.e., incorporating PA into the curriculum), PA breaks in the classroom (i.e., with or without academic content) and before/after school PA programs.[30] One strategy for increasing children's activity levels during the school day that may simultaneously improve children's academic outcomes, is scheduling active lessons and breaks during school class time, known as classroom-based physical activity (CBPA).[16,138] Classroom-based PA involves: (i) incorporating PA into academic lessons, (ii) providing PA breaks between lessons (with or without an academic focus), or (iii) incorporating PA into transitions from one location to another.[16,46,138,146] Consequently, over the last decade, increasing attention has shifted to exploring the impact of classroom-based PA on children's PA-related and educational outcomes and thus the following section will summarise the empirical literature conducted on this topic to date.

A narrative review by Kibbe et al.[147] published in 2011 provided a summary of the results of nine studies evaluating the impact of the classroom-based PA program, "Take 10!", on children's PA and academic outcomes. "Take 10!" is a curriculum tool used to engage students in PA while reinforcing academic content. Randomisation occurred in only three of the nine studies included in the review. Outcomes assessed related to academic performance (e.g., standardised test scores, student behaviour), PA (e.g., PA levels, step counts, energy expenditure) and health (e.g., body mass index, blood pressure). Findings revealed that integrating movement into academic lessons was feasible and there was promising evidence to suggest that children participating in the "Take 10!" program achieved higher levels of PA during class time, exhibited moderate energy expenditure, demonstrated reduced time off task and showed improvements in their academic outcomes.

A meta-analysis published by Erwin et al.[43] in 2012 investigated the impact of classroom-based PA interventions on children's PA, health and learning outcomes. A total of nine studies conducted over the period from 1990 to 2010 were included. Key outcomes assessed included objectively or subjectively measured PA (n = 5) (e.g., PA levels/activity count per minute, average step count per day), learning outcomes (n = 4) (e.g., reading scores, on-task behaviour) and health outcomes (n = 4) (e.g., bone-mass indices). Classroom-based PA interventions included "Take 10!" or "Energizers" (a combination of movement with academic content). Overall findings suggested a significant and moderate effect of classroom-based PA interventions on children's PA and learning outcomes. The weighted mean difference (under a random-effects model) was 0.99 (SE = 0.40, 95% CI: 0.20, 1.77, z = 2.46, p = .007) for the classroom-based PA intervention effect on PA outcomes. For learning outcomes, the estimated overall effect size (under a random-effects model) was 0.67 (SE = 0.21, 95% CI: 0.26, 1.09, z = 3.17, p < .001). However, the authors[43] stated that results should be interpreted with caution due to the small number of studies included in the review, the considerably large variation in effect sizes, and low methodological quality of studies.

A systematic review by Norris et al.[44] published in 2015 investigated the effect of physically active lessons on children's PA and educational outcomes. A total of 11 studies (n = 8 controlled trials, n = 3 pre/post-test) were eligible for inclusion in the review with eight of the studies rated as having a moderate to high risk of bias. Key outcomes included PA (n = 8) (e.g., PA levels, step counts, activity counts/min as measured using accelerometers, pedometers and self-report measures) and educational outcomes (*n* = 6) (e.g., academic achievement, on-task behaviour, intelligence, reading comprehension, session knowledge recall). Encouraging evidence was found to support improved levels of PA following physically active lessons (in 6/7 studies). However, mixed findings were apparent for children's educational outcomes following physically active lessons, with improvements in on-task behaviour and academic achievement reported following physically active lessons in some studies but not others. A number of limitations were reported in the included studies, including variability in the outcome measures assessed, the moderate to high risk of bias in the studies and a lack of detail regarding the interventions used in the studies. The authors identified the need for further research to be conducted to more confidently ascertain the effects of physically active lessons on children's PA and educational outcomes.

A few years later in 2017, Martin and Murtagh[45] conducted another systematic review investigating the effect of physically active lessons on children's PA and learning outcomes; however, effects on facilitators of learning and health outcomes were also evaluated. A total of 15 studies (*n* = 6 RCT) published between 1990 to 2015 met the inclusion criteria. Key outcomes included PA levels, learning outcomes (e.g., academic achievement in maths, reading), facilitators of learning (i.e., on-task behaviour, student enjoyment, teacher approval) and health (e.g., body mass index). Findings revealed that children participating in physically active lessons achieved increased levels of PA, with medium to large effect sizes reported in six of 10 studies. Positive effects for physically active lessons on children's learning outcomes were also reported in all four studies evaluating this outcome. Key limitations included a lack of robust study designs included in the review with many studies rated as having a high risk of bias and thus the authors concluded that results should be interpreted with caution.[45]

Finally, a systematic review and meta-analysis published in 2017 by Watson et al.[46] evaluated the impact of acute and chronic classroom-based PA interventions on children's on-task behaviour, cognitive function, academic performance and PA levels. A total of 39 studies met the inclusion criteria for the review, with 16 studies (RCT or quasi-experimental design) included in the meta-analysis. The methodological quality was rated as weak to moderate for 36 of the 39 studies. Classroom-based PA interventions included physically active lessons (*n* = 13 studies) and PA breaks with (*n*

= 7) and without (*n* = 19) an academic focus. Results from the meta-analysis revealed that classroom-based PA had a positive effect on on-task behaviour (*n* = 4 studies) (standardised mean difference (SMD) = 0.60, 95% CI: 0.20, 1.00, z = 2.93, *p* = .003, I^2 = 85%) and academic performance when assessed using a progress-monitoring tool (*n* = 4 studies) (SMD = 1.03, 95% CI: -0.22, 1.84, z = 2.48, *p* = .01, I^2 = 92%). However, classroom-based PA did not have a positive effect on academic performance when assessed using standardised tests (*n* = 6 studies, *p* = .67), cognitive outcomes (*n* = 5 studies, *p* = .14) or levels of PA (*n* = 3 studies, p = .15). Notably, there was considerable variation across studies in relation to their design, outcome measures and intervention parameters, as well as weak to moderate methodological quality. Similar to other reviews conducted on the topic, the authors[46] concluded that results need to be interpreted with caution.

Overall, it is apparent that there has been rapid growth in the body of literature examining the impact of classroom-based PA on children's PA and educational outcomes. In reviews that conducted meta-analyses, the overall effect size range reported by studies for intervention effects on academic outcomes ranged from 0.67[43] to 1.03 (when assessed using a progress-monitoring tool).[46] Although there appears to be promising results suggesting positive relationships between participation in classroom-based PA interventions and improvements in children's PA and educational outcomes, a high risk of bias has been identified in studies included in the reviews with few studies employing randomised controlled designs. There is also considerable heterogeneity across studies in relation to (i) experimental study designs, (ii) PA interventions; including the context (e.g., physically active academic lesson, PA break with academic focus, PA break without academic focus) and parameters (including type of PA – "Take 10!", "Energizers", virtual walk, basic aerobic movements) and (iii) outcomes measures used: PA (energy expenditure, step counts, PA levels, time in MVPA), health (e.g., body mass index), academic performance (e.g., standardised tests, on task behaviour) and cognitive performance.

2.7 Conclusions from the narrative review of the literature

Following a broad narrative review of the empirical literature, evidence from observational studies predominantly supports a positive relationship between PA, physical fitness, cognition and academic performance in children and adolescents.

However, despite the rapidly expanding research conducted on this topic, there is currently inconclusive evidence to support a beneficial effect of PA interventions, including classroom-based PA interventions, on cognition and overall academic performance. However, there is promising evidence to support a beneficial effect on children's mathematical outcomes.[34]

Several key gaps were evident following a comprehensive review of the literature. Firstly, in relation to observational studies examining the relationship between PA, cognition and academic performance in children and adolescents, the majority of these studies examined relationships between subjectively or objectively measured PA and/or the components health-related fitness with cognition and academic performance. No systematic reviews were identified that examined relationships between motor proficiency and specific academic outcomes in school-aged children and adolescents,[47] even though both motor proficiency and the components of health-related physical fitness are considered core aspects of children's physical development. Therefore, there is a need to specifically investigate relationships between motor proficiency and academic performance in specific areas such as mathematics and reading in school-aged children and adolescents.

Secondly, the majority of experimental studies evaluated the impact of PA interventions on children's cognition and academic outcomes, with some studies also evaluating their impact on children's PA-related outcomes. However, very few studies evaluated the impact of PA interventions on children's motor proficiency outcomes. Considerable variability was evident in the types of PA interventions examined in studies; however, studies predominantly investigated the impact of aerobic types of PA interventions on children's cognition and academic performance with fewer studies examining the impact of motor skill interventions. Thirdly, in relation to classroom-based PA interventions, the majority of experimental studies evaluated their impact on children's PA and academic outcomes, but seldom their impact on children's motor proficiency outcomes. Experimental studies also primarily investigated the impact of aerobic types of classroom-based PA interventions on children's PA and academic outcomes. Therefore, further exploration is warranted regarding the impact of classroom-based motor skill interventions on children's academic (specifically numeracy and literacy) and motor proficiency outcomes. These key gaps identified in the literature will be explored further in the **Systematic review** reported in the next chapter.[3]

[3] Please note that all references in this chapter are presented in the References section of the thesis

Chapter 3: Relationships between Motor Proficiency and Academic Performance in Mathematics and Reading in School-Aged Children and Adolescents: A Systematic Review

3.1 Preface

The preceding **Narrative review (Chapter 2)** summarised existing trends regarding the physical development of Australian children, indicating low levels of physical activity, physical fitness and motor skill proficiency. Positive relationships between PA, cognition and academic performance in children and adolescents were consistently reported in the literature. However, the need to further examine relationships between motor proficiency and specific academic outcomes in school-aged children and adolescents was identified. The systematic review reported in this chapter further progresses *Stage 1 (problem definition)* of the thesis framework by exploring the identified gap in the literature regarding relationships between motor proficiency and academic performance in mathematics and reading.

The systematic review reported in this chapter was published in a peer-reviewed journal in 2018. The formatting of the original published manuscript has been amended to be consistent with the thesis style. The published manuscript is as follows: https://www.mdpi.com/1660-4601/15/8/1603

Macdonald K, Milne N, Orr R, Pope R. Relationships between motor proficiency and academic performance in mathematics and reading in school-aged children and adolescents: a systematic review. *Int J of Environ Res and Public Health*. 2018; 15(8): 1603. doi: 10.3390/ijerph15081603 under Creative Commons Attribution Licence (CC BY 4.0)

A copy of the two data extraction tables submitted with the journal article as supplementary material are referred to as Table S1 and Table S2 within this chapter. Table S1 and Table S2 can be found in Appendix A and Appendix B respectively.

3.2 Abstract[4]

Positive associations exist between physical activity, cognition, and academic performance in children and adolescents. Further research is required to examine which factors underpin the relationships between physical activity and academic performance. This systematic review aimed to identify, critically appraise, and synthesise findings of studies examining relationships between motor proficiency and academic performance in mathematics and reading in typically developing school-aged children and adolescents. A systematic search of electronic databases was performed to identify relevant studies. Fifty-five eligible articles were critically appraised and key data were extracted and synthesised. Findings support associations between several components of motor proficiency and academic performance in mathematics and reading. There was evidence that fine motor proficiency was significantly and positively associated with academic performance in mathematics and reading, particularly during the early years of school. Significant positive associations were also evident between academic performance and components of gross motor proficiency, specifically speed and agility, upper-limb coordination, and total gross motor scores. Preliminary evidence from a small number of experimental studies suggests motor skill interventions in primary school settings may have a positive impact on academic performance in mathematics and/or reading. Future research should include more robust study designs to explore more extensively the impact of motor skill interventions on academic performance.

[4] The format of this abstract has remained consistent (i.e., unstructured) with those of the journal for which it was published.

3.3 Background

Early childhood curriculum and pedagogical approaches aim to promote holistic attitudes to teaching and learning which recognise the important contribution a child's physical, cognitive, social, and emotional development has on their learning and readiness to start school.[2] However, upon school entry, the primary focus of learning often shifts to developing students' academic skills, particularly in numeracy and literacy.[3] Consequently, there may be less dedicated time in the school curriculum for encouraging the ongoing physical development of students, which ideally aims to support the acquisition of motor skills and foster positive attitudes towards physical activity (PA).[130] The disparity between the competing priorities of physical versus academic development has been debated in recent years due to increasing awareness of the global public health implications of growing physical inactivity and sedentary time in youth.[20]

The importance of PA is widely recognised, with regular and adequate levels of PA leading to improvements in muscular and cardiorespiratory fitness (CRF) and bone health, along with a reduction in levels of cardiovascular disease, cancer, and diabetes.[20,84] Furthermore, social, emotional, and intellectual benefits of PA, such as improved self-esteem and confidence and enhanced concentration, have also been reported.[20,84] However, recent surveys suggest that only approximately 19% of Australian children and young people aged five to 17 years meet the recommended 60 min of moderate to vigorous PA per day.[148] Several reviews[28,30,35,44,120,149,150] have consistently reported significant, positive associations between PA and cognition and/or academic performance in children and adolescents. However, it remains unclear as to the exact type, frequency, duration, and intensity of PA that is required to impact cognitive functioning in children and adolescents.[30,151]

The majority of studies investigating the impact of PA on cognition and academic performance in school-aged children have measured either overall levels of PA (objectively, using accelerometers[42], or subjectively, through questionnaires[152]) or health-related physical fitness, in particular CRF.[30] For example, a recently published systematic review by Donnelly et al.[30] comprehensively summarised the findings of studies examining the relationships between PA, fitness, cognitive function, and academic achievement. The synthesis included a summary of findings from 27 observational studies that examined the relationship between physical fitness and academic achievement in children aged five to 13 years, demonstrating largely positive findings, although it highlighted several limitations in relation to study quality and reporting that resulted in inconsistent findings. Notably, the components of physical fitness measured by these studies included CRF, muscular strength and endurance, flexibility, and body composition. However, as engagement in PA is dependent not only on health-related physical fitness but also on performance-related physical fitness, which we have termed 'motor proficiency' in this review, further examination of the relationships between motor proficiency, cognition, and academic performance is warranted, as reviews to date on these relationships have been scant.[37]

Over several decades, researchers have reviewed the impacts of perceptual motor programs on the academic performance of school students, providing inconsistent findings and insufficient evidence, as many of the studies had notable methodological flaws.[153,154] Perceptual motor skills require the integration of sensory input (visual, auditory, and kinaesthetic) with fine or gross motor responses.[153] More recently, the focus has shifted to investigating the relationship between fine motor skills and academic performance, given emerging findings that fine motor skills may be a significant indicator for school readiness.[155,156] A systematic review published in 2015 by van der Fels et al.[47] summarised the findings from studies examining the relationship between motor and cognitive skills in typically developing school children and also noted inconsistent findings, with either no association reported in the literature or insufficient evidence for or against many associations between motor and cognitive variables. However, the authors[47] highlighted that weak to strong evidence was found to support the relationship between more complex motor skills, such as bilateral body coordination and cognitive skills.

In recent years, several systematic reviews[30,44-46] have evaluated the impact of school-based PA interventions on the educational and health outcomes of school students. For example, one approach of providing PA opportunities to students during the school day, distinct from physical education (PE) classes and break times, is classroom-based PA.[46,146] Classroom-based PA may involve the integration of PA into academic lessons or may include incorporating PA into the regular classroom routine without an academic focus.[46,146] However, research evaluating the impact of classroom-based PA on learning is still in its infancy, with inconsistent findings from a small number of studies with varying methodological quality and study designs reported in recently published systematic reviews.[45,46] However, there is preliminary evidence to suggest that classroom-based PA, particularly with an academic focus, may have a positive impact on both academic performance and overall levels of PA.[30,44-46] To date, no systematic review on this topic has specifically evaluated the impact of motor proficiency-related interventions in the school setting on academic performance and motor proficiency outcomes.

The present systematic review builds on the reviews published by van der Fels et al.[47] and Donnelly et al.[30] by examining, in greater detail than previously reported, the underlying domains of motor proficiency (i.e., fine and gross motor skills) that may be associated with academic performance of school students. This review also expands on findings from reviews investigating the impact of classroom-based PA on learning outcomes by specifying motor skills as the type of PA being evaluated and academic performance in mathematics and reading as the learning outcomes of interest. Academic performance in mathematics and reading has specifically been chosen for this review due to the priority for students to develop foundational skills in numeracy and literacy upon entry to school. Therefore, the overall objective of this systematic review was to identify, critically appraise, and synthesise the findings of studies examining the relationship between motor proficiency and academic performance in mathematics and reading in typically developing school-aged children and adolescents. Two main aims were developed to address this objective: (1) to determine whether a relationship exists between motor proficiency and academic performance in mathematics and reading in typically developing school-aged children and adolescents; and (2) to determine whether motor proficiency-related interventions impact academic performance in mathematics and reading in typically developing school-aged children and adolescents.

3.4 Methods

3.4.1 Identification of studies

To identify relevant studies, a comprehensive search of health and education databases was undertaken using a four-step approach, and documented in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol.[157] Firstly, electronic databases (EBSCO, PubMed, PsycINFO, and Web of Science) were searched on 21 February 2018 using key search terms to identify literature relevant to this topic. The key search terms were: ((motor AND (proficiency OR competency OR skill* OR development OR ability OR performance OR movement OR gross OR fine)) AND ("academic performance" OR "academic achievement" OR "academic grades" OR math* OR numeracy OR reading OR literacy) AND (child* OR adolescen* OR "school student")). The search terms for each database are available upon request from the authors.

3.4.2 Screening and selection

Following removal of duplicates, the titles and abstracts of the remaining studies identified in the database searches were screened with reference to pre-determined inclusion and exclusion criteria to assess their potential eligibility for inclusion in this review. Studies in which the abstract clearly indicated the study would be ineligible for inclusion in the review were eliminated, but studies for which any doubt regarding eligibility existed and those considered likely to be eligible were retained; full text copies of these studies were subsequently obtained. The full text copies of these remaining studies were then independently assessed for eligibility for inclusion in the review by one of the reviewers (K.M.), using the pre-determined inclusion and exclusion criteria described below. For inclusion in this review, studies were required to meet the following criteria:

(1) The study population had to include typically developing school children aged between four and 18 years.

(2) For observational studies, at least one component of motor proficiency had to have been objectively measured and reported. Motor proficiency, as described by Bruininks and Bruininks,[59] incorporates the following components: fine motor precision, fine motor integration (visual motor integration), manual dexterity, upper limb coordination, bilateral coordination, balance, running speed and agility, and strength. For experimental studies, the intervention had to specifically incorporate a component of motor proficiency delivered during the school day (e.g., academic and/or PE lessons), designed to impact academic performance in mathematics and/or reading.

(3) For observational studies, associations between an objective measure of fine or gross motor proficiency AND an objective measure of academic performance (specifically in mathematics, reading or their underlying constructs) had to have

been reported. Appropriate statistical analyses for reporting associations included correlations and regression or structural equation modelling. For experimental studies, the pre-test and post-test values of motor proficiency and academic outcomes in mathematics and reading for both control and experimental groups or a measure of treatment effect on academic performance needed to be reported.

(4) Studies had to be either observational or experimental in design.

(5) Studies had to have been published after January 2000, due to the methodological limitations in studies published prior to 2000 previously described.[153,154]

Following application of these inclusion criteria, five exclusion criteria were applied in the study selection process, these being:

(1) Studies involving a population of school-aged children diagnosed with either an intellectual disability or a neurodevelopmental disorder (e.g., Specific Learning Disorder, Developmental Coordination Disorder, Attention Deficit Hyperactivity Disorder or Autism Spectrum Disorder), as defined by the Diagnostic and Statistical Manual of Mental Disorders (5th Edition).[116]

(2) For experimental studies, intervention(s) focussed on health-related fitness (e.g., CRF) or general physical activity rather than an intervention specifically focussed on motor proficiency or motor proficiency-related interventions that were implemented outside school hours.

(3) Studies reporting motor outcomes that included only an overall fitness score (i.e., a combination of performance and health-related physical fitness).

(4) Studies reporting academic outcomes in terms of an overall academic performance score only (i.e., a combination of mathematics and reading) but not an individual score for mathematics and/or reading.

(5) Studies published in a language other than English, where a translated version could not be sourced.

Eligible studies were retained and included in the review and were subject to subsequent quality assessment, data extraction, and synthesis. Reference lists of all eligible articles were also reviewed, and potentially eligible studies not previously identified were sourced in full text and subjected to the same selection process.

3.4.3 Critical appraisal of methodological quality

Two authors (K.M., N.M.) independently assessed the methodological quality of included studies using the Downs and Black checklist.[158] The checklist includes five subcategories including: reporting quality, external validity, internal validity (bias and confounding), and statistical power. The checklist consists of 27 items, of which 25 items use a scoring system of 1 = Yes, 0 = No, or 0 = Unable to determine. Two of the questions have a greater scoring range. Item 5 is normally scored from 0 to 2 points, where 1 point is awarded for partially detailed confounding factors and 2 points are awarded for comprehensively detailed confounding factors. Item 27 is normally scored from 0 to 5 points based on the statistical power of the study. For this review, item 27 was modified to be scored with either 1 point if the study outlined the statistical power or basis for the sample size for the study, or 0 points if the study did not describe the statistical power or basis for the sample size. This modified approach has been previously reported.[159] To provide a rating of quality, the rating system described by Kennelly[160] was used, and was slightly adapted as discussed below. Kennelly's rating system is based on the original scoring system reported by Downs and Black;[158] however, due to the modifications made to the checklist in the present review, critical appraisal scores of studies were first converted to percentages before these percentages were used to assign a quality rating to each of the studies.

To address the first aim of the current review, which was to determine whether a relationship exists between motor proficiency and academic performance in mathematics and reading in typically developing school-aged children, the methodological quality of included observational studies was assessed. However, items 4, 8, 13, 14, 15, 19, 23, and 24 of the Downs and Black checklist[158] were not assessed for these studies, as these items were specifically relevant to the methodologies used in experimental studies, and not to methods used in observational study designs. For example, item 4 asks: 'Are the interventions of interest clearly described?'[158] To provide a rating of quality, the raw total score from the modified Downs and Black checklist for each observational study was converted to a critical appraisal percentage (CAP) by dividing the raw score by 20 points (the maximum possible score) and multiplying it by 100. This method for modifying the Downs and Black checklist[158] for observational studies was previously published by Lyons et al.[161] Studies were then allocated a methodological quality rating, with studies achieving a

CAP ≥71% classified as ‘good’ quality, 54–70% classified as ‘fair’ quality, and ≤53% classified as ‘poor’ quality.[160]

To address the second aim of the review, to determine whether motor proficiency-related interventions impact academic performance in mathematics and reading in typically developing school-aged children and adolescents, the methodological quality of eligible experimental studies was assessed using all items of the Downs and Black checklist.[158] To provide a rating of quality, the raw score for each experimental study was converted to a critical appraisal percentage (CAP) by dividing each study’s raw score by 28 points and multiplying it by 100. All studies were then allocated a methodological quality rating score, with studies achieving a CAP ≥71% classified as ‘good’ quality, 54–70% classified as ‘fair’ quality and ≤53% classified as ‘poor’ quality.[160] This method for determining the quality rating score has been previously described by Terry et al.[162]

To determine the level of agreement between the critical appraisal scores derived by the two independent reviewers (K.M. and N.M.) when applying the modified Downs and Black checklist, a kappa coefficient was calculated by a third author (R.O.) and graded using methods previously reported by Viera and Garrett.[163] Following this process, any discrepancies in critical appraisal scores between the two authors (K.M. and N.M.) which could not be resolved by discussion and consensus were moderated by the third author (R.O.).

3.4.4 Synthesis

The first aim of the review was to examine the relationships between motor proficiency and academic performance in mathematics and reading, and thus associations between these variables in each included study (when reported) were extracted and considered in a critical narrative synthesis of key findings from the included studies. For the purposes of the synthesis, motor proficiency, as described by Bruininks and Bruininks,[59] was categorised into the eight motor subtests of the Bruininks-Oseretsky Test of Motor Proficiency – 2nd Edition (BOT-2). The BOT-2 is a valid and reliable standardised assessment tool, suitable for evaluating the fine and gross motor proficiency of individuals aged four to 21 years.[59] Key findings extracted from included studies for the following components of fine motor proficiency were considered in the synthesis: (1) fine motor precision; (2) fine motor integration; (3) manual dexterity; and

(4) total fine motor score. Key findings extracted for the following components of gross motor proficiency were also considered in the synthesis: (1) upper limb coordination; (2) balance; (3) bilateral coordination; (4) speed and agility; (5) strength; and (6) total gross motor score. Findings for total motor proficiency score, representing the sum of fine and gross motor scores, were also considered in the synthesis.

During the synthesis of key findings, interpretation of the strengths of the correlations (r) between the different areas of motor proficiency and academic performance in mathematics and reading was guided by a rating scale described by Evans[164] as follows: r = 0.00–0.19 (very weak), r = 0.20–0.39 (weak), r = 0.40–0.59 (moderate), r = 0.60–0.79 (strong), and r = 0.80–1.0 (very strong). Significant and non-significant associations reported in studies included in the review were then summarised and coded using an approach adapted from that originally described by Sallis et al.[165] for observational studies investigating relationships between variables in the field of public health. For each component of motor proficiency, a percentage was calculated to represent the proportion of reported associations between that component of motor proficiency and academic performance that reached statistical significance. The overall result was then classified as: (1) no association, coded '0' (indicating 0–33% of reported associations reached statistical significance); (2) inconsistent/uncertain association, coded '?' (indicating 34–59% of reported associations reached statistical significance or less than four studies examined the relationship); or (3) a positive or negative association coded '+' or '−' (indicating that ≥60% of reported associations reached statistical significance, based on results of four or more studies). In the latter case, when four or more studies with a Kennelly rating[160] of 'fair' or 'good' methodological quality reported a statistically significant positive or negative association between a given motor proficiency variable and a particular academic performance variable, the positive or negative association was coded '+ +' or '− −', respectively, representing the fact that strong evidence, based on multiple studies of 'fair' or 'good' methodological quality, supported the significant association. This latter approach is similar to that used by Lubans et al.[9] and Cliff et al.[166] in their systematic reviews.

To address the second aim of the review, a critical narrative synthesis was also undertaken to synthesise the key findings from the included experimental studies that investigated whether motor proficiency-related interventions impacted academic performance in typically developing school-aged children and adolescents. Given the heterogeneity between studies in their design, outcome measures and study quality, a meta-analysis was not conducted.

3.5 Results

3.5.1 Included studies and study characteristics

The PRISMA diagram[157] in Figure 9 summarises the results of the four-step approach taken to identify, screen, and select studies for inclusion in this review. Following completion of screening and selection, a total of 55 studies were deemed eligible for inclusion. Table S1 summarises the key characteristics extracted from the 51 observational studies (26 longitudinal and 25 cross-sectional) included in the review. Table S2 summarises the key characteristics extracted from the four experimental studies (one cluster randomised controlled trial and three quasi-experimental studies). A copy of Tables S1 and S2 can also be found in Appendix A and Appendix B respectively.

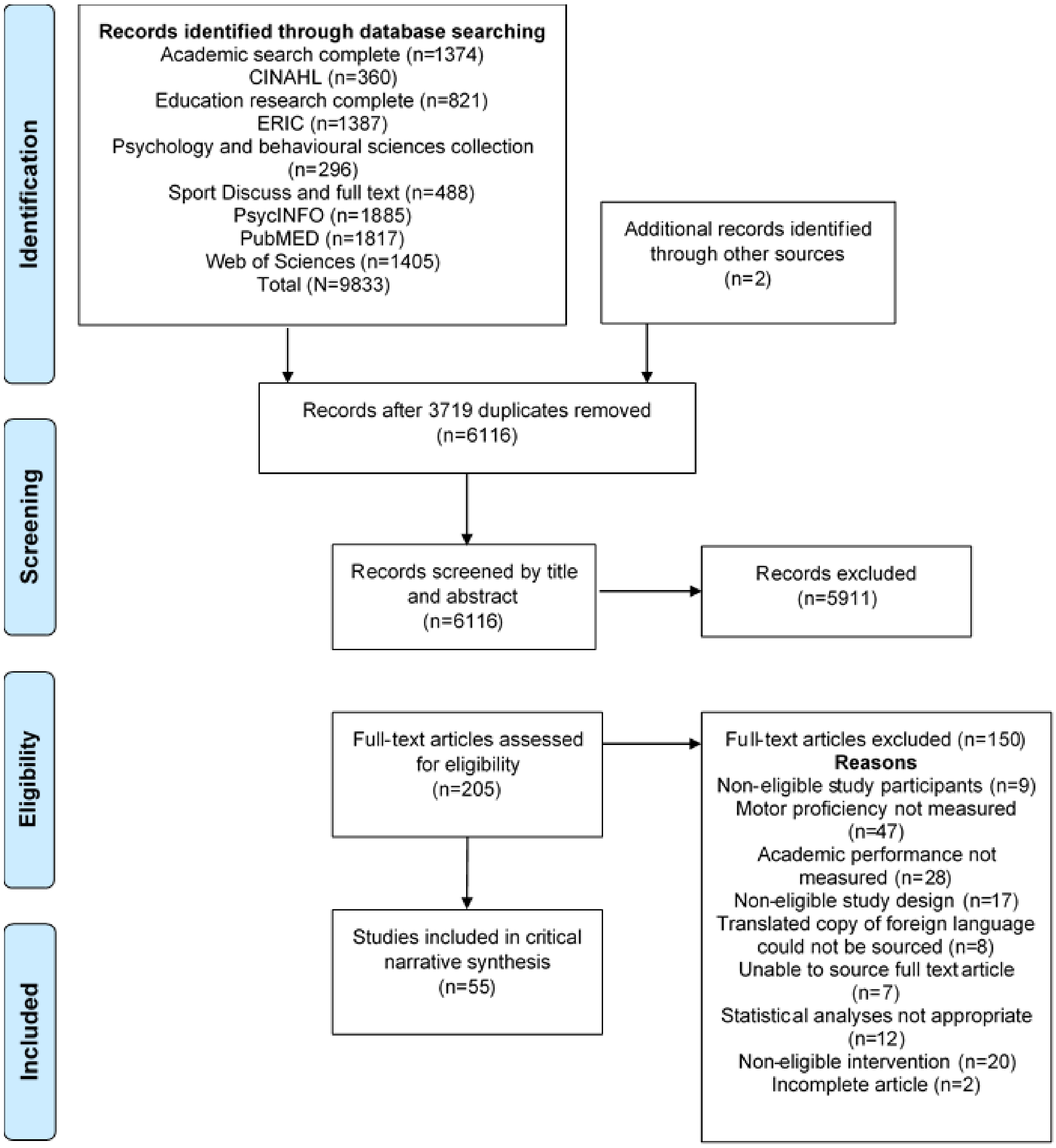

Figure 9: Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram depicting results of the search, screening and selection processes.[157]

As noted in Tables S1 and S2, just over half (56%) of the studies included in the review had been published since 2014. Total participant sample sizes in studies included in the review varied between 36[167] and 19173.[168] Studies were undertaken in a broad range of developed and developing countries, with 19 (35%) conducted in the USA. Study participants were most frequently children from the early year levels of school (i.e., pre-Kindergarten to Year 2), with 44 studies (80%) reporting outcomes for academic performance and motor proficiency in children at these year levels. Only seven (13%) studies[169-175] involved school students in high school (i.e., Year 7 to 12). Socioeconomic status (SES) of study participants varied, with several studies undertaken specifically in socio-economically disadvantaged communities.[176-182] As outlined in Tables S1 and S2, a range of instruments were used to evaluate the different components of fine and gross motor proficiency. Examples of these instruments included standardised motor assessments, standardised developmental assessments, and individual motor subtests. A wide variety of instruments were also used to evaluate academic performance in mathematics and reading (Tables S1 and S2), often chosen depending upon the country in which the study was undertaken. Examples of these instruments included standardised academic achievement tests, national standardised assessments, teacher-reported academic reports, and grade point average (GPA). It is it is important to acknowledge that a wide range of covariates were also measured in the studies included in this review (Tables S1 and S2) and factored into their subsequent statistical analyses. For example, executive function (EF) was one of the key cognitive variables that was consistently reported in the included studies as a covariate. Components of EF that were assessed included working memory, cognitive flexibility (e.g., planning, problem solving, reasoning), inhibitory control, attention and behavioural self-regulation. Examples of additional covariates measured included age, gender, intelligence, visual perception, other academic variables (e.g., vocabulary, writing, spelling), family characteristics (e.g., SES, parental education, ethnicity), behavioural characteristics (e.g., social behaviour, classroom engagement), and physical characteristics (e.g., body mass index, PA levels, CRF, pubertal status).

3.5.2 Methodological quality of included studies

The critical appraisal percentage (CAP) for each of the studies is shown in Tables S1 and S2. The level of agreement established between the two reviewers (K.M., N.M.) in their assessments of methodological quality was considered ‘substantial agreement’, based on the Cohen’s kappa analysis (k = 0.758).[163] The mean (±SD) methodological quality score of the 51 observational studies in the review was 12.80 (±3.21) out of a possible 20 points, equating to a CAP of 64.02% (±16.06), with a CAP range of 20–90% (Table S1). A total of 16 (31%) of the observational studies were categorised as having ‘good’ methodological quality, 22 (43%) as being of “fair” methodological quality, and 13 (25%) as having ‘poor’ methodological quality. According to the five subcategories of the modified Downs and Black checklist, collectively across the observational studies the most notable limitations were in external and internal validity (both bias and confounding). For example, many studies included samples that were not considered representative of the population, limiting the ability to generalise findings to other populations. There were also deficits in reporting of the distributions of principle confounders in each group, as well as reporting of actual probability values for the main outcomes. Very few studies were adequately powered or provided the basis for the study sample. Notable strengths of the studies were in the reporting quality category, meaning that the studies commonly provided descriptions of the study aim, main outcomes to be measured and participant inclusion and exclusion criteria, and used appropriate statistical tests to assess the main outcomes.

The mean (±SD) methodological quality score of the four experimental studies included in the review was 14 (±5.35) out of a possible 28 points, equating to a CAP of 50% (±19.12), with a CAP range of 25–71% (Table S2). One (25%) study was classified as being of 'good' methodological quality, one (25%) as being of 'fair' methodological quality, and the remaining two (50%) as having 'poor' methodological quality. The most notable limitations across the experimental studies were in the categories of external and internal validity, particularly confounding (selection bias) as well as a lack of sufficient power to detect a clinically important effect. For example, limitations in the reporting category included a lack of reporting of participant details, distributions of principle confounders in each group, adverse events, and characteristics of patients lost to follow up. In relation to external and internal validity, there were also limitations in representative sampling, blinding of subjects to the intervention, blinding of those measuring the primary outcomes, randomisation into groups, concealment of randomised intervention, and reporting of whether participants lost to follow up were considered.

3.5.3 Aim 1: Relationships between motor proficiency and academic performance in mathematics and reading

3.5.3.1 Fine motor proficiency and academic performance in mathematics

A total of 29 (57%) of the observational studies (14 longitudinal and 15 cross-sectional) from the present review investigated the relationship between fine motor proficiency and academic performance in mathematics. Most studies (86%) examining these variables reported findings from participants in pre-Kindergarten to Year 2, with only three (11%) studies[171-173] reporting findings from participants in high school. A total of 19 (65%) studies[156,168,172,176,177,180,181,183-194] used standardised assessment tools to measure both fine motor proficiency and academic performance in mathematics. Of the 29 studies that examined these variables, 12 (41%)[168,176,179,182,184,185,187,192-195] were categorised as having 'good' methodological quality, 10 (34%)[172,177,180,183,186,188-190,196,197] were categorised as having 'fair' methodological quality, and seven (24%)[156 171,173,181,191,198,199] were categorised as having 'poor' methodological quality. A summary of the associations between the components of fine motor proficiency and academic performance in mathematics, along with the levels of evidence supporting the associations can be found in Table 9.

Table 9: Overall levels of evidence from studies examining associations between specific components of motor proficiency and academic performance in mathematics in school-aged children and adolescents.

Motor Proficiency	Associated with academic performance in mathematics (references)	Not associated with academic performance in mathematics (references)	Summary Coding [a]	
			n/*N* showing significant associations for outcome (%) [b]	Association (+,−,0,?) [c]
Fine motor proficiency				
Fine motor precision	173,181,184,194	183,184	4/6 (67%)	(+)
Fine motor integration	176,177,180-186,188,190-192,196,198	173	15/16 (94%)	(++)
Manual dexterity	171,176,180,183,194,200	172,173,190,200	6/10 (60%)	(+)
Total fine motor score	156,168,179,183,187,193,195,197,199		9/9 (100%)	(++)
Gross motor proficiency				
Upper limb coordination	170-172,201	170,173	4/6 (67%)	(+)
Balance	202	172,173,200,202,203	1/6 (17%)	(0)
Bilateral coordination	173,196,203	173	3/4 (75%)	(?)
Speed and agility	170,173,174,200,201,204	170,200,203	6/9 (67%)	(++)
Strength	173,204		2/2 (100%)	(?)
Total gross motor score	170,175,183,185,187,195,197,200,205,206	156,169,179,200	10/14 (71%)	(++)
Total motor proficiency (fine and gross motor scores)	173,182,189		3/3 (100%)	(?)

[a] Summary coding provides an overall summary of findings. [b] *n* = number of studies that reported a statistically significant association, *N* = number of studies that reported associations between the specific component of motor proficiency and academic performance in mathematics. [c] Association coded as '+' or '−' indicates a 'positive or negative association' (≥60% of reported associations reached statistical significance, based on results of four or more studies); '++' or '− −' indicates 'strong evidence for a positive or negative association' (≥60% of reported associations reached statistical significance, based on results of four or more studies with fair-to-good methodological quality); '0' indicates 'no association' (0–33% of reported associations reached statistical significance); and '?' indicates 'inconsistent or uncertain association' (34–59% of reported associations reached statistical significance or less than four studies examined the relationship).

A total of five studies[173,181,183,184,194] examined the relationship between fine motor precision and academic performance in mathematics. Significant very weak to moderate positive correlations (r = 0.13−0.597) between fine motor precision and mathematics performance variables were reported by four studies[173,181,184,194] however only two of the studies were classified as having fair to good methodological quality.[184,194] A longitudinal study by Kim et al.[184] found several significant positive partial correlations (controlling for age) between fine motor coordination and mathematical skills for Kindergarten and Grade 1 cohorts at different measurement points across the study. However, several non-significant associations between fine motor coordination and mathematical skills were also reported for the cohorts at other measurement points. Kim et al.[184] concluded from their analyses that fine motor coordination seemed to contribute to mathematics performance indirectly, through visual motor integration, across Kindergarten and Grade 1.[184] Another study[183] also reported non-significant associations between a draw-a-person task and applied problems subtest in Kindergarten children. Overall summary coding suggests that despite inconsistent findings, there was evidence to support a significant very weak to moderate positive association between fine motor precision and academic performance in mathematics (Table 9).

When taking into consideration all studies that examined associations between fine motor integration (also referred to as visual motor integration or copying skills) and mathematics performance variables (Table S1), 15 of the 16 studies found significant positive associations, with 12 of these significant associations reported by studies with fair to good methodological quality.[176,177,180,182-186,188,190,192,196] In studies analysing correlations between fine motor integration and mathematics performance, six studies[176,180,183,185,186,191] reported significant very weak to weak associations (r = 0.16−0.38), seven studies[177,181,184,186,188,192,198] reported moderate associations (r = 0.417−0.59), and two studies[184,192] reported a strong association (r = 0.612−0.673). The one study[173] that did not report a significant association between fine motor integration and mathematics performance was the only study conducted with high school participants. Overall, summary coding suggests there was a strong level of evidence to support a significant very weak to strong positive association between fine motor integration and academic performance in mathematics (Table 9).

The relationship between manual dexterity and academic performance in mathematics was examined by nine studies.[171-173,176,180,183,190,194,200] Five of the six studies[171,176,180,183,194,200] reporting significant positive associations were classified as having fair to good methodological quality. The four studies[176,180,183,194] that reported results from correlation analyses found significant very weak to weak positive correlations (r = 0.11−0.37) between manual dexterity tasks and mathematical ability. One longitudinal study[200] found that the smaller number of cubes moved in a box and block task was associated with poorer arithmetic skills for boys in Grades 1 and 2, but not for girls in the same grades. Another study,[171] classified as having 'poor' methodological quality, reported significant strong correlations between the time taken to stack a tower of cubes and scores on a mathematics skills test for children aged nine to 16 years (r = −0.643 to −0.727, $p < 0.05$). Two other studies[172,173] conducted with participants in high school did not report significant associations between manual dexterity and mathematics performance. Summary coding suggests that despite mixed findings, overall, there was sufficient evidence to support a significant positive very weak to weak association between manual dexterity and mathematical skills (Table 9).

A total of nine studies[156,168,179,183,187,193,195,197,199] examined associations between total fine motor scores and academic performance in mathematics. All studies reported significant positive associations with seven studies[168,179,183,187,193,195,197] classified as having fair to good methodological quality. Of note is that four studies[156,168,187,193] reported findings from the Early Childhood Longitudinal Study — Kindergarten Cohort and collectively found that fine motor skills were predictive of later mathematics achievement. Furthermore, five studies[183,187,195,197,199] reported results from correlational analyses and found significant very weak to strong positive associations (r = 0.25–0.73). Overall, summary coding suggests there was a strong level of evidence to support a significant very weak to strong positive relationship between total fine motor scores and mathematics performance (Table 9).

3.5.3.2 Gross motor proficiency and academic performance in mathematics

A total of 24 (47%) observational studies (10 longitudinal and 14 cross-sectional) from the review investigated the relationship between gross motor proficiency and academic performance in mathematics. A summary of the data extracted from these studies can be found in Table S1. Findings from participants in pre-Kindergarten to Year 2 were reported in 14 (58%) studies, whereas seven (29%) studies[169-175] reported findings from participants in high school. Less than half (46%) of the studies[156,169,172,183,185,187,189,201,203,204,206] used standardised assessment tools to measure both gross motor proficiency and academic performance in mathematics. Of the 24 studies that examined these variables, eight (33%)[170,179,182,185,187,195,200,201] were categorised as having 'good' methodological quality, ten (42%)[172,174,183,189,196,197,202-204,206] were categorised as having 'fair' methodological quality, and six (25%)[156,169,171,173,175,205] were categorised as having 'poor' methodological quality. The overall levels of evidence from studies examining associations between gross motor proficiency and academic performance in mathematics in typically developing school-aged children and adolescents are outlined in Table 9.

It was apparent that associations between several components of gross motor proficiency, particularly bilateral coordination and strength, and mathematical performance had been examined less frequently by the studies included in the review, leading to more uncertain findings overall. The five studies[170-173,201] that examined associations between upper limb coordination and mathematical performance involved participants in school year levels 4–10. Significant very weak to moderate positive correlations (r = 0.13–0.439) between upper limb coordination tasks and mathematics performance were reported by four studies,[170-173,201] with three of these studies[170,172,201] classified as having fair to good methodological quality. The two studies[170,173] that found non-significant associations assessed upper limb coordination through a dribbling task and used teacher-reported grades to assess mathematics performance. For example, one longitudinal study[170] reported conflicting findings, with significant very weak positive correlations ($r = 0.18$, $p < 0.05$) found between a dribbling task assessed in Grade 7 and maths for boys only, with no significant associations found between these variables for girls. Overall, despite inconsistent findings, summary coding suggests there was sufficient evidence to support a significant very weak to moderate positive association between upper limb coordination and mathematical skills (Table 9).

A total of five studies[172,173,200,202,203] analysed the relationship between balance and academic performance in mathematics. One study[202] assessed balance using a static single leg balance task, reporting several significant very weak to weak positive correlations (r = 0.26–0.37) between the balance task and mathematical performance. This same study[202] reported significant partial correlations (controlling for age, attentional and reasoning capabilities) between balance tasks with eyes closed and complex arithmetic tasks but non-significant partial correlations with more simple arithmetic tasks. Collectively, the three remaining studies,[172,200,203] with fair to good methodological quality, found no significant association between balance and mathematics performance. Overall, summary coding suggests there was a sufficient level of evidence to support no significant relationship between balance and academic performance in mathematics (Table 9).

Only three studies[173,196,203] examined associations between bilateral coordination and academic performance in mathematics. One study by Geertsen et al.[196] found that better performance in a gross motor task (i.e., a shorter time to complete a coordination wall task) was associated with better scores on a standardised mathematics test. Another study by Murrihy et al.[203] reported a significant weak positive correlation (r = 0.26, p < 0.05) between a finger-to-nose test and a standardised mathematics test. However, a study by Van Niekerk et al.[173] reported conflicting results, with a significant weak positive correlation (r = 0.23, p < 0.05) found between a task involving tapping feet and fingers and teacher-reported maths results for boys and girls, but no significant association found between a jumping-in-place task (same sides synchronised) and teacher-reported maths results. Overall, summary coding suggests the level of evidence to support a significant relationship between bilateral coordination and mathematics was uncertain, due to a limited number of studies examining these variables (Table 9).

A total of seven studies[170,173,174,200,201,203,204] examined the relationship between speed and agility and mathematical skills, with six studies[170,173,174,200,201,204] using the shuttle run to assess speed and agility. Only one study[173] was classified as having 'poor' methodological quality. Significant positive associations between speed and agility and academic performance in mathematics were reported by six studies.[170,173,174,200,201,204] In analysing correlations between speed and agility and mathematics variables, two studies[170,173] reported significant very weak to weak positive associations (r = 0.18–0.20). One longitudinal study[170] found significant very weak positive correlations (r = 0.18–0.20) between the 10 × 5 m shuttle run (assessed in Grade 8) and marks in mathematics (assessed in Grade 9) for both boys and girls. However, several non-significant correlations between these variables were reported at other measurement times in the study[170] for girls more often than boys. Another longitudinal study[200] reported a similar trend with significant findings between shuttle run test times and arithmetic skills reported more often for boys than girls in Grades 1–3. Three other studies[200,201,204] reported that shuttle run test times were significantly but inversely associated with mathematics performance, with longer shuttle run test times related to poorer mathematics performance. Finally, one study[203] reported no significant association between performance on a jumping task and standardised maths test. Overall, summary coding suggests there was a strong level of evidence to support very weak-to-weak positive associations between speed and agility and mathematics performance (Table 9).

Only two studies[173,204] with poor to fair methodological quality investigated the relationship between strength and mathematics performance, reporting significant very weak to weak positive associations (r = 0.15–0.29). The components of strength that were assessed in one of the studies included the sit up and standing broad jump from the European physical fitness test battery,[204] while the other study assessed push ups and sit ups from the BOT-2 (Short Form).[173] Overall, summary coding suggests the level of evidence to support a significant relationship between strength and mathematics performance was uncertain due to a limited number of studies examining these variables (Table 9).

Associations between total gross motor scores and academic performance in mathematics were examined often, with 10[170,175,183,185,187,195,197,200,205,206] of 13 studies reporting significant findings between these outcomes. Eight[170,183,185,187,195,197,200,206] of these 10 studies were classified as having fair to good methodological quality. Significant positive correlations reported in studies ranged from very weak to moderate (r = 0.16–0.41). Of the four studies that reported non-significant associations between total gross motor scores and mathematical performance, two[156,169] were classified as having 'poor' methodological quality. One longitudinal study[200] found significant positive associations between overall motor performance and arithmetic skills for boys in Grades 1–3, but not for girls in Grades 1 and 3. The findings from regression analyses reported in two other longitudinal studies[156,179] revealed that total gross motor scores (as measured by developmental motor assessments) were not a significant predictor of later mathematics ability. Another study[169] conducted with high school students found no significant associations between total gross motor coordination scores and a national standardised mathematics test. Overall, despite several conflicting findings, summary coding suggests there was a strong level of evidence to support a very weak to moderate positive association between total gross motor scores and mathematical skills (Table 9).

Finally, a total of three studies[173,182,189] with poor to good methodological quality reported significant associations between total motor proficiency (a combination of fine and gross motor scores) and academic performance in mathematics using the BOT-2

(Short Form) to assess total motor proficiency. Significant positive correlations reported were found to be weak (r = 0.21–0.23). In summary, there was some evidence to support a significant relationship between total motor proficiency and academic performance in mathematics; however, summary coding suggests that overall, the level of evidence for an association was uncertain due to a limited number of studies in the review examining these variables (Table 9).

3.5.3.3 Fine motor proficiency and academic performance in reading

A total of 30 (58%) observational studies (16 longitudinal and 14 cross-sectional) from the present review investigated the relationship between fine motor proficiency and academic performance in reading. A summary of the data extracted from these studies can be found in Table S1. Findings from participants in pre-Kindergarten to Year 2 were reported in the majority (90%) of studies, with only one study examining these variables in participants in high school.[172] Standardised assessment tools were used to measure both fine motor proficiency and academic performance in reading for 24 (80%) of the studies. Of the 30 studies that examined these variables, nine (30%)[168,176,182,185,187,194,200,207,208] were categorised as having ‘good’ methodological quality, 14 (47%)[172,180,183,186,188-190,196,209-214] were categorised as having ‘fair’ methodological quality, and seven (23%)[156,167,181,191,198,215,216] were categorised as having ‘poor’ methodological quality. A summary of the overall levels of evidence from the studies examining the associations between the components of fine motor proficiency and academic performance in reading can be found in Table 10.

Table 10: Overall level of evidence from studies examining associations between specific components of motor proficiency and academic performance in reading in school-aged children and adolescents.

Motor Proficiency	Associated with academic performance in reading (references)	Not associated with academic performance in reading (references)	Summary Coding [a]	
			n/*N* showing significant associations for outcome (%) [b]	Association (+,−,0,?) [c]
Fine motor proficiency				
Fine motor precision	183,194,214	181	3/4 (75%)	(?)
Fine motor integration	167,176,180-183,186,188,191,196,198,209,211,213-216	167,185,190,207,213	17/22 (77%)	(++)
Manual dexterity	176,180,183,194,200,210,214	172,190,200,214,215	7/12 (58%)	(?)
Total fine motor score	156,168,183,187,195,214	214	6/7 (86%)	(++)
Gross motor proficiency				
Upper limb coordination	170,172,201,217	170,201	4/6 (67%)	(++)
Balance	200,215	172,200,203	2/5 (40%)	(?)
Bilateral coordination	196,203		2/2 (100%)	(?)
Speed and agility	170,200,201,217	170,200,203,204	4/8 (50%)	(?)
Strength	204	204	1/2 (50%)	(?)
Total gross motor score	170,183,185,187,195,200,206,212,217	156,169,170,175,183,206	9/15 (60%)	(++)
Total motor proficiency (fine and gross motor scores)	182,189,208	212	3/4 (75%)	(?)

[a] Summary coding provides an overall summary of findings. [b] *n* = number of studies that reported a statistically significant association, *N* = number of studies that reported associations between the specific component of motor proficiency and academic performance in reading. [c] Association coded as '+' or '−' indicates a 'positive or negative association' (≥60% of reported associations reached statistical significance, based on results of four or more studies); '++' or '− −' indicates 'strong evidence for a positive or negative association' (≥60% of reported associations reached statistical significance, based on results of four or more studies with fair-to-good methodological quality); '0' indicates 'no association' (0–33% of reported associations reached statistical significance); and '?' indicates 'inconsistent or uncertain association' (34–59% of reported associations reached statistical significance or less than four studies examined the relationship).

A total of four studies[181,183,194,214] examined associations between fine motor precision and academic performance in reading for children in pre-Kindergarten to Year 1. Three studies[183,194,214] with fair to good methodological quality reported significant positive associations between fine motor precision and reading variables, with the strength of the correlation classified as very weak to weak (r = 0.15–0.28). However, one study[181] reported no significant associations between the fine motor precision subtest from the BOT-2 and a word reading subtest from a standardised reading test. In summary, while there was some evidence to support a significant positive association between fine motor precision and reading performance, overall, summary coding suggests the level of evidence for an association was uncertain due to a limited number of studies examining these outcomes (Table 10).

The relationship between fine motor integration skills and academic performance in reading was examined most often, with 17[167,176,180-183,186,188,191,196,198,209,211,213-216] significant positive associations out of the 22 reported. In relation to the strength of correlations between variables reported, 10 studies[176,180,181,183,186,191,209,211,213,215] found very weak to weak correlations (*r* = 0.163–0.38), six studies[167,186,187,198,209,216] found moderate associations (*r* = 0.40–0.47), and two studies[188,198] reported a strong correlation (*r* = 0.60–0.62). A total of 11[176,180,182,183,186,188,196,209,211,213,214] of the 17 studies reporting significant associations had fair-to-good methodological quality. Two studies[167,213] reported mixed findings with significant positive associations found between visual motor integration tasks and certain constructs of reading performance but non-significant findings for other constructs of reading (Table S1). Eight studies[167,181,185,190,191,207,211,213] reported that when other known predictors of reading (e.g., intelligence quotient (IQ), vocabulary, phonological awareness) were included in regression analyses, fine motor integration was not found to contribute significantly to predicting reading achievement. However, four[167,181,211,213] of the eight studies reported significant correlations between fine motor integration and reading performance prior to accounting for these covariates. In summary, despite several inconsistencies reported between studies, summary coding suggests there was a strong level of evidence to support a significant very weak to strong positive relationship between fine motor integration and reading performance (Table 10).

A total of seven[176,180,183,194,200,210,214] studies with fair to good methodological quality reported significant positive associations between manual dexterity and academic performance in reading. The level of correlation reported ranged from very weak to weak (*r* = 0.15–0.36). One study[200] reported mixed results for associations between a box and block test and two reading variables, with significant associations found for reading fluency, particularly for boys, but non-significant associations reported for reading comprehension. Furthermore, six studies[172,180,190,194,210,214] conducted regression analyses and found that manual dexterity performance did not make a unique contribution to reading performance in the presence of other predictors (e.g., executive function, phonological awareness). However, four[180,194,210,214] of these studies reported significant positive correlations between manual dexterity and reading performance. Overall, summary coding suggests the level of evidence to support a relationship between manual dexterity and reading performance was inconsistent as less than 60% of studies supported this relationship (Table 10).

Finally, all six studies[156,168,183,187,195,214] that examined the relationship between total fine motor scores and reading performance reported significant positive associations. Fair to good methodological quality was found for five[168,183,187,195,214] of the six studies. A study by Suggate et al.[214] found mixed results, reporting significant very weak to weak positive correlations (r = 0.18–0.23) between the total score of the manual dexterity subtest of the Movement Assessment Battery for Children (MABC) and reading outcomes (specifically phonemic awareness and word reading); however, associations between manual dexterity and a letter naming subtest were not significant. Conversely, three studies[156,168,187] reported findings from the Early Childhood Longitudinal Study — Kindergarten Cohort (ECLS-K) and collectively found that fine motor skills were positively associated with and a very strong and consistent predictor of later achievement in reading. In the ECLS-K study,[156,168,187] the Early Screening Inventory — Revised was used to assess performance on seven fine motor tasks. Overall, summary coding suggests there was a strong level of evidence to support a significant very weak-to-weak positive association between total fine motor scores and reading performance (Table 10).

3.5.3.4 Gross motor proficiency and academic performance in reading

A total of 21 (41%) studies (11 longitudinal and 10 cross-sectional) from the present review investigated the relationship between gross motor proficiency and academic performance in reading. A summary of the data extracted from these studies can be found in Table S1. Findings from participants in pre-Kindergarten to Year 2 were reported in 14 (67%) studies, and four (19%) studies[169,170,172,175] examined these variables in participants in high school. A total of 14 (67%) studies[156,169,172,183,185,187,189,201,203,204,206,208,212,217] used standardised assessment tools to measure both gross motor proficiency and academic performance in reading. Of the 21 studies that examined these variables, eight (38%)[170,182,185,187,195,200,201,208] were categorised as having 'good' methodological quality, nine (43%)[172,183,189,196,203,204,206,212,217] were categorised as having 'fair' methodological quality, and four (19%)[156,169,175,215] were categorised as having 'poor' methodological quality. A summary of the overall levels of evidence from the studies examining the associations between the components of gross motor proficiency and academic performance in reading can be found in Table 10.

A total of four studies[170,172,201,217] with fair to good methodological quality reported significant very weak to weak positive correlations (r = 0.10–0.28) between upper limb coordination and reading skills. A study by Aadland et al.[201] found significant associations between the catching subtest from the Movement Assessment Battery for Children – 2nd Edition (MABC-2) and results on a standardised reading test but non-significant associations between the aiming subtest from the MABC-2 and reading performance. Mixed results were also reported in another study[170] where significant very weak positive correlations ($r = 0.17$, $p < 0.05$) were found between a dribbling task and marks in Finnish language for girls in Grade 7 but not for boys. Overall, despite some inconsistencies in findings, summary coding suggests there was a strong level of evidence to support a significant weak positive association between upper limb coordination and reading performance (Table 10).

Associations between balance and academic performance in reading were examined by four studies[172,200,203,215] that assessed balance using different instruments. One study[215] reported significant very weak to weak associations (r = −0.117 to −0.251) between the inclination from upright measured in a postural stability task and performance on a reading task. The other three studies,[172,200,203] classified as having fair to good methodological quality, found no significant associations between balance and reading performance, except for the study by Haapala et al.[200] who found that poor performance on a static single leg balance test was related to poor reading comprehension for boys in Grade 1. In summary, there was some evidence that no significant association exists between balance and academic performance in reading; however, summary coding suggests that overall, the level of evidence was uncertain due to an insufficient number of studies in the review examining these variables (Table 10).

Only two studies[196,203] categorised as having 'fair' methodological quality examined the association between bilateral coordination and reading performance, both reporting significant positive associations between coordination tasks and standardised reading tests. A study by Murrihy et al.[203] reported the strength of the correlation between a finger-to-nose task and letter–word identification subtest was weak ($r = 0.33$, $p < 0.001$). Another study[196] found that a shorter time to complete a wall coordination task was associated with better scores in a standardised reading test. In summary, there was some evidence to support a significant relationship between bilateral coordination and reading performance; however, overall summary coding suggests the level of evidence was uncertain due to a limited number of studies in the review examining these variables (Table 10).

Associations between speed and agility and reading performance were examined by six studies.[170,200,201,203,204,217] The four studies[170,200,201,217] that reported significant positive associations had fair to good methodological quality. Two studies[170,217] reported significant very weak to weak positive correlations ($r = 0.16–0.31$) between locomotor skills (e.g., leaping, hopping) and reading outcomes. Another two studies[200,201] reported that shuttle run test times were significantly but inversely associated with reading performance; however, in one study this applied only to boys in Grades 1–3. These findings were consistent with those reported by Jaakkola et al.[170] who reported significant correlations between a 5 × 10 m shuttle run test and marks in Finnish language for boys in Grades 7 and 8 but found non-significant correlations for girls. Another study[204] did not find a significant relationship between the time taken to perform a 5 × 10 m shuttle run and a standardised reading test in participants aged 7–12 years. In summary, there appears to be some inconsistency in the findings reported in the studies examining the associations between speed and agility and reading performance, potentially due to the instrument used to measure speed and agility (e.g., assessment of locomotor skills vs shuttle run). Therefore, despite there being some evidence to support a significant association between speed and agility and academic performance in reading, overall summary coding suggests the level of evidence was inconsistent as less than 60% of studies supported a significant relationship (Table 10).

Mixed findings were reported in the only study[204] that examined the relationship between strength and reading performance. For example, a significant very weak positive association ($r = 0.18$, $p < 0.01$) was found between distance measured on the standing broad jump and scores on a standardised reading test; however, no significant association was found between the number of sit-ups performed and the same standardised reading test. Overall, summary coding suggests the level of evidence to support a significant association between strength and reading performance was uncertain, due to a limited number of studies examining these variables (Table 10).

A total of 12 studies[156,169,170,175,183,185,187,195,200,206,212,217] examined the relationship between total gross motor scores and academic performance in reading with eight studies using standardised tests to assess both outcomes. Eight studies[170,183,185,187,195,206,212,217] reported significant very weak to moderate positive correlations (r = 0.15–0.404). Another study[200] also found that poor overall motor performance was associated with worse academic results in reading fluency and reading comprehension. All nine studies reporting significant associations had fair to good methodological quality. However, there were inconsistencies in the findings reported within three studies,[170,183,206] often dependent on gender or the academic variable being assessed. Two studies[206,212] found significant positive associations between gross motor composite scores and reading performance in 9-10-year-old girls only. Another study[170] reported significant very weak to weak correlations (r = 0.17–0.23) between marks in Finnish language and total scores for fundamental movement skills for boys in Grades 7–9 but found non-significant associations for girls. A study by Cameron et al.[183] reported several significant very weak to weak correlations (r = 0.17–0.20) between gross motor composite scores from a developmental assessment and reading composite scores, but non-significant associations between gross motor composite scores and results on individual reading subtests, assessed at a different time. Finally, four studies[156,183,185,206] reported that following regression analyses, total gross motor scores did not make a unique contribution to reading performance in the presence of other predictors. In summary, despite several inconsistencies reported between studies, overall summary coding suggests there was a strong level of evidence to support a significant very weak to moderate positive association between total gross motor scores and academic performance in reading (Table 10).

Finally, four studies[182,189,208,212] classified as having fair to good methodological quality, examined associations between total motor proficiency (combined fine and gross motor scores) and academic performance in reading. Total fine and gross motor scores were assessed using the MABC[208,212] and the BOT-2 (Short Form).[182,189] A study by Pienaar et al.[182] reported a strong positive relationship between total motor proficiency and academic performance in reading. However, a study by McPhillips et al.[208] found that although motor skills were weakly predictive of reading without confounders, they were not predictive of reading in the context of other predictors. A study by Cadoret et al.[189] reported a significant weak positive correlation ($r = 0.28$, $p < 0.01$) between total motor proficiency and academic achievement in reading; however, a structural equation modelling analysis found that the mechanism appeared to be through an indirect path, via cognitive ability. Another study[212] found no significant association between overall motor competence and a reading achievement test in children aged 9–10 years. In summary, there was some evidence to support a significant relationship between total motor proficiency and reading performance; however, summary coding suggests that overall, the level of evidence for an association was uncertain due to a limited number of studies in the review examining these variables (Table 10).

3.5.4 Aim 2: Impact of motor proficiency-related interventions on academic performance in mathematics and/or reading

A total of four experimental studies[178,218-220] investigating the impact of motor proficiency-related interventions on academic performance in mathematics and reading of school-aged children were eligible for inclusion in the review (Table S2). A cluster randomised study by Beck et al.[218] investigated whether fine or gross motor activity integrated into mathematics lessons over a 6-week period could improve children's mathematical performance. A quasi-experimental study by Callcott et al.[219] investigated whether pre-Kindergarten children who participated in a year-long program involving literacy and movement would demonstrate superior results in measures of movement and early literacy skills when compared with students receiving a literacy only intervention, movement only intervention or no intervention (control group). A further quasi-experimental study by Erasmus et al.[178] aimed to establish the effect of a 10-week perceptual–motor intervention programme on school readiness (including assessment of a number concept subtest) of children in pre-Kindergarten. Finally, another quasi-experimental study by Ericsson[220] measured whether daily PE and motor training over a 3-year period would impact attention and school results in reading and mathematics.

The interventions described in each study were delivered in the primary school setting, with participants in the early year levels of school (pre-Kindergarten to Year 2). Interventions ranged in duration from 6 weeks[218] to 3 years.[220] The interventions described in each study involved implementing motor skills into a prescribed number of lessons each week for a specified timeframe. Intervention parameters, including the type, duration and frequency of the intervention varied across studies. For example, the intervention described by Beck et al.[218] involved the implementation of fine or gross motor activities into a 60-min mathematics lesson, three days a week over a 6-week period (Table S2). Two interventions were delivered by the classroom teacher,[218,219] one intervention was delivered by the researcher,[178] and one intervention was delivered by the PE teachers and representatives from local sports clubs.[220] Two studies[218,219] described their strategies to enhance compliance with the intervention, with these strategies including the provision of professional development workshops to classroom teachers, to teach them how to implement the intervention, along with follow up support throughout the intervention period.

All four experimental studies[178,218-220] reported a statistically significant effect of the motor skill intervention on academic performance in mathematics and/or reading. Two experimental studies[178,218] in the review incorporated fine motor skills into their interventions to examine their effect on academic performance. In their cluster randomised control trial, Beck et al.[218] reported that participants in the fine motor-enriched learning group, particularly those with normal mathematics performance, improved their performance on the mathematics task following the 6-week intervention. Statistical analyses were conducted to determine the specific impact of fine motor enriched learning activities on mathematical performance, with Beck et al.[218] reporting that changes in fine motor skill performance accounted for approximately 10.7% of the effects of the intervention on mathematics performance. The intervention outlined in the study by Erasmus et al.[178] involved the provision of a 40-min lesson incorporating fine motor, gross motor, and perceptual-motor skills, three days per week over 10 weeks. Participation in the intervention led to a significant improvement in results on the number concept subtest of a standardised developmental assessment ($p < 0.012$, Cohen's effect size d = 1.13). However, improvements in the number concept subtest were not significantly better than the control group following the intervention (controlling for differences in pre-test scores).[178] Each of the four experimental studies in the review incorporated gross motor skills into their interventions to examine their effect on academic performance.[178,218-220] Beck et al.[218] incorporated gross motor-enriched learning activities into mathematics lessons, leading to greater improvements in mathematical performance compared to the conventional (control) group and fine motor enriched learning group, particularly in students with normal mathematics performance. Beck et al.[218] reported that changes in gross motor skill performance accounted for approximately 25% of the effects of the intervention on mathematics performance. However, there were no differences in mathematics performance reported between groups when re-assessed 8 weeks after the intervention.[218] A quasi-experimental study by Callcott et al.[219] found that incorporating a combination of movement (i.e., 15 min of action songs) and literacy skills (15 min of phonological awareness and decoding activities) into daily lessons led to students performing significantly better on reading measures (phonological awareness) than students in the literacy only, movement only and conventional (control) groups. As previously mentioned, following the 10-week motor skill intervention outlined by Erasmus et al.[178] the experimental group significantly improved their mathematical skills (number concept) but not significantly more than the control group. Finally, the quasi-experimental study by Ericsson[220] found that participation in daily lessons of PE and motor training led to students in the intervention group achieving better results than those in the control group in national tests for reading (overall large difference in results between groups, Cramer's index 0.29) and for mathematics (overall small difference in results between groups, Cramer's index 0.21).

In summary, a limited number of experimental studies with varied study designs, intervention parameters, and methodological quality have examined whether motor proficiency-related interventions impact academic performance in mathematics and reading. However, there were findings of a statistically significant effect of the motor skill interventions on academic performance that warrants further investigation.

3.6 Discussion

3.6.1 Overview of findings

The overall objective of this systematic review was to identify, critically appraise, and synthesise the findings of studies examining the relationship between motor proficiency and academic performance in mathematics and reading in typically developing school-aged children and adolescents. To address the first aim of the review, 51 observational studies were examined to determine whether there was evidence for significant associations between components of motor proficiency and academic performance in mathematics and reading. In summary, based on the findings from observational studies, of which 74% were classified as having fair to good methodological quality, there was sufficient evidence to support significant very weak to strong positive associations between all components of fine motor proficiency and academic performance in mathematics. Although fewer studies in the review examined the relationship between the components of gross motor proficiency and academic performance in mathematics, sufficient evidence also emerged to support significant very weak to weak positive associations between gross motor proficiency (specifically the components of upper limb coordination, speed and agility, and total gross motor scores) and academic performance in mathematics. There was also sufficient evidence to support no significant association between balance and mathematics performance. A similar trend of significant associations was evident in studies examining the relationship between motor proficiency and academic performance in reading, although there were more inconsistencies reported between studies. Overall, there was evidence to support a significant very weak to strong relationship between fine motor proficiency (specifically the components of fine motor integration and total fine motor scores) and academic performance in reading. There was also sufficient evidence to support a significant very weak to weak positive association between academic performance in reading and upper limb coordination, as well as total gross motor scores.

To address the second aim of the review, the findings from four experimental studies were synthesised to determine whether motor proficiency-related interventions impact academic performance in mathematics and/or reading in typically developing school-aged children and adolescents. Based on the findings from one cluster randomised controlled trial and three quasi-experimental studies, there was evidence for a statistically significant effect of the motor skill intervention on academic performance compared to the control group in each study for students in the early years of school (pre-Kindergarten to Year 2). However, several methodological limitations relating to the external and internal validity (bias and confounding) of studies were apparent; thus, it is difficult to infer the exact underlying mechanisms for the effects of the interventions, and results should be interpreted with caution.

3.6.2 Relationships between motor proficiency and academic performance

3.6.2.1 Fine motor proficiency and academic performance

There was consistency in findings among studies included in the review that a relationship exists between motor proficiency and academic performance in mathematics and reading; however, this association differed between the components of fine and gross motor proficiency. There was evidence from observational studies for significant positive associations between the majority of components of fine motor proficiency and academic performance in mathematics and reading. This was with the exception of the components of fine motor precision and manual dexterity and their associations with reading performance as there was either an insufficient number of studies in the review examining these variables or inconsistent evidence.

Differences in associations between motor proficiency and academic variables for children and adolescents were also apparent, consistent with those reported by van der Fels et al.[47] Interestingly, the majority (86%) of observational studies in the present review that reported significant positive associations between the components of fine motor proficiency and academic performance involved study participants in the early year levels of school (pre-Kindergarten to Year 2). In particular, relationships between fine motor integration (visual motor integration) and academic performance in mathematics and reading were examined most often in this age group, with a strong level of evidence found to support very weak to strong positive associations between these variables. Thus, findings from this review may have important implications for this age group upon entry to school. Only seven studies in the present review involved high school students and consequently there was insufficient evidence to support associations between fine motor proficiency and academic performance in mathematics and reading in this older age group. However, non-significant associations in adolescents have been proposed by the authors of some studies by a potential ‘ceiling effect’ that occurs as primary school students achieve automaticity with their fine motor precision and manual dexterity skills.[193]

It is worth noting that many studies examining the relationship between fine motor proficiency and academic performance in mathematics and reading in the present review conducted statistical analyses that accounted for other covariates, in addition to correlational analyses. For example, regression analyses accounting for key cognitive confounders (e.g., visual-spatial skills, executive function) were performed in several studies investigating the relationship between fine motor proficiency and mathematics and found that fine motor integration remained independently predictive of academic performance in mathematics. However, when examining the relationship between fine motor proficiency and reading performance, it was often reported that in the presence of other predictors (e.g., IQ, executive function, phonological awareness), fine motor integration and manual dexterity did not uniquely contribute to reading performance.[185,190,211,213] The underlying mechanisms to potentially explain the difference in findings between the components of fine motor proficiency and these two core academic areas is beyond the scope of the present review; however, it has been proposed there may be both biological and learning mechanisms that underpin these relationships.[108,221] Furthermore, it suggests that future studies should ensure that covariates known to impact on the relationship between motor proficiency and academic performance, such as age, gender, SES, executive function (and its components), body mass index, and CRF, are measured and reported on when examining these outcomes in school-aged children and adolescents.

3.6.2.2 Gross motor proficiency and academic performance

The relationships between the components of gross motor proficiency and academic performance in mathematics and reading have been investigated less frequently in the literature. For example, four or less studies in the review investigated associations between academic performance in mathematics and reading and the components bilateral coordination and strength, along with total motor proficiency scores. Consequently, the evidence to support associations between these variables was uncertain, despite several significant positive associations reported by the studies examining them. There was sufficient evidence to suggest there was no association between balance and academic performance in mathematics, with similar trends reported for reading, though this was based on findings from a limited number of studies. However, there was sufficient evidence to support a significant very weak to weak positive association between academic performance in mathematics and reading and upper limb coordination, with promising findings also found for speed and agility. Interestingly, these relationships were assessed in several studies involving high school participants. This warrants further investigation to determine whether more complex gross motor skill training may impact the academic performance of students in both primary and high school.

Several findings from the present review appear to be consistent with those reported in the systematic review by van der Fels et al.[47] in that the authors also found evidence to support a weak to moderate relationship between academic skills and object control skills. However, in contrast to the findings in the present review, van der Fels et al.[47] reported there was insufficient evidence to support a relationship between academic skills and fine and gross motor skills and they found no evidence to support a relationship between academic skills and bilateral body coordination and timed performance in movements. This contrast in findings from the present review is not surprising, given the limited number of studies that specifically examined the relationship between academic skills and motor skills that were eligible for inclusion in the review by van der Fels et al.[47] Therefore, the findings from the present review can contribute significantly in synthesising the rapidly expanding body of literature examining the relationship between motor proficiency and academic performance in mathematics and reading in typically developing school-aged children and adolescents.

3.6.2.3. Impact of motor proficiency interventions on academic performance

Collectively, the findings from the four experimental studies included in the review provide results of a statistically significant effect of motor skill interventions on the mathematics and reading performance of children, particularly in the early years of school. These results add to the growing body of literature investigating the impact of classroom-based PA on the educational outcomes of school students. However, to date, studies on this topic have generally been unable to consistently provide sufficient detail regarding whether the type of PA used in classroom-based interventions involves aerobic, motor, or strength-based activities, or a combination of all types of PA.[146] This information is essential in understanding the exact type, frequency, duration, and intensity of PA used in classroom-based PA interventions that may be required to impact learning.[30,146] Therefore, the present review included studies that specifically incorporated motor skill interventions into the regular school day with studies evaluating both academic performance and motor proficiency outcomes before and after the interventions.

The interventions outlined in the studies by Beck et al.[218] and Callcott et al.[219] involved the integration of movement into mathematics and literacy lessons, respectively, thus providing examples of classroom-based PA with an academic focus specifically incorporating motor skills as the type of PA. The positive findings from these two studies included in the present review are generally consistent with those reported by several recently published systematic reviews.[30,44-46] In their review, Donnelly et al.[30]

reported mixed findings from five studies investigating the impact of integrating PA into academic lessons (or physically active lessons) on academic achievement. However, three of the five studies found positive associations for increased academic achievement in mathematics following physically active lessons.[30] A recently published systematic review and meta-analysis by Watson et al.[46] evaluated the impact of classroom-based PA interventions on academic-related outcomes reported in 39 studies. A total of seven studies from the review assessed the effect of physically active lessons on mathematics achievement, with four of the seven studies reporting positive outcomes.[46] A total of five studies assessed the effect of physically active lessons on reading performance, with three of the five studies reporting improved reading performance in the intervention group. Overall, the authors from both reviews[30,46] concluded that despite some inconsistent findings, the integration of PA into academic lessons generally appeared to have a positive impact on academic performance.

Classroom-based PA can also involve incorporating PA into the regular school day routine, without an academic focus. In the present review, the intervention described in the study by Erasmus et al.[178] involved a 10-week program delivered by the researcher that involved incorporating fine, gross, and perceptual motor exercises into the regular school day; however, the program did not appear to have a specific academic focus. In their review, Donnelly et al.[30] reported that two studies examined the impact of specialised PA programs in the school setting on academic performance, such as the one described by Erasmus et al.,[178] with both studies also reporting significant improvements in academic performance in mathematics and reading.

The intervention outlined in the study by Ericsson[220] in the present review involved the addition of three extra PE classes into the school week, along with one extra motor training class. The positive findings in this study are in contrast to those reported in the review by Donnelly et al.[30] who found that only two of six studies reported a positive effect on academic achievement scores when implementing additional or enhanced PE into the school day. However, it is worth noting that the studies included in the review by Donnelly et al.[30] used cluster randomised designs whereas the study by Ericsson[220] was classified as having ‘poor’ methodological quality.

Collectively the authors from reviews on this topic[30,44-46] highlighted that the implementation of classroom-based PA into the school environment is still a relatively new concept and thus the methodological quality of intervention studies is varied. Several limitations within experimental study designs were noted, including variation in study design, intervention content, and outcome assessment.[30,46] In addition, few studies reported the theoretical rationale behind the intervention and provided sufficient details about the intervention, including examples of intervention sessions. This is consistent with the present review where a varying level of methodological quality was also apparent in the four experimental studies, along with varied intervention parameters. This suggests that further research is required using more robust study designs, to explore further the impact of integrating motor skills into academic lessons and/or the regular school day.

3.6.3. Strengths and limitations

The present review had several key strengths. Firstly, this review systematically synthesised the findings of 55 peer-reviewed studies including a large sample of typically developing school-aged participants from over 20 different countries. Secondly, to minimise reporting bias, a comprehensive search of health and education databases was conducted in accordance with the PRISMA guidelines,[157] followed by a systematic screening approach to identify eligible studies. Thirdly, to address the first aim of the study, a thorough appraisal of the methodological quality of each study was undertaken using the modified Downs and Black tool[159] that helped guide the interpretation of levels of evidence reported by cross-sectional and longitudinal studies for associations between motor proficiency and academic performance variables. Finally, this review allowed for a more in-depth examination of associations between the individual components of performance-related physical fitness (motor proficiency in this instance) and two core academic areas at school (mathematics and reading) than previously reported. Understanding which specific components of fine and gross motor proficiency are more strongly related to mathematical and reading skills may inform the design of future experimental studies to further ascertain whether a cause and effect relationship exists.

However, it is important to acknowledge there were also several key limitations in this review. Firstly, a limited number of experimental studies with robust study designs (e.g., randomised controlled trials) were eligible for inclusion in the present review, with findings synthesised from predominantly cross-sectional, longitudinal studies and quasi-experimental designs. Secondly, there was considerable heterogeneity of the outcome measures used between studies to assess motor proficiency and academic performance in mathematics and reading, making it difficult to clearly compare and interpret the findings across studies.

The approach used to classify different motor skills measured by studies into components of motor proficiency may also be a potential limitation in the current review. For example, it was the authors' discretion to determine the most appropriate category of motor proficiency for each motor skill measured, based on Bruininks and Bruininks' definitions of motor proficiency subtests.[59] Additionally, outcomes for academic performance in mathematics and reading were categorised broadly in the present review for ease of interpretation, in favour of being classified by their underlying constructs. Therefore, we were unable to determine which specific constructs of mathematics and reading may be more strongly related to each component of motor proficiency.

The search strategy in this review was limited to including studies specifically examining associations between motor proficiency and academic performance in mathematics and reading. However, it was evident that numerous covariates may also impact the findings reported in studies when examining typically developing school-aged children and adolescents. These covariates included demographic factors (e.g., age, gender, SES), cognitive factors (e.g., executive function and its components), and physical factors (e.g., body mass index, PA levels, CRF, and other health-related fitness measures). Although the covariates reported by each eligible study were extracted and recorded, their potential contribution to the overall findings were not discussed in detail as this was beyond the scope of the review.

There was variation in the parameters for the motor skill interventions reported among the four experimental studies included in the review; thus, factors such as type and intensity of motor skill training, along with the duration and frequency of lessons per week, differed in each study, making it difficult to determine the most effective dose. Given the strict inclusion/exclusion criteria for the present review, several experimental studies reporting motor skill interventions were ineligible for inclusion in the review. These studies were ineligible as they did not report findings for academic performance in mathematics or reading separately, often combining scores of multiple academic areas to provide an overall academic achievement score.[222,223] Other experimental studies were ineligible as they reported an overall fitness score (e.g., a combination of health and performance-related fitness)[224] or they did not assess motor proficiency at all.[225,226] The collective findings reported by these five experimental studies,[222-226] ineligible for inclusion in the present review, also found a positive impact of motor skill programs delivered in the school setting on academic performance. Finally, the findings from experimental studies synthesised in the present review are based on the published evidence available, and thus, publication bias may potentially exist if several other studies that have not found significant findings remain unpublished.

3.7 Conclusion

This systematic review adds considerably to the rapidly expanding body of literature examining associations between PA, fitness, cognition, and academic performance. The present review found evidence to support significant positive associations between several components of motor proficiency and measures of academic performance in mathematics and reading. There was evidence that all components of fine motor proficiency were significantly and positively associated with academic performance in mathematics, particularly during the early years of school. Similar evidence was found to support a significant positive relationship between fine motor proficiency (specifically fine motor integration and total fine motor scores) and academic performance in reading. There was also evidence for significant positive associations between academic performance in mathematics and reading and components of gross motor proficiency, specifically upper limb coordination and speed and agility, along with overall gross motor proficiency scores. There was also evidence that balance was not significantly associated with academic performance in mathematics and reading. However, there was either inconsistent or insufficient evidence to support associations between the other components of gross motor proficiency along with total motor proficiency scores and academic performance. Finally, there was some preliminary evidence from a small number of experimental studies that the implementation of motor skill interventions in the school setting may have a positive impact on academic performance in mathematics and/or reading; however, further research is needed to confirm this possibility. Due to the varying levels of methodological quality found in the studies included in the review, further investigation is warranted, using more robust study designs to explore further the impact of motor skill interventions on academic performance.

3.7.1 Recommendations and implications for future research

To allow more accurate comparisons of findings between studies in the future, researchers should consider consistently using valid and reliable, standardised instruments to assess both fine and gross motor proficiency and academic performance variables. Furthermore, to better understand and explain the underlying mechanisms of the associations between motor proficiency and academic performance, studies should be designed to provide adequate evidence of causality through robust experimental designs that compare the effects of both health-related and performance-related physical fitness (motor proficiency) interventions on the academic performance of school students. Ideally, study designs will also aim to control for known demographic, cognitive, and physical confounders. Future findings from experimental studies may then be able to ascertain whether motor skill training, aerobic fitness, or a combination of both impact cognitive and academic outcomes. Finally, given that students with neurodevelopmental disorders attend mainstream schools, future research should also examine relationships between motor, cognitive, and academic skills in this population to inform potential intervention pathways.

3.7.2 Recommendations and implications for policy and practice

Findings from future high-quality experimental studies aimed at enhancing the PA levels, physical fitness, and academic performance of school students may inform school wellbeing policies and pedagogical approaches to teaching and learning, particularly during the early years of school. This topic is relevant to both education and paediatric health professionals (including physiotherapists and occupational therapists) through their role in the early identification of children experiencing difficulty with motor skills, as this may also impact their academic performance. Furthermore, given that gross motor skills may be linked to academic performance in high school, school policy makers should consider prioritising, from school entry, students' acquisition of motor skills.[5]

[5] Please note that all references in this chapter are presented in the References section of the thesis

Chapter 4: Associations between Motor Proficiency and Academic Performance in Mathematics and Reading in Year 1 School Children: A Cross-Sectional Study

4.1 Preface

Several gaps in the literature were identified in Stage 1 of the thesis framework which focussed on defining the problem. With the problem defined (*Stage 1*), *Stage 2* of the thesis framework commenced with an intent to generate solutions and address the gaps in the literature. The **Narrative review (Chapter 2)** identified trends in the physical development of Australian children including low levels of physical activity, physical fitness and motor skill proficiency. These trends were of note given the volume of evidence supporting positive relationships between PA, cognition and academic performance in children and adolescents. The **Systematic review (Chapter 3)** revealed that there was insufficient evidence found to support associations between academic performance and several components of gross motor proficiency (specifically bilateral coordination and strength) and total motor proficiency (i.e., a combination of fine and gross motor proficiency), given a limited number of studies had investigated these specific outcomes. Additionally, it was acknowledged that valid and reliable, standardised assessment tools were not consistently used in studies to measure motor proficiency.

Therefore, the study reported in this chapter examined the associations between fine and gross motor proficiency and academic performance in mathematics and reading specifically in Year 1 children. This study involved examining baseline data collected from the cohort of 55 Year 1 children involved in a school-based participatory action project, the Tweed Healthy Schools Project. Data collection occurred prior to the commencement of the 12-week classroom-based gross motor program that is described in **Study 4 (Chapter 7)**.

The cross-sectional study reported in this chapter was published in a peer-reviewed journal in 2020. The formatting of the original published manuscript has been amended to be consistent with the thesis style, and the citation for the published manuscript is: https://bmcpediatr.biomedcentral.com/articles/10.1186/s12887-020-1967-8

Macdonald K, Milne N, Orr R, Pope R. Associations between motor proficiency and academic performance in mathematics and reading in year 1 school children: a cross-sectional study. *BMC Pediatr.* 2020; 20: 69. doi: 10.1186/s12887-020-1967-8 under

4.2 Abstract

Background: A key priority for learning during the early years of school is for children to develop skills in numeracy and literacy. Consequently, less time may be allocated in the curriculum to foster other important developmental areas, including the ongoing motor skill development of school children, which has been positively linked to academic performance. In order to promote holistic approaches to teaching and learning in the early years of school, it is necessary to further delineate the nature of associations between motor skills and foundation academic skills. The aim of this study was to examine associations between fine and gross motor proficiency and academic performance in mathematics and reading in Year 1 children.

Methods: A cross-sectional study was conducted with Year 1 children from two primary schools in New South Wales, Australia ($N = 55$; 25 boys, 30 girls; mean age = 6.77 ± 0.40 years). The Bruininks-Oseretsky Test of Motor Proficiency – 2nd Edition and the Wechsler Individual Achievement Test – 2nd Edition – Australian Standardised Edition were used to assess motor proficiency and academic performance in mathematics and reading, respectively. Associations between the components of motor proficiency and academic outcomes were examined using Pearson's and Spearman's correlation analyses. Hierarchical multiple linear regression analyses were conducted to determine how much variance in mathematics and reading composite scores could be explained by motor proficiency after controlling for age.

Results: A significant moderate positive association was found between total motor composite and mathematics composite scores ($r = .466$, $p < .001$). Fine manual control composite scores were significantly associated with both mathematics ($r_s = .572$, $p < .001$) and reading ($r_s = .476$, $p = .001$) composite scores. After controlling for age, fine motor integration was the only component of motor proficiency that explained significant variance in mathematics and reading composite scores.

Conclusions: The results of the study revealed that Year 1 children's overall motor proficiency was significantly related to their mathematical ability. Children's fine motor integration skills were also predictive of mathematics and reading ability. These study findings may interest both early childhood educators and paediatric health professionals.

4.3 Background

The foundation for every child's physical, cognitive, social and emotional development is laid during the early childhood period.[1] Success in these closely interrelated developmental domains during the early years is proposed to lead to positive health, education and social outcomes during adulthood.[53] In Australia, a key priority in the early years of school is for children to develop foundation skills in numeracy and literacy.[3] Consequently, there may be less time allocated in the curriculum to foster other important developmental areas, including the ongoing motor skill development of school children. Low competency in movement skills is reported to be associated with lower cardiorespiratory fitness (CRF) and physical activity (PA) levels in Australian children and adolescents.[89] This is concerning, considering the physical health and socio-emotional benefits of children and young people's participation in regular PA are well-established and important in the prevention of non-communicable diseases such as heart disease and stroke.[82,85]

Beyond the home environment, schools play an integral role in promoting the holistic development of students in the early years of school.[3] In fact, an expanding body of literature has identified that significant, positive relationships exist between PA, health and skill (or performance) related physical fitness, cognition and academic performance in children and adolescents; however, evidence for causality is yet to be determined.[30,34] It has been proposed that coordination or perceptual-motor tasks and aerobic activities may differ in the way they affect the structure and function of the developing brain.[38,39,41] However, relationships between motor proficiency, cognition and academic performance have received less attention than relationships between the components of health-related physical fitness, such as CRF, cognition and academic performance.[41]

Early studies investigating relationships between motor skill development and academic performance reported significant positive longitudinal associations between fine and gross motor composite scores assessed in Kindergarten and mathematics and reading achievement assessed in the later years of primary school.[156,185,187,193] A recently published systematic review by Macdonald et al.[227] found a strong level of evidence from observational studies to support significant positive associations between fine motor proficiency, particularly fine motor integration, and academic performance in mathematics and reading in children. There was also evidence, although weaker, to support several significant positive associations between academic performance and gross motor proficiency; specifically upper limb coordination, speed and agility and gross motor composite scores.[227] Associations between specific gross motor skills and academic outcomes have been investigated less extensively than associations between fine motor skills and academic outcomes in children in the early years of school, with the majority of studies reporting outcomes for gross motor composite scores or total motor composite scores (i.e., a combination of fine and gross motor skills).[156,187,193] Consequently, inconsistent or insufficient findings have been reported regarding the relationships between several specific components of gross motor proficiency and academic performance in mathematics and reading.[227]

Overall, a more comprehensive understanding of how the different components of gross motor proficiency are related to mathematics and reading skills in children in the early years of school is needed. Given this background, the aim of this study was to examine associations between fine and gross motor proficiency and academic performance in mathematics and reading in Year 1 school children. It was hypothesised that motor proficiency would be positively related to academic performance in mathematics and reading; however, it was anticipated that fine motor proficiency would be more strongly related to mathematics and reading outcomes than gross motor proficiency.

4.4 Methods

4.4.1 Setting and study design

This study was conducted in parallel with the Tweed Healthy Schools Project (THSP), an interprofessional clinical placement program for university health science students based in a school setting. A cross-sectional research design was employed, examining data collected at the start of the THSP. Ethics approval for the study was obtained from the Bond University Human Research Ethics Committee (Protocol number RO1836) and gatekeeper approval was granted by the State Education Research Approval Process in New South Wales, Australia (Reference number: 2014075). Parental consent was obtained in writing to confirm participation of each student involved in the study.

4.4.2 Recruitment and study participants

Students from three mainstream Year 1 classes enrolled at two public primary schools in the northern region of New South Wales, Australia, were recruited from May to July 2014 to participate in the study. Following gatekeeper approval from the principals at both schools, information sheets and consent forms were circulated to the parents of children across the three Year 1 classes. All students enrolled in the three Year 1 classes (*n* = 64) were invited and eligible to participate in the study provided their parents consented and the students themselves indicated assent. The study sample consisted of 55 Year 1 children (*n* = 25 boys; *n* = 30 girls; mean age 6.77±0.40 years, range 5.42-7.75 years).

4.4.3 Predictors, outcome measures and covariates

4.4.3.1 Motor proficiency

The Bruininks-Oseretsky Test of Motor Proficiency – 2nd Edition (BOT-2) Complete Form is a valid and reliable standardised motor assessment tool used for both clinical and research purposes.[59] The BOT-2 assesses the motor proficiency of individuals aged four to 21 years.[59] The tool measures fine and gross motor proficiency across eight individual subtests. Components of fine motor proficiency include fine motor precision (e.g., precise control of finger/hand movement), fine motor integration (e.g., precise control of finger/hand movement with the ability to integrate visual stimuli with motor control) and manual dexterity (e.g., reaching, grasping and bimanual coordination with small objects).[59] The components of gross motor proficiency include upper limb coordination (e.g., visual tracking with coordinated arm and hand movement), bilateral coordination (e.g., body control, sequential and simultaneous coordination of the upper and lower limbs), balance (e.g., motor control skills integral for maintaining posture when standing, walking), running speed and agility (e.g., shuttle run, hopping and jumping over a balance beam) and strength (e.g., trunk, upper and lower body strength).[59] Subtests may then be aggregated to yield four motor composites, including fine manual control (fine motor precision, fine motor integration), manual coordination (manual dexterity, upper limb coordination), body coordination (bilateral coordination, balance) and strength and agility (running speed and agility, strength). Due to differences in performance between girls and boys in subtests, sex and age-specific norms are used to interpret the scores of each assessment item. The total point score of each item was converted to scale scores for subtests and standard scores for motor composites. A total motor composite score was then calculated from the sum of standard scores for the motor composites. A standard score between 40 to 60 equates to a descriptive category of ‘average’ motor proficiency. Strong evidence for test-retest reliability (r = 0.63-0.91 for ages 4-7 years), internal consistency (α = 0.76-0.95 for mean age 4-7 years) and interrater reliability (r = 0.86-0.99 for ages 4-21 years) has been reported for the BOT-2.[59,74] The BOT-2 is also deemed a valid test for evaluating motor proficiency, with scores able to differentiate between different clinical groups (e.g., groups with Developmental Coordination Disorder, Autism Spectrum Disorder).[59,74]

4.4.3.2 Academic performance in mathematics and reading

The Wechsler Individual Achievement Test – 2nd Edition – Australian Standardised Edition (WIAT-II Australian) is a valid and reliable test of academic performance.[112] The WIAT-II Australian measures the achievement of individuals aged four to 85 years across the academic areas of reading, mathematics, written language and oral language.[112] The mathematics and reading composites were administered in this study, comprising five of the nine individual subtests in the achievement test. The mathematics composite included the maths reasoning and numerical operations (e.g., identifying and writing numbers) subtests. The reading composite included the word reading (e.g., phonological awareness and decoding skills), pseudoword decoding (e.g., phonetic decoding skills) and reading comprehension subtests. Standard scores were calculated based on participant age (in years and months) for each subtest, reading composite and mathematics composite. A standard score between 90 and 110 equates to a descriptive category of ‘average’ achievement. The age-based, inter-item reliability coefficients for the mathematics and reading subtests for children aged six and seven years range between 0.79 and 0.98.[112] The content, construct and criterion-related validity of the test have been investigated and correlations with other individually administered achievement tests are considered adequate.[112] The user level assigned to the WIAT-II Australian restricts administration of the test to Allied Health (including physiotherapy) or Special Education professionals.[228]

4.4.3.3 Covariates

Age, sex, ethnicity, school class and the Index of Community Socio-Educational Advantage (ICSEA) were measured as potential covariates. ICSEA is a scale of socio-educational advantage that takes into account the family background of school students, along with school level factors such as geographical location and student demographics.[229] The ICSEA is set at an average of 1000 with the lower the ICSEA value, the lower the level of educational advantage of students attending the school. Parents/caregivers were also asked to complete a questionnaire outlining any relevant medical history for their child, along with any reason why their child may not be able to participate in the study.

4.4.4 Procedure

Motor and academic assessments were conducted on separate days at the beginning of the third school term (July 2014). All assessments took place during the regular school day, with permission from the classroom teacher. Prior to the commencement of the study, three physiotherapy and three exercise science university students were trained by a registered physiotherapist to administer the BOT-2. Under the supervision of a registered physiotherapist, physiotherapy and exercise science university students administered the BOT-2 Complete Form, which took approximately 40 to 60 min per participant. The WIAT-II Australian test was individually administered by a registered physiotherapist who had completed the recommended training prior to administering the assessment tool and also had experience working with children. The test took approximately 45 to 60 min for each participant and took place in a quiet room to minimise the influence of distractions on performance.

4.4.5 Statistical analysis

Statistical analyses for this study were conducted using the Statistical Package for the Social Sciences (Version 26).[230] Descriptive statistics including mean, standard deviation (SD) and range were calculated for numerical variables including age, motor proficiency and academic performance. Frequencies (%) were calculated for categorical variables including sex and ethnicity. Normality of distributions and equality of variances were assessed to determine whether assumptions for parametric statistics were met. When variables did not meet the assumptions for using parametric tests, non-parametric statistical tests were employed. When assessing sex as a potential covariate for subsequent analyses examining relationships between motor proficiency and academic performance, independent samples t-tests were performed to determine any significant differences in mean age, academic scores and motor proficiency scores between girls and boys within the participant sample. Similarly, one way analyses of variance (ANOVA) with Bonferroni post hoc tests (using an overall alpha level of .05) were performed to determine any significant differences between the three classes and three ethnic groups in academic performance scores. Pearson's and Spearman's correlation analyses were performed to examine relationships between both age and academic performance scores. Pearson's correlation analyses were subsequently used to examine the relationships between motor proficiency and academic performance in mathematics and reading for the total sample. Where assumptions of normality were not met, Spearman's correlation analyses were performed on ranked data to analyse relationships between motor proficiency and academic performance variables. To account for multiple analyses of associations, Bonferroni corrections were applied to tests of significance in the correlational analyses. To describe the strength of correlation (r) between motor proficiency and academic performance variables, the rating guide described by Evans[164] was used as follows; r = 0.00–0.19 (very weak), r = 0.20–0.39 (weak), r = 0.40–0.59 (moderate), r = 0.60–0.79 (strong), and r = 0.80–1.0 (very strong). Finally, hierarchical multiple linear regression analyses were performed to determine how much variance in mathematics or reading composite scores (dependent variables) could be explained by each of the motor proficiency scale scores (independent variables) while controlling for covariates, enabling the relative predictive contribution of the components of motor proficiency to be assessed. Sensitivity analyses were conducted by repeating regression analyses with the removal of any outliers that were identified. To determine the effect size for the proportion of unique variance in academic performance explained by each predictor variable, Cohen's f^2 was calculated. According to Cohen's[231] conventions, an effect size of .02 can be considered small, .15 can be considered medium and .35 can be considered large. A significance level of 5% (α = 0.05) was applied to all statistical tests, with Bonferroni corrections when appropriate. A statistical power analysis using G*Power 3[232] indicated that the correlation analyses would have an 80% power to detect a correlation between two variables of 0.39 (a weak correlation) or greater if the sample numbered at least 50 participants, assuming an alpha level of 0.05.

4.5 Results

While 64 Year 1 children were invited to participate in the study, the parents of nine children did not provide consent for their child's participation, leaving data for 55 children available for analysis. Figure 10 summarises the flow of participants through the study.

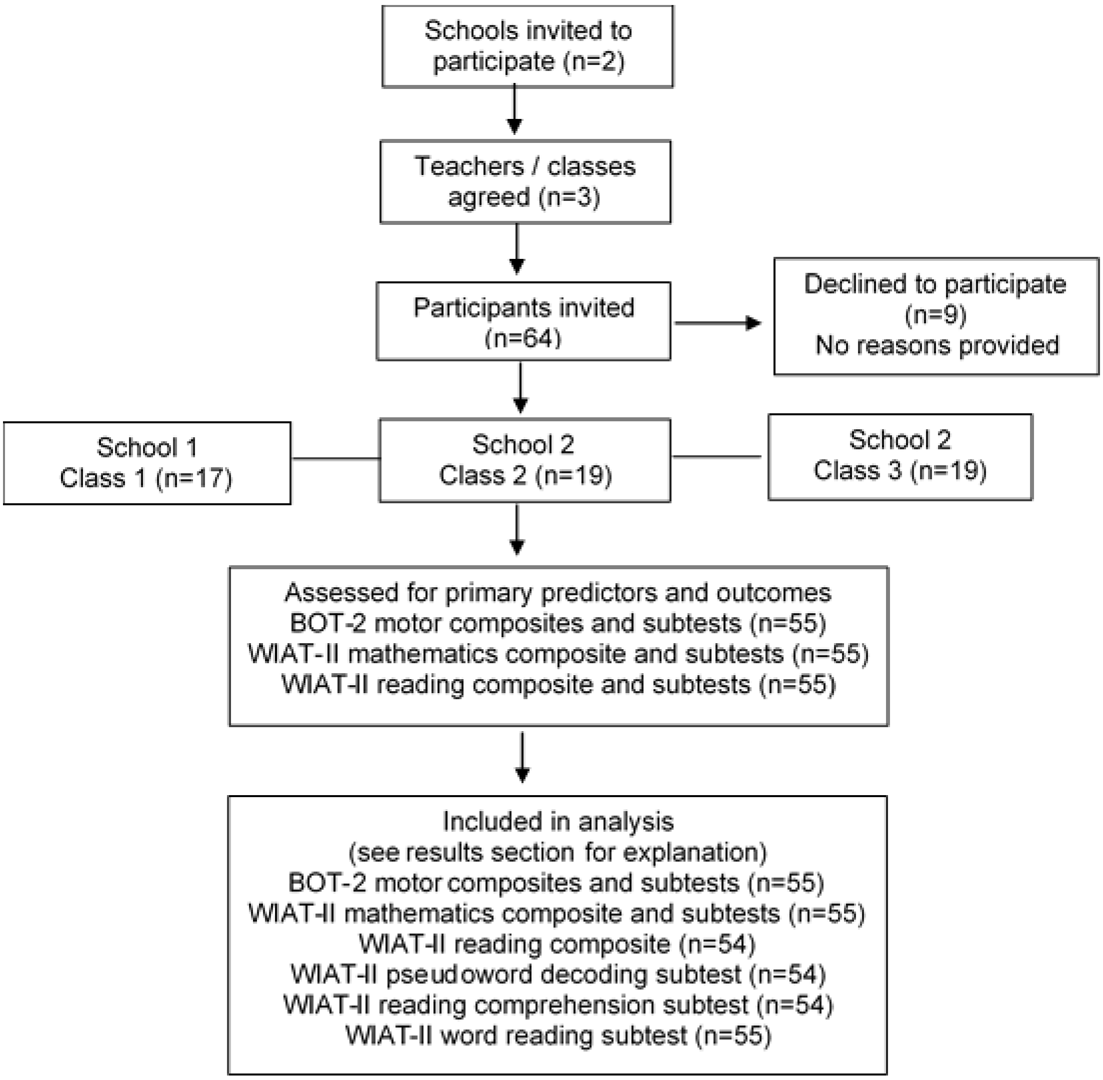

Figure 10: Flow of participants through the study**.**

Characteristics of the study participants are presented in Table 11.

Table 11: Characteristics of the Year 1 student participants.

Characteristic		**n (%)**
Sex	Boys	25 (45.5)
	Girls	30 (54.5)
Ethnicity^	White	48 (87)
	Asian/Pacific Islander	3 (6)
	Other	4 (7)
ICSEA	ICSEA 965	38 (69)
	ICSEA 1011	17 (31)

ICSEA = Index of Community Socio-Educational Advantage (average = 1000)
^ Ethnicity classified according to the categories outlined in the BOT-2.

Based on responses from parental/caregiver questionnaires, no child included in the present study had been previously diagnosed with an intellectual disability. Additionally, all children were drawn from and functioning in mainstream Year 1 classes.

4.5.1 Motor proficiency and academic performance

The Australian normative scores for the pseudoword decoding subtest, reading comprehension subtest and the reading composite of the WIAT-II Australian were only available for participants aged 5 years, 8 months and older, resulting in this data being unavailable for one participant (age = 5.42 years) and leaving data available for these subtests from 54 of the 55 participants (Figure 9). Means, SD and ranges of performance data for the BOT-2 and WIAT-II Australian (both by total sample and sex) are presented in Table 12.

Overall, the mean total motor composite standard score for the total sample was 51.56 ± 10.65 (range 22-79), which was considered ‘average’ motor proficiency. This was consistent with the mean of the normative sample,[59] falling between ±1 SD for age and sex-specific norms (i.e., mean = 50, SD = 10, range 20-80). The mean mathematics composite standard score (94.87 ± 15.60, range 64-148) and mean reading composite standard score (97.96 ± 16.70, range 66-132) for the total sample were considered ‘average’ achievement. Each was slightly below but still within ±1 SD of the mean of the Australian normative sample (i.e., mean = 100, SD = 15, range 40-160).[112] Finally, the mean total motor composite, mathematics composite and reading composite standard scores were categorised ‘average’ for both boys and girls (Table 12).

Table 12: Mean, standard deviation (SD) and ranges for age, motor proficiency, mathematics ability and reading ability for all participants and separately for boys and girls.

Measure	**Total (*n* = 55)**			**Boys (*n* = 25)**			**Girls (*n* = 30)**		
	Mean	**SD**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**
Age (years)	6.77	0.40	5.42-7.75	6.81	0.31	6.25-7.42	6.74	0.46	5.42-7.75
Motor proficiency									
Fine motor precision[a]	13.67	3.83	3-24	13.88	3.79	5-24	13.50	3.92	3-22
Fine motor integration[a]	15.95	4.47	3-23	16.76	3.96	5-23	15.27	4.82	3-22
Fine manual control[b]	49.53	8.73	23-68	50.84	8.05	29-68	48.43	9.25	23-66
Manual dexterity[a]	14.25	4.22	4-21	15.32	3.90	5-21	13.37	4.33	4-19
Upper limb coordination[a]	16.31	6.13	1-28	16.56	5.80	4-25	16.10	6.49	1-28
Manual coordination[b]	50.98	10.12	24-66	52.40	9.59	30-64	49.80	10.55	24-66
Bilateral coordination[a]	17.58	4.01	5-24	18.76	3.63	8-22	16.60	4.11	5-24
Balance[a]	15.89	4.02	7-25	16.28	3.78	7-23	15.57	4.25	8-25
Body coordination[b]	54.49	9.11	32-70	56.64	8.49	34-70	52.70	9.36	32-68
Running speed and agility[a]	16.65	4.53	4-29	17.08	4.96	4-29	16.30	4.19	7-24
Strength[a]	13.67	4.92	4-26	13.60	4.64	5-26	13.73	5.22	4-24
Strength and agility[b]	49.87	9.49	29-80	50.72	10.21	29-80	49.17	8.95	29-65
Total motor composite[b]	51.56	10.65	22-79	53.40	10.54	27-79	50.03	10.67	22-70
Mathematics ability									
Maths reasoning[c]	93.84	16.33	51-144	97.80	17.06	51-144	90.53	15.20	63-116
Numerical operations[c]	94.67	14.96	61-140	95.56	15.93	66-140	93.93	14.33	61-131
Mathematics composite[c]	94.87	15.60	64-148	97.48	16.52	70-148	92.70	14.71	64-125
Reading ability									
Pseudoword decoding[c] (n=54)	96.61	15.00	71-127	97.88	15.99	75-126	95.52	14.29	71-127
Word reading[c]	100.27	16.84	69-132	100.28	17.69	70-131	100.27	16.40	69-132
Reading comprehension[c] (n=54)	97.09	13.52	62-127	96.92	15.31	62-127	97.24	12.04	66-124
Reading composite[c] (n=54)	97.96	16.70	66-132	98.88	18.35	67-132	97.17	15.43	66-127

[a] Motor proficiency assessed by BOT-2: Normative sample scale score (M = 15, SD = 5, range = 1-35). Scores adjusted for chronological age (in years and months) and sex.
[b] Motor proficiency assessed by BOT-2: Normative sample standard score (M = 50, SD = 10, range = 20-80). Scores adjusted for chronological age (in years and months) and sex.
[c] Mathematics and reading ability assessed by WIAT-II Australian: Normative sample standard score (M = 100, SD = 15, range = 40-160). Scores adjusted for chronological age (in years and months)

4.5.2 Relationships between motor proficiency and mathematical skills

Overall, for the total sample, significant moderate positive correlations were found between mathematics composite scores and total motor composite (r = .466, p <. 001) and fine manual control composite scores (r_s = .572, p < .001) (Table 13). Significant moderate positive correlations were evident between mathematics composite scores and the fine motor precision (r_s = .449, p = .001) and fine motor integration (r_s = .525, p < .001) subtests (Table 14). Significant moderate positive correlations were also found between the maths reasoning subtest and the fine motor precision (r_s = .449, p = .001), fine motor integration (r_s = .530, p < .001) and manual dexterity (r_s = .436, p = .001) subtests (Table 14). However, significant moderate positive correlations were only found for the numerical operations subtest with the fine motor integration subtest (r_s = .461, p < .001) (Table 14).

Table 13: Correlations between motor proficiency composites (standard scores) and mathematical and reading outcomes (standard scores) for total sample.

Measure	**Fine manual control**	**Manual coordination**	**Body coordination**	**Strength and agility**	**Total motor composite**
Mathematics composite (n = 55)	r_s = .572 (<.001)*	r =.399 (.003)	r_s = .296 (.028)	r = .389 (.003)	r = .466 (<.001)*
Maths reasoning (n = 55)	r_s = .587 (<.001)*	r = .382 (.004)	r_s = .264 (.051)	r = .354 (.008)	r = .448 (.001)*
Numerical operations (n = 55)	r_s = .472 (<.001)*	r = .382 (.004)	r_s = .264 (.051)	r = .387 (.004)	r = .439 (.001)*
Reading composite (n = 54)	r_s = .476 (.001)*	r_s = .299 (.028)	r_s = .142 (.307)	r_s = .180 (.193)	r_s = .316 (.020)
Pseudoword decoding (n = 54)	r_s = .438 (.001)*	r_s = .296 (.030)	r_s = .194 (.159)	r_s = .195 (.158)	r_s = .344 (.011)
Word reading (n = 55)	r_s = .521 (<.001)*	r = .319 (.017)	r_s = .154 (.263)	r = .215 (.115)	r = .362 (.007)
Reading comprehension (n = 54)	r_s = .395 (.003)	r = .284 (.037)	r_s = .029 (.832)	r = .144 (.298)	r = .270 (.048)

Spearman's rho (r_s) and Pearson's (r) correlation coefficients are reported as appropriate.
*$p \leq .05$ (significant correlations after conducting Bonferroni correction at $\alpha = 0.05 / 35 = 0.0014$)

Table 14: Correlations between motor proficiency subtests (scale scores) and mathematical and reading outcomes (standard scores) for total sample.

Measure	Fine motor precision	Fine motor integration	Manual dexterity	Upper limb coordination	Bilateral coordination	Balance	Running speed and agility	Strength
Mathematics composite (n = 55)	r_s = .449 (.001)*	r_s = .525 (<.001)*	r_s = .391 (.003)	r = .274 (.043)	r_s = .361 (.007)	r = .231 (.090)	r = .387 (.004)	r = .291 (.031)
Maths reasoning (n = 55)	r_s = .449 (.001)*	r_s = .530 (<.001)*	r_s = .436 (.001)*	r = .233 (.087)	r_s = .331 (.013)	r = .224 (.100)	r = .365 (.006)	r = .256 (.059)
Numerical operations (n = 55)	r_s = .357 (.007)	r_s = .461 (<.001)*	r_s = .306 (.023)	r = .296 (.028)	r_s = .331 (.014)	r = .217 (.111)	r = .380 (.004)	r = .293 (.030)
Reading composite (n = 54)	r_s = .368 (.006)	r_s = .470 (<.001)*	r_s = .254 (.064)	r_s = .289 (.034)	r_s = .259 (.058)	r_s = .163 (.240)	r_s = .252 (.065)	r_s = .162 (.241)
Pseudoword decoding (n = 54)	r_s = .311 (.022)	r_s = .459 (<.001)*	r_s = .250 (.069)	r_s = .279 (.041)	r_s = .353 (.009)	r_s = .156 (.261)	r_s = .251 (.068)	r_s = .188 (.174)
Word reading (n = 55)	r_s = .395 (.003)	r_s = .512 (<.001)*	r_s = .210 (.123)	r = .301 (.026)	r_s = .221 (.104)	r = .235 (.084)	r = .269 (.047)	r = .122 (.375)
Reading comprehension (n = 54)	r_s = .301 (.027)	r_s = .391 (.004)	r_s = .245 (.074)	r = .214 (.120)	r_s = .141 (.308)	r = .174 (.209)	r = .200 (.147)	r = .078 (.576)

Spearman's rho (r_s) and Pearson's (r) correlation coefficients are reported as appropriate.
*$p \leq .05$ (significant correlations after conducting Bonferroni correction at $\alpha = 0.05 / 56 \approx 0.001$)

4.5.3 Relationships between motor proficiency and reading skills

Significant moderate positive correlations were evident between the reading composite and fine manual control composite (r_s = .476, p = .001) (Table 13) and fine motor integration subtest (r_s = .470, p < .001) (Table 13). There were significant moderate positive correlations between the pseudoword decoding and word reading subtests and the fine manual control composite (r_s = .438, p = .001 and r_s = .521, p < .001 respectively) (Table 12) and fine motor integration subtest (r_s = .459, p < .001 and r_s = .512, p <.001 respectively) (Table 14).

4.5.4 Covariates

Following consideration of a range of possible covariates, only participant age was included in subsequent regression analyses. Correlation analyses revealed a significant negative weak correlation between age (measured in years and months) and mathematics composite scores (r = -.327, p = .015) but a non-significant relationship between age and reading composite scores (r_s = -.197, p = .154). Although no such relationship was found for reading composite scores, given that age is known to be a key factor affecting scores on academic tests, it was included in subsequent regression analyses as a covariate wherever mathematics composite or reading composite scores were the dependent variables. No significant relationships between mathematics or reading composite scores and sex or school class or ICSEA or ethnicity were detected, and thus none of these were included as covariates in subsequent analyses.

4.5.5 Predictors of academic performance in mathematics

To determine how much variance in mathematics performance could be explained by the components of motor proficiency beyond that accounted for by age, a hierarchical multiple regression analysis was conducted. Findings from the simple correlation analyses (Tables 13 and 14) were used to guide the motor proficiency variables that were entered into regression models, and these included fine motor integration and fine motor precision. Preliminary analyses found no violation of the assumptions of linearity, multicollinearity and homoscedasticity.[233,234] However, a standardised residual greater than 3SD was found for one participant and was thus identified as an outlier and subsequently considered in a sensitivity analysis. Variables were entered into the model in the following steps: Age at step 1, fine motor precision at step 2 and fine motor integration at step 3 (Table 15). In combination, at step 3, the three predictor variables explained 34.7% of the variance in mathematics performance (R^2 = .347, adjusted R^2 = .309, ΔR^2 = .094, F(3, 51) = 9.03, p < .001). By Cohen's[231] convention, this was considered a large combined effect (f^2 = 0.53). As can be seen in Table 15, in the final regression model, only fine motor integration (β = .430, p = .009) was a significant predictor of mathematics performance.

A sensitivity analysis was performed to examine whether results from this hierarchical multiple regression analysis were influenced by the outlier in the sample (Table 16). Following removal of the outlier, in combination, at step 3, the three predictor variables explained 39.2% of the variance in mathematics performance (R^2 = .392, adjusted R^2 = .355, ΔR^2 = .084, F(3, 50) = 10.73, p < .001). By Cohen's[231] convention, this was considered a large combined effect (f^2 = 0.64). When the outlier was removed from the sample, fine motor integration (β=.407, p=.012) and age (β = -.244, p = .036) were both significant predictors of mathematics performance (Table 16).

Table 15: Proportions of variance in (i) mathematical performance of Year 1 students that could be explained by fine motor precision and fine motor integration subtests, beyond that accounted for by age; (ii) reading performance of Year 1 students that could be explained by fine motor precision and fine motor integration subtests, beyond that accounted for by age.

	R	**R^2**	**F, (df), p**	**Adj R^2**	**ΔR^2**	**ΔF, (df), p**	**B, [95% CI], SE B**	**β**	**t, p**
Mathematics									
Step 1	.327	.107	6.37, (1, 53), **<.015**	.090	.107	6.37, (1, 53), **.015**	181.35, [112.49, 250.22], 34.34		5.28, **<.001**
Age							-12.77, [-22.92, -2.62], 5.06	-.327	-2.52, **.015**
Step 2	.503	.253	8.82, (2, 52), **.001**	.225	.146	10.18, (1, 52), **.002**	145.97, [78.58, 213.36], 33.58		4.35, **<.001**
Age							-10.72, [-20.19, -1.25], 4.72	-.275	-2.27, **.027**
Fine motor precision							1.57, [0.58, 2.56], 0.49	.386	3.19, **.002**
Step 3	.589	.347	9.03, (3, 51), **<.001**	.309	.094	7.31, (1, 51), **.009**	124.19, [58.50, 189.88], 32.72		3.80, **<.001**
Age							-8.65, [-17.72, 0.43], 4.52	-.222	-1.91, .061
Fine motor precision							0.39, [-0.89, 1.67], 0.64	.096	0.61, .544
Fine motor integration							1.50, [0.39, 2.61], 0.55	.430	2.70, **.009**
Reading									
Step 1	.202	.041	2.21, (1, 52), .143	.022	.041	2.21, (1, 52), .143	162.04, [75.40, 248.68], 43.18		3.75, **<.001**
Age							-9.43, [-22.16, 3.30], 6.34	-.202	-1.49, .143
Step 2	.387	.150	4.50, (2, 51), .**016**	.117	.109	6.56, (1, 51), **.013**	124.47, [36.98, 211.97], 43.58		2.86, **.006**
Age							-6.82, [-19.10, 5.46], 6.12	-.146	-1.12, .270
Fine motor precision							1.45, [0.31, 2.59], 0.57	.335	2.56, **.013**
Step 3	.502	.252	5.60, (3, 50), **.002**	.207	.102	6.79, (1, 50), **.012**	109.41, [25.65, 193.18], 41.71		2.62, **.012**
Age							-5.81, [-17.47, 5.86], 5.81	-.124	-1.00, .322
Fine motor precision							0.10, [-1.40, 1.60], 0.75	.022	0.13, .898
Fine motor integration							1.68, [0.39, 2.98], 0.65	.450	2.61, **.012**

R square (R^2), Adjusted R square (Adj R^2), F-statistic (F), degrees of freedom (df), unstandardised coefficient (B), standardised (β) regression coefficients; confidence interval (CI), standard error (SE), t-statistic (t). Significant p-values (p < .05) in bold

Table 16: Proportions of variance in mathematical performance of Year 1 students that could be explained by fine motor precision and fine motor integration subtests, beyond that accounted for by age following removal of outlier.

	R	R^2	F, (df), p	Adj R^2	ΔR^2	ΔF, (df), p	B, [95% CI], SE B	β	t, p
Mathematics									
Step 1	.352	.124	7.37, (1, 52), **.009**	.107	.124	7.37, (1, 52), **.009**	176.19, [115.24, 237.14], 30.37		5.80, <**.001**
Age							-12.15, [-21.13, -3.17], 4.48	-.352	-2.71, **.009**
Step 2	.555	.308	11.35, (2, 51), **<.001**	.281	.184	13.56, (1, 51), **.001**	141.13, [83.17, 199.10], 28.87		4.89, <**.001**
Age							-10.12, [-18.26, -1.98], 4.06	-.293	-2.50, **.016**
Fine motor precision							1.56, [0.71, 2.41], 0.42	.433	3.68, **.001**
Step 3	.626	.392	10.73, (3, 50), **<.001**	.355	.084	6.87, (1, 50), **.012**	123.13, [66.51, 179.76], 28.19		4.37, <**.001**
Age							-8.42, [-16.24, -0.59], 3.90	-.244	-2.16, **.036**
Fine motor precision							0.57, [-0.54, 1.67], 0.55	.157	1.03, .310
Fine motor integration							1.26, [0.30, 2.23], 0.48	.407	2.62, **.012**

R square (R^2), Adjusted R square (Adj R^2), F-statistic (F), degrees of freedom (df), unstandardised coefficient (B), standardised (β) regression coefficients; confidence interval (CI), standard error (SE), t-statistic (t). Significant p-values (p < .05) in bold

4.5.6 Predictors of academic performance in reading

To determine how much variance in reading performance could be explained by the components of motor proficiency beyond that accounted for by age, a separate hierarchical multiple regression analysis was conducted. The two motor proficiency subtests most significantly correlated with reading composite scores were fine motor precision and fine motor integration (Table 14). Variables were entered into the model in the following steps: Age at step 1, fine motor precision at step 2 and fine motor integration at step 3 (Table 15). In combination, at step 3, the three predictor variables explained 25.2% of the variance in reading performance (R^2 = .252, adjusted R^2 = .207, ΔR^2 = .102, F(3, 50) = 5.60, p = .002). By Cohen's[231] convention, this was considered a medium combined effect (f^2 = 0.34). As can be seen in Table 15, in the final regression model, fine motor integration (β = .450, p = .012) was the only significant predictor of reading performance.

4.6 Discussion

The purpose of this study was to examine associations between fine and gross motor proficiency and academic performance in mathematics and reading in Year 1 school children. Several key findings were evident. Firstly, significant moderate positive correlations were found between total motor composite and mathematics composite scores. Secondly, the fine manual control composite was significantly associated with both mathematics and reading composite scores. Finally, after controlling for age, fine motor integration was the only component of motor proficiency that was a significant predictor of mathematics and reading composite scores. The combined effect also appeared to be larger for mathematics (f^2 = 0.53) than reading (f^2 = 0.34) suggesting that fine motor integration skills may have a stronger association with mathematics than reading performance. Collectively, the findings from this study highlight the importance of educators promoting the holistic development of students, including their motor skill development, in early primary school classrooms.

4.6.1 Fine motor proficiency, mathematics and reading ability

Findings from the present study are consistent with other cross-sectional research examining associations between fine motor proficiency, mathematics and reading skills in Year 1 children.[181,182] For example, Pienaar et al.[182] found that visual motor integration skills were more strongly associated with mathematics and reading performance than total motor proficiency in a large sample of socio-economically disadvantaged first grade learners from South Africa. Significant medium to strong correlations between the maths reasoning subtest of the WIAT-II and the fine motor precision (r = .597, p < .001) and fine motor integration (r = .569, p < .001) subtests of the BOT-2 have also been reported in a small sample of Year 1 children in the UK.[181] However, similar to the findings in the present study, significant correlations were only found between the word reading and fine motor integration subtests (r = .377, p = .003), but not fine motor precision (r = .198, p = .129) in the sample of Year 1 children in the UK.[181]

Analyses conducted in the present study revealed that after accounting for age and fine motor integration, fine motor precision was not a significant predictor of mathematics and reading composite scores in this sample of Year 1 children. This is consistent with other studies that have specifically evaluated relationships between academic performance in mathematics and reading and the individual components of fine motor skills, including fine motor integration (or visual motor integration), fine motor precision and manual dexterity (or fine motor manipulation / coordination).[176,184,235] For example, a longitudinal study by Kim et al.[184] found that fine motor coordination and visual motor integration were related to the mathematical ability of students in Kindergarten; however, only visual motor integration was related to mathematical skills in the same sample of students when they reached Year 1. The authors suggested that children's mastery over fine motor coordination skills may explain why they were no longer related to children's mathematical skills in Year 1.[184]

It was beyond the scope of this study to ascertain the underlying mechanisms that may explain the observed study findings. However, one potential explanation as to why fine motor integration may be more strongly related to mathematics and reading in Year 1 children than other fine motor skills (i.e., fine motor precision and manual dexterity) has been proposed in the literature, and relates to the notion of automaticity.[184,236] Motor and cognitive processes (such as executive functions) may share similar neural pathways in the brain with researchers conducting functional neuroimaging studies demonstrating that when tasks are novel or complex, the cerebellum and pre-frontal cortex are both activated.[108] Motor tasks appear to become more automatic with practice leading to a reduction of activity in these two regions.[108,119]

4.6.2 Gross motor proficiency, mathematics and reading ability

Previous studies examining relationships between gross motor composite scores and mathematical skills in children in the early years of school (e.g. pre-Kindergarten to Year 2) have reported significant very weak to moderate positive associations.[227] However, few studies have previously investigated relationships between the individual components of gross motor proficiency and academic performance in mathematics in Year 1 children, like the present study.[200,227] Overall, the components of gross motor proficiency that were most strongly related to mathematics composite scores were running speed and agility and bilateral coordination, though these relationships did not reach statistical significance after adjusting for multiple comparisons. The lack of significant findings are thus in contrast to those reported in the systematic review by Macdonald et al.[227] who found a strong level of evidence to support significant very weak to weak positive associations between speed and agility and mathematical ability in studies conducted with slightly older children aged nine to 13 years.

Significant very weak to moderate positive correlations between gross motor composite scores and reading skills in children in the early years of school have also previously been reported.[227] In the present study, upper limb coordination appeared to be the component of gross motor proficiency most strongly related with reading composite scores, particularly pre-reading skills including word reading and pseudoword decoding, but these relationships did not reach statistical significance. Again, the lack of significant findings are in contrast with the systematic review by Macdonald et al.[227] who found evidence to support significant weak positive associations between upper limb coordination and reading ability, including in Kindergarten children,[217] students in Year 5[201] and adolescents.[170,172]

4.6.3 Limitations

Several limitations are important to acknowledge in this study. Firstly, due to the cross-sectional design, the results cannot infer causality nor provide evidence of the underlying mechanisms for observed associations between motor proficiency and academic performance in mathematics and reading in this cohort of Year 1 children. Secondly, a relatively small sample size (n = 55) was included in the study; however, this was pre-determined by the study being conducted in parallel with the THSP. This may have limited the statistical power of the study to detect relationships between variables reflecting smaller effect sizes. Thirdly, variables including cognitive skills (e.g., IQ, executive functions such as working memory, inhibitory control, cognitive flexibility), measures of health-related fitness (e.g., body mass index, cardiorespiratory fitness) and PA levels were not assessed and thus not taken into account. Finally, the cohort of Year 1 children came from two public primary schools in the same region of Australia and thus caution should be applied in generalising the findings to other regions or schools with a different school ICSEA status.

4.7 Conclusion

The collective findings from this study revealed several significant positive relationships between motor proficiency and academic performance, particularly in mathematics, in this cohort of Year 1 children. Specifically, Year 1 children's overall motor proficiency was significantly related to their mathematical skills. Additionally, children's fine motor integration skills were predictive of their mathematical and reading ability. The results of this study may interest both early childhood educators and paediatric health professionals. For example, knowledge of associations between motor skills and academic outcomes may prompt educators to identify early, for further investigation, any children with poorly developed or delayed motor skills as they transition to school. Finally, study findings may be useful in guiding the future design of fine and gross motor skill interventions for children in the early years of school to evaluate more rigorously their impact on foundation scholastic skills.[6]

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[6] Please note that all references in this chapter are presented in the References section of the thesis

Chapter 5: Directly Observed Physical Activity of Year 1 Children during School Class Time: A Cross-Sectional Study

5.1 Preface

While defining the problem as part of *Stage 1* of the thesis framework, it was apparent that few studies examining the effectiveness of school-based motor skill interventions on children's academic and motor proficiency outcomes have been published **(Systematic review, Chapter 3)**. As part of *Stage 2* (*solution generation*) of the thesis framework, **Study 1 (Chapter 4)** revealed several significant positive relationships between Year 1 children's motor proficiency and their academic performance, particularly mathematical skills. However, prior to designing school-based motor skill intervention programs with children in the early years of primary school in Australia, existing PA practices of students during class time need to be determined.

Therefore, the study reported in this chapter sought to gain insight into existing practices in Australia regarding the frequency, type and context of PA opportunities being provided to students in the early years of primary school during class time. As part of this study, the PhD candidate (a registered physiotherapist) spent time in the school environment, observing existing routines of Year 1 children during school class time. Specifically, children's PA practices in the context of the Year 1 Australian Curriculum were observed.

It is important to note that when seeking research approval for this study from the school research jurisdiction, permission was initially sought to assess participants' PA using accelerometry and direct observation. The aim was to then triangulate and contextualise data collected from accelerometers with data collected during the school week using direct observation. However, the use of accelerometers with Year 1 study participants was considered 'invasive' and approval was not granted by the school research jurisdiction. Therefore, the design of the study was modified to assess participants' PA during school class time using direct observation only.

The cross-sectional study reported in this chapter was published in a peer-reviewed journal in 2021. The formatting of the original published manuscript has been amended to be consistent with the thesis style, and the citation for the published manuscript is as follows: https://www.mdpi.com/1660-4601/18/7/3676.

Macdonald K, Milne N, Pope R, Orr R. Directly observed physical activity of year 1 children during school class time: a cross-sectional study. *Int J of Environ Res and*

Public Health. 2021; 18, 3676. doi: 10.3390/ijerph18073676 under

The manuscript belongs to the Special Issue: Promoting Physical Activity in and through Schools. Two supplementary tables are referred to as Table S3 and Table S4 within this chapter. These tables can be found at the end of the chapter.

5.2 Abstract[7]

Providing physical activity opportunities to children throughout the school day may be beneficial for children's health and learning. Existing practices regarding the frequency, type and context of physical activity opportunities being provided to children in the early years of primary school remains largely unknown. The aim of this study was to observe Year 1 children's physical activity and its contexts during school class time and identify opportunities to incorporate additional activity. A cross-sectional study was conducted with 34 Year 1 children (20 boys, 14 girls; mean age = 6.36 ± 0.34 years) from one primary school in Queensland, Australia. A modified version of the Observational System for Recording Physical Activity in Children – Elementary School was used to assess children's physical activity and its contexts during school class time. Observational data were collected over a four-week period. The frequencies (and percentages) of intervals of children's physical activity observed in sedentary, light and moderate-to-vigorous intensities during different instructional and social contexts and physical settings were recorded and calculated. Pearson's Chi-Square Test of Association was conducted to evaluate whether social context (group composition) was related to incidental physical activity. A total of 5305 observation intervals (i.e., 5 s observation interval followed by a 25 s recording interval) were available for analysis (~44 h of observation). Year 1 children were sedentary for the majority (86%) of observed intervals during school class time. Children spent limited time performing light (12% of intervals) and moderate-to-vigorous physical activity (2% of intervals). Organised physical activity observed during class time included physical education / school sport (5.9% of intervals) and classroom-based physical activity (2.8% of intervals). When children completed activities in small groups, they were significantly more likely to engage in incidental physical activity than when they completed activities as a whole class ($\chi^2 = 94.73$, $p < .001$). Incorporating movement into academic lessons or during transitions between lessons and classrooms may encourage children to be more active. Incidental physical activity may also be promoted through small group activities. Schools should ideally be encouraged and supported to employ a whole-of-

[7] The format of this abstract has remained consistent (i.e., unstructured) with those of the journal for which it was published.

school approach to physical activity promotion, which includes identifying and implementing opportunities for children to be active during class time.

5.3 Background

Overcoming low levels of physical activity (PA) among children and youth remains a public health priority globally, with recent figures suggesting the recommended 60 minutes of moderate-to-vigorous physical activity (MVPA) per day for optimal health are still not being adequately achieved.[21] A child or young person's participation in regular PA is positively associated with numerous physical and mental health indicators, including cognition and academic performance.[20,82,85,237] Consequently, research evaluating the effectiveness of school-based PA interventions for improving children's health and education outcomes has gained considerable momentum in recent years.[30,34,238] Although evidence to support beneficial effects of PA interventions on children's cognition and overall academic performance remains inconclusive, strong evidence for beneficial effects on children's mathematical outcomes has been reported.[30,34] Researchers have proposed a number of mechanisms that may underpin the PA-cognition relationship, including biological, learning and psychosocial mechanisms; however, hypotheses regarding these underlying mechanisms continue to be tested.[38-40]

Healthy habits and behaviours are formed during the early childhood period.[24] Therefore, schools are ideally placed to positively influence children's PA behaviour, particularly during the early years of primary school.[20,130] For example, schools have been encouraged to employ a whole-of-school approach to plan, implement, and evaluate opportunities for children to be active throughout the school day through the development of a comprehensive school physical activity program (CSPAP).[138] The provision of PA opportunities to students during the school day is considered a core component of a CSPAP. Organised PA during school class time has been defined as PA undertaken during physical education (PE) lessons, school sport and classroom-based PA and is exclusive of participation in PA during recess and lunch time.[16] Classroom-based PA involves: (i) integrating PA into academic lessons, (ii) providing PA breaks between lessons (with or without an academic focus), or (iii) incorporating PA into transitions from one location to another.[16,46,138,146]

Several systematic reviews have reported beneficial effects of classroom-based PA interventions on the health (e.g. increased PA levels) and education (e.g. classroom behaviour and academic performance) outcomes of school students.[44-46] However, notable limitations in the methodological quality of studies included in these reviews have been highlighted.[44-46] Despite these promising findings, to date there appears to be limited objective data available regarding how often classroom teachers are currently implementing classroom-based PA and which methods are being utilised.[146,239]

During the early years of primary school, information regarding the frequency, type and exact context of children's PA during class time is also limited.[239] Children's PA in the school setting is commonly assessed using objective methods (e.g., accelerometery, pedometry, direct observation, and heart rate monitoring) and/or subjective methods (e.g., teacher, parent or self-report PA questionnaires or diaries).[60,71,72] Whilst in recent years accelerometery and pedometry have been the most common methods utilised to objectively measure children's PA,[30,34,46,82] these methods are limited in their ability to capture the types and contexts of PA.[60,73] Direct (or systematic) observation may be the most suitable method for collecting information about the frequency, type and intensity of PA, whilst simultaneously recording information about the physical and social environment in which the PA occurs, along with the educational context.[60,73]

To inform the design of future school-based PA interventions, particularly classroom-based PA interventions, with children in the early years of primary school, it is necessary to determine existing practices regarding the frequency, type and context of PA opportunities being provided during class time. Observation of these practices will assist in identifying which PA opportunities may be the most realistic and practical for educators to incorporate into an already busy classroom schedule. Therefore, the aim of this study was to directly observe Year 1 children's PA and the context of their PA during school class time and identify opportunities to incorporate additional activity. Based on the findings from the few studies which have investigated children's PA across the primary school day using direct observation,[239,240] it was hypothesised that Year 1 children would be predominantly sedentary during school class time, with limited opportunities to engage in active lessons and active breaks.

5.4 Methods

5.4.1 Study design

A cross-sectional research design was employed for this study and involved the collection of observational data over a four-week period. Ethics approval was obtained for the study from the Bond University Human Research Ethics Committee (Reference number: 15547). Research approval was also granted by the Queensland Department of Education (Reference number: 17/77163).

5.4.2 Setting and participants

School principals from a representative selection of public, independent and Catholic primary schools in south east Queensland and northern New South Wales, Australia, were invited via email or telephone to involve their schools in the study, over the period from July to December 2017. The school principal at one public primary school in south east Queensland accepted the invitation and provided gatekeeper approval for four mainstream Year 1 classes to be involved. All children enrolled in the four Year 1 classes were invited to participate in the study. Information sheets and consent forms were circulated to the parents and guardians of 100 children from four Year 1 classes at the school. A recruitment goal of 40 participants was set, allowing a maximum of 10 participants to be selected from each Year 1 class. This number of participants was calculated to provide a margin of error of +/-15% for the population estimates derived from the sample of proportions of classroom time spent in different levels of PA, assuming a 95% level of confidence and a large underlying population of Year 1 children.[241] The high number of data points arising from observation of each additional child meant that observation of a larger number of participants, in order to further reduce the margin of error, was not feasible in the study context and within the available time frame. Written parental consent was obtained for 34 Year 1 children (n = 20 boys, n = 14 girls, mean age = 6.36 ± 0.34 years, range 5.42-7.25 years).

5.4.3 Outcome measures

5.4.3.1 Demographics

Age and sex were recorded for each participant and the Index of Community Socio-Educational Advantage (ICSEA) was noted for the school. The ICSEA is a scale of socio-educational advantage calculated for Australian schools.[229] The ICSEA values are set at an average of 1000 with an approximate range from 500 (schools with students with extremely educationally disadvantaged backgrounds) to 1300 (schools with students with very educationally advantaged backgrounds).[229] A questionnaire was also completed by parents/caregivers regarding any relevant medical history for their child.

5.4.3.2 Observational System for Recording Physical Activity in Children – Elementary School (OSRAC-E)

A modified version of the Observational System for Recording Physical Activity in Children – Elementary School (OSRAC-E)[240] was used to directly observe the participating Year 1 children's PA in this study. The OSRAC-E is a direct observation tool designed to collect information about children's PA within the primary school setting.[240] In addition to recording the intensity level and type of PA, the contextual and behavioural circumstances of children's PA throughout the school day may be collected. This is in contrast to other direct observation tools, including the System for Observing Fitness Instruction Time (SOFIT)[242] and System for Observing Play and Leisure Activity in Youth (SOPLAY),[243] which specifically assess children's PA during physical education (PE) lessons and outdoor play, respectively.

Direct observation is considered a valid and reliable method for assessing PA in children aged 3-18 years.[60,73] The OSRAC-E has been found to be a reliable direct observation system but has yet to be validated against other measures of PA.[240,244] However, to optimise reliability and validity in the present study, data were collected using the OSRAC-E in accordance with the recommendations developed by McKenzie and van der Mars for assessing children's PA using systematic observation.[73] For example, prior to training, the observer (a registered physiotherapist) contacted the researchers who developed the OSRAC-E[240] to obtain the observation protocol, which included all category definitions and coding symbols. Advice was also sought regarding the most suitable software program to utilise to collect data electronically and subsequently the Multi-Option Observation System for Experimental Studies (MOOSES) software program[245] was recommended. The observer reviewed the recommended training manual and undertook video observation and coding practice prior to live coding practice. As only one observer was involved in the study, interobserver reliability was not of concern. Finally, the developer of the MOOSES software program[245] was consulted to ensure correct use of the software program.

OSRAC-E observation protocol

The observation protocol for this study was based on that previously described by the researchers who developed the OSRAC-E.[240] The protocol involved observing one focal child at a time and used a momentary time-sampling procedure with a 5 s observation interval followed by a 25 s recording interval. A 20 min observation period was chosen for this study in accordance with the Year 1 class timetable, resulting in 40 observation intervals for the focal child who was being observed during each observation period. Each selected study participant was observed for approximately four 20 min periods (i.e., a total of 80 min per study participant). Observations were coded using the MOOSES software program[245] on a Microsoft Surface Pro tablet. For each observation session, the participant's PA and its contexts were also recorded on a paper copy of the OSRAC-E, and where additional contextual information was required for the observed activity, qualitative information was noted.

Observation categories and codes

Observational information was collected, coded, and qualitatively documented across seven observational categories including; location, PA intensity level, PA type, physical setting, instructional setting, activity context, and group composition (for further information regarding the categories, codes and descriptions see McIver et al.[240]). Additional contextual information was also noted, including the time of day, reactivity to the presence of the observer, prompts for activity, information regarding who initiated the activity and whether transitions were directed by the teacher or incidental in nature.

Several modifications to observation categories and codes were made to contextualise the OSRAC-E tool for the Australian primary school setting (see Table S3). The *instructional setting* category was modified to include codes relating to the learning areas of the Year 1 Australian Curriculum, including the core (or priority) learning areas of English and mathematics.[246] The *other* code in the *instructional setting* category encompassed non-academic activities that were observed, including morning roll call, free play, show and share, meditation/mindfulness and organised school sport (excluding PE). The *activity context* category was also modified to include codes relating to classroom-based PA. The rationale for this modification was to allow for objective recording of the frequencies and types of classroom-based PA currently being provided to students in Year 1 classrooms. The coding of classroom-based PA was based on the definitions from the System for Observing Student Movement in Academic Routines and Transitions (SOSMART).[239] For example, when classroom-based PA (excluding PE/school sport) was observed during school class time, it was noted whether these opportunities were *teacher-led* or *technology-led* (i.e., the teacher used technology, for example, online dance videos, to lead the activity) and whether there was an *academic* or *non-academic* focus to the activity. The *group composition* category of the OSRAC-E tool was also modified to record whether the class activity involved (i) the whole class engaged at the same time (e.g., all children sitting on the carpet listening to the teacher read a book) or (ii) small groups (e.g., children completing an activity while sitting at desks/on the carpet with or in the presence of a small group of peers).

Minor modifications were also made to the definitions of several types of transitions that were coded under observation categories. For the *instructional setting* category, the *change class* code was used when the teacher changed from one activity context to another. For example, when the corresponding *activity context* category was coded as *transition, snack break* or *classroom-based physical activity (non-academic)*. For the *activity context* category, the *transition* code was used when there was also a change from one activity context to another; however, this excluded *classroom-based PA* and *snack breaks,* as they were coded separately to better describe the nature of the transition. Transitions resulting in any light PA or MVPA for the focal child during academic lessons (i.e., excluding PE, school sport and classroom-based PA) were also recorded based on the definitions from the SOSMART.[239] For example, when teachers instructed the focal child to move from one area to another (e.g., from the carpet to desks) this was recorded as a *teacher-directed transition*. When the focal child moved without being instructed, this was recorded as an *incidental transition*.

5.4.4 Procedure

Observational data were collected over a four-week period during the second school term, from the end of May to the end of June 2018. The observations were conducted and recorded by a registered physiotherapist with experience working with Year 1 children in the primary school setting. For each of the Year 1 classes, observation intervals occurred across one school week (i.e., Monday to Friday). All observation intervals took place during scheduled school class time (excluding recess and lunch breaks). Prior to observing each Year 1 class, the classroom teacher provided the observer with a copy of the class timetable. The observation intervals were then randomly selected from the class timetable using a random number generator to allocate four observation intervals for each participant from the available 20 min time periods across the school day. In cases where a participant was absent from class during their pre-planned observation interval, an alternative observation interval was allocated. To minimise student reactivity to the observer being present within the classroom, the teacher introduced the observer to the class on the Monday morning and observation intervals were not recorded during the first lesson, whilst the children adjusted to the observer being present. The classroom teacher and children in the class were not aware of exactly when observations occurred, and which study participant was being observed at any given time. Classroom teachers were advised to deliver their regular classroom curriculum, and to not modify their curriculum in any way due to the presence of the observer.

5.4.5 Statistical analysis

Statistical analyses for this study were conducted using the Statistical Package for the Social Sciences (SPSS) (Version 26).[230] Using the MOOSES software program,[245] event frequencies and durations were calculated within each code group. The output from this process was then exported into an excel spreadsheet and SPSS analysis software. The number of observation intervals coded within each category was then calculated. In line with the previously published study using the OSRAC-E,[240] PA intensity level was further coded and analysed as follows: Sedentary (stationary or limbs) = Level 1 code (stationary or motionless with no major limb movement or major joint movements) and Level 2 code (stationary with easy movement of limbs or trunk without translocation); Light PA = Level 3 code (translocation at a slow and easy pace); Moderate to vigorous PA = Level 4 code (translocation at a moderate pace) and Level 5 code (translocation at a fast or very fast pace) (see McIver et al.[240] for a detailed description of activity level codes). Cross-tabulation was used to calculate the numbers of intervals and percentages of total intervals observed in the different PA intensity levels by specific physical (i.e., location, physical setting), educational (instructional setting, activity context) and social (group composition) contexts. Pearson's Chi Square Test of Independence was used to evaluate whether group composition (i.e., 'whole class' or 'group') was related to PA intensity level. Pearson's Chi-Square Test of Association was conducted to evaluate whether group composition was related to numbers of incidental transitions. To determine the effect size for the proportion of variance that was common to the two variables, Cramer's V was calculated.[233] According to Cohen's[231] conventions, an effect size ω of 0.1 can be considered small, 0.3 can be considered medium and 0.5 can be considered large.[233] A significance level of 5% ($\alpha = 0.05$) was applied to all statistical tests.

5.5 Results

Data were collected for 34 study participants from four mainstream Year 1 classes at the cooperating Australian public primary school (*n* = 20 boys, mean age = 6.39 ± 0.23 years, range 5.92-6.75 years; *n* = 14 girls, mean age = 6.31 ± 0.46 years, range 5.42-7.25 years). The school ICSEA value was listed as 1059. Figure 11 summarises the flow of participants through the study. A total of 5440 observation intervals were recorded (i.e., 2 observations/min x 20 min period x 4 periods x 34 participants). Of these observation intervals, 135 were coded as ‘can’t tell’ for various categories due to participants moving out of the observer’s line of sight during indoor or outdoor activities. As such, a total of 5305 observation intervals were available for analysis following removal of these intervals.

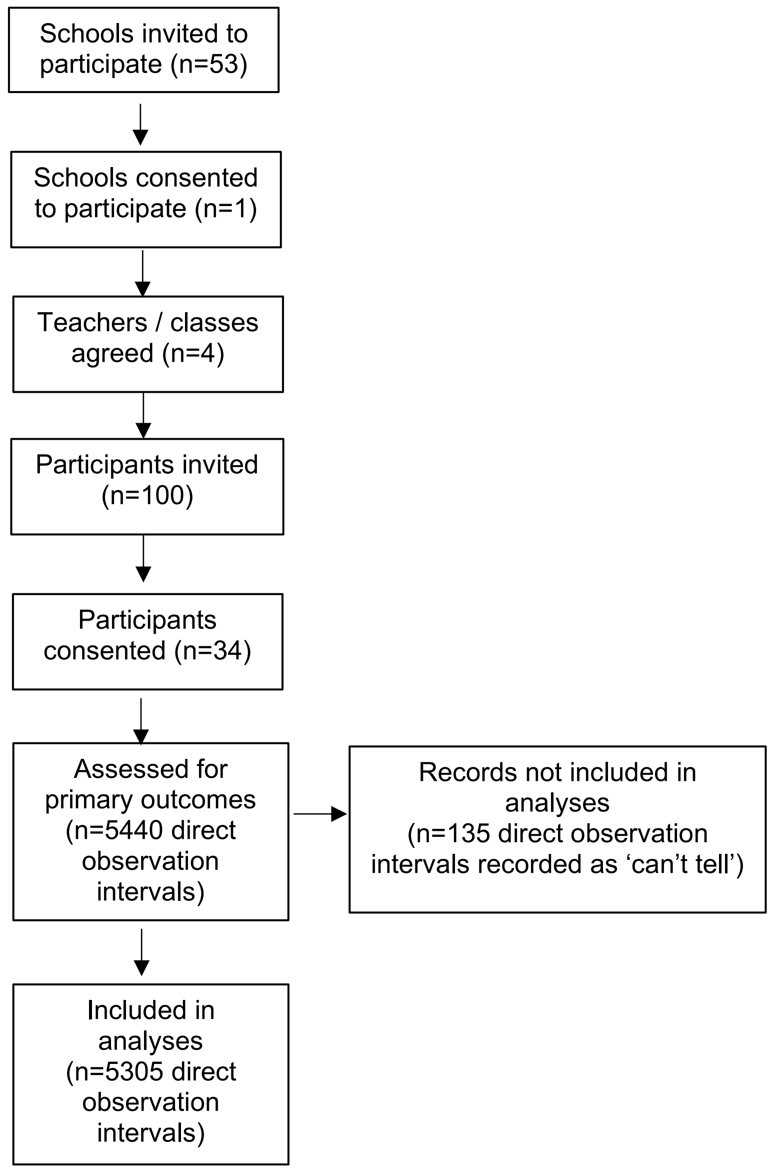


Figure 11: Flow of participants through the study.

The frequencies of observation intervals, including percentages of total observation intervals, occurring within each descriptive category for the observation intervals are presented in Table 17. The frequencies of observation intervals and percentages of observation intervals categorised as sedentary (i.e., level 1 and 2 codes), light PA (i.e., level 3 codes) and MVPA (i.e., level 4 and 5 codes) within each descriptive category are also presented in Table 17.

Table 17: (i) Frequencies of observed intervals (and percentages of total intervals) in each category that were associated with each observation code; and (ii) frequencies of observed intervals (and percentage of intervals) in each category that were coded as sedentary, light and moderate-to-vigorous PA.

Observed categories	Observed codes	Observed intervals (% Total)	Observed intervals (%) by physical activity intensity level		
			Sedentary (Levels 1 & 2)	Light PA (Level 3)	Moderate-vigorous PA (Levels 4 & 5)
	Total	5305 (100)	4570 (86.1)	639 (12.0)	96 (1.8)
Time of day	Morning	2465 (46.5)	2116 (85.8)	301 (12.2)	48 (1.9)
	Middle	2565 (48.4)	2220 (86.5)	298 (11.6)	47 (1.8)
	Afternoon	275 (5.2)	234 (85.1)	40 (14.5)	1 (0.4)
Location	Indoors	4906 (92.5)	4338 (88.4)	545 (11.1)	23 (0.5)
	Outdoors	339 (6.4)	217 (64.0)	57 (16.8)	65 (19.2)
	Transition	60 (1.1)	15 (25.0)	37 (61.7)	8 (13.3)
Physical activity type	Climb	11 (0.2)	11 (100)	0 (0)	0 (0)
	Crawl	22 (0.4)	0 (0)	21 (95.5)	1 (4.5)
	Dance	40 (0.8)	27 (67.5)	7 (17.5)	6 (15.0)
	Jump/skip	19 (0.4)	0 (0)	0 (0)	19 (100)
	Lie down	125 (2.4)	123 (98.4)	2 (1.6)	0 (0)
	Pull/push	29 (0.5)	23 (79.3)	1 (3.4)	5 (17.2)
	Run	59 (1.1)	0 (0)	0 (0)	59 (100)
	Sit/squat/kneel	3177 (59.9)	3177 (100)	0 (0)	0 (0)
	Stand	1187 (22.4)	1187 (100)	0 (0)	0 (0)
	Throw	22 (0.4)	22 (100)	0 (0)	0 (0)
	Walk	614 (11.6)	0 (0)	608 (99)	6 (1)
Physical setting	Classroom	4916 (92.7)	4349 (88.5)	544 (11.1)	23 (0.5)
	Hallway	50 (0.9)	15 (30.0)	29 (58.0)	6 (12.0)
	Sports field	339 (6.4)	206 (60.8)	66 (19.5)	67 (19.8)
Instructional setting	Change class*	298 (5.6)	218 (73.2)	65 (21.8)	15 (5.0)
	Core learning lessons* (English/mathematics)	3828 (72.2)	3399 (88.8)	421 (11)	8 (0.2)
	Physical education (PE)	233 (4.4)	145 (62.2)	39 (16.7)	49 (21.0)
	Languages	75 (1.4)	73 (97.3)	2 (2.7)	0 (0)
	Music	91 (1.7)	91 (100)	0 (0)	0 (0)
	Other*	355 (6.7)	301 (84.8)	36 (10.1)	18 (5.1)
	Science	130 (2.5)	124 (95.4)	6 (4.6)	0 (0)
	Technologies	40 (0.8)	24 (60)	14 (35)	2 (5)
	Visual arts	255 (4.8)	195 (76.5)	56 (22.0)	4 (1.6)
Activity context	Academics – Total	4337 (81.8)	3848 (88.7)	475 (11.0)	14 (0.3)
	Academics – English	2435 (45.9)	2183 (89.7)	247 (10.1)	5 (0.2)
	Academics – mathematics	1311 (24.7)	1158 (88.3)	150 (11.4)	3 (0.2)
	CBPA (excludes PE/school sport)	151 (2.8)	121 (80.1)	17 (11.3)	13 (8.6)
	CBPA (Teacher-led, non-academic)	50 (0.9)	41 (82.0)	2 (4.0)	7 (14.0)
	CBPA (Teacher-led, academic)	10 (0.2)	10 (100)	0 (0)	0 (0)
	CBPA (Technology-led, non-academic)	77 (1.5)	60 (77.9)	11 (14.3)	6 (7.8)
	CBPA (Technology-led, academic)	14 (0.3)	10 (71.4)	4 (28.6)	0 (0)
	PE and school sport	313 (5.9)	192 (61.3)	56 (17.9)	65 (20.8)
	Non-academic	224 (4.2)	211 (94.2)	13 (5.8)	0 (0)
	Snack	124 (2.3)	92 (74.2)	32 (25.8)	0 (0)
	Transition*	130 (2.5)	82 (63.1)	44 (33.8)	4 (3.1)
	TV/video	26 (0.5)	24 (92.3)	2 (7.7)	0 (0)

Observed categories	Observed codes	Observed intervals (% Total)	Observed intervals (%) by physical activity intensity level		
			Sedentary (Levels 1 & 2)	Light PA (Level 3)	Moderate-vigorous PA (Levels 4 & 5)
Group composition	Whole class	2482 (46.8)	2153 (86.7)	241 (9.7)	88 (3.5)
	Group*	2823 (53.2)	2417 (85.6%)	398 (14.1)	8 (0.3)
Transitions	Teacher-directed transition*	223 (4.2)			
	Incidental transition*	353 (6.7)			

CBPA: classroom-based physical activity; PA: physical activity; PE: physical education.
Values may not add up to exactly 100% due to rounding.
Sedentary (stationary or limbs) = Level 1 code (stationary or motionless with no major limb movement or major joint movements) and Level 2 code (stationary with easy movement of limbs or trunk without translocation; Light PA = Level 3 code (translocation at a slow and easy pace); Moderate to vigorous PA = Level 4 code (translocation at a moderate pace) and Level 5 code (translocation at a fast or very fast pace) (See McIver et al.[240] for detailed description of activity level codes)
*See Table S3 for definitions of modified OSRAC-E codes

5.5.1 Location and physical setting

Overall, the majority of observation intervals of Year 1 participants during school class time occurred indoors within the classroom (92.7%) and these indoor intervals involved predominantly sedentary activities (88.5% sedentary, 11.1% light PA, 0.5% MVPA; Table 16). In contrast, Year 1 participants spent a considerably greater proportion of observation intervals engaged in light PA and MVPA when lessons were conducted outdoors on the sports field (light:19.5%; MVPA:19.8%).

5.5.2 Instructional setting

The core learning areas of English and mathematics (72.2% of total intervals) represented the most common instructional contexts observed during school class time. The majority (88.8%) of intervals observed during core lessons involved sedentary activities, with minimal amounts of light PA (11%) and MVPA (0.2%) occurring. PE lessons were delivered by a specialist PE teacher once a week for a duration of 60 min and represented 4.4% of the total observed intervals. The types of activities observed during PE lessons targeted aerobic fitness (e.g., running, jumping) and motor skill development (e.g., throwing, catching, kicking). Consequently, participants undertook more light PA (16.7%) and MVPA (21.0%) during PE lessons than during core learning lessons, however, 62.2% of the observed intervals during PE lessons still involved activities classified as being sedentary. Close examination of the full set of PA intensity codes recorded for PE lessons (see Table S4) revealed that 22.3% of observed intervals involved activities where participants were stationary with limb/trunk movement, consistent with activities such as standing while throwing, catching or kicking.

5.5.3 Activity context and activity type

The majority of the observed intervals (81.8%) involved activities that were academic in nature and involved participants undertaking predominantly sedentary (88.7%) types of activities, often whilst sitting and standing. Of the academic learning areas of the Year 1 Australian Curriculum, participants were observed engaging in activities mainly relating to English (45.9%) and mathematics (24.7%). The regular class routine also comprised non-academic activities (e.g., morning roll call or free-time; 4.2% of total observed intervals) and short breaks where students were allowed to have fruit as a mid-morning snack.

Classroom-based PA (excluding PE and school sport) represented 2.8% of the total observed intervals. Classroom-based PA predominantly had a non-academic focus and was either delivered by the teacher (50 intervals or 0.9% of total observed intervals) or the teacher used technology (e.g., online dance video) to deliver the activity (77 intervals or 1.5% of total observed intervals). Classroom-based PA was mostly scheduled at times when teachers were transitioning students from one instructional context to another (*change class)*. Academic content was seldom incorporated into classroom-based PA that was delivered by the teacher (10 intervals or 0.2% of total observed intervals) or delivered using technology (14 intervals or 0.3% of total observed intervals). Overall, children's PA intensity levels during all types of classroom-based PA were classified as primarily sedentary (80.1%) with minimal light PA (11.3%) and MVPA (8.6%). However, examination of the full set of PA intensity codes recorded during classroom-based PA (Table S4) revealed that observed intervals involved slightly more stationary activities with limb/trunk movement (45.7%) than purely stationary activities (35.1%). This is consistent with the observation that the most common types of activities during classroom-based PA included standing and copying actions (43%), dancing (22.5%; e.g., copying a dance video), sitting while performing yoga (19.9%), walking around the classroom (5.3%), jumping/skipping (4.0%), movements while lying down (3.3%) and running on the spot (1.3%) (Table 18).

Table 18: Types of physical activity observed during classroom-based physical activity.

Observation category	Observation Code	Observed intervals (%)
Activity type	Total	151 (100)
	Climb	0 (0)
	Crawl	1 (0.7)
	Dance	34 (22.5)
	Jump/skip	6 (4.0)
	Lie down	5 (3.3)
	Pull/push	0 (0)
	Run	2 (1.3)
	Sit/squat/kneel	30 (19.9)
	Stand	65 (43.0)
	Throw	0 (0)
	Walk	8 (5.3)

5.5.4 Group composition

Classroom teachers used several different ways to group children during class activities. Nearly half (46.8%) of the observed intervals involved the whole class being engaged in activities at the same time. Just over a half (53.2%) of the intervals involved participants undertaking activities with or in the presence of a small group of peers (e.g., English / mathematics group rotations or sitting at desks with a group of peers). The Pearson's Chi-square Test of Independence conducted to examine the relationship between group composition and levels of PA intensity indicated a significant association between the two variables ($\chi^2 = 98.98$, $p < .001$) and so this relationship was further explored, graphically. Graphical representation of the observed intervals (Figure 12) indicates that when participants were involved in whole class activities, they were more likely to engage in MVPA, though MVPA remained relatively infrequent. Conversely, when participants completed activities in groups, with or in the presence of their peers, they were more likely to engage in light PA.

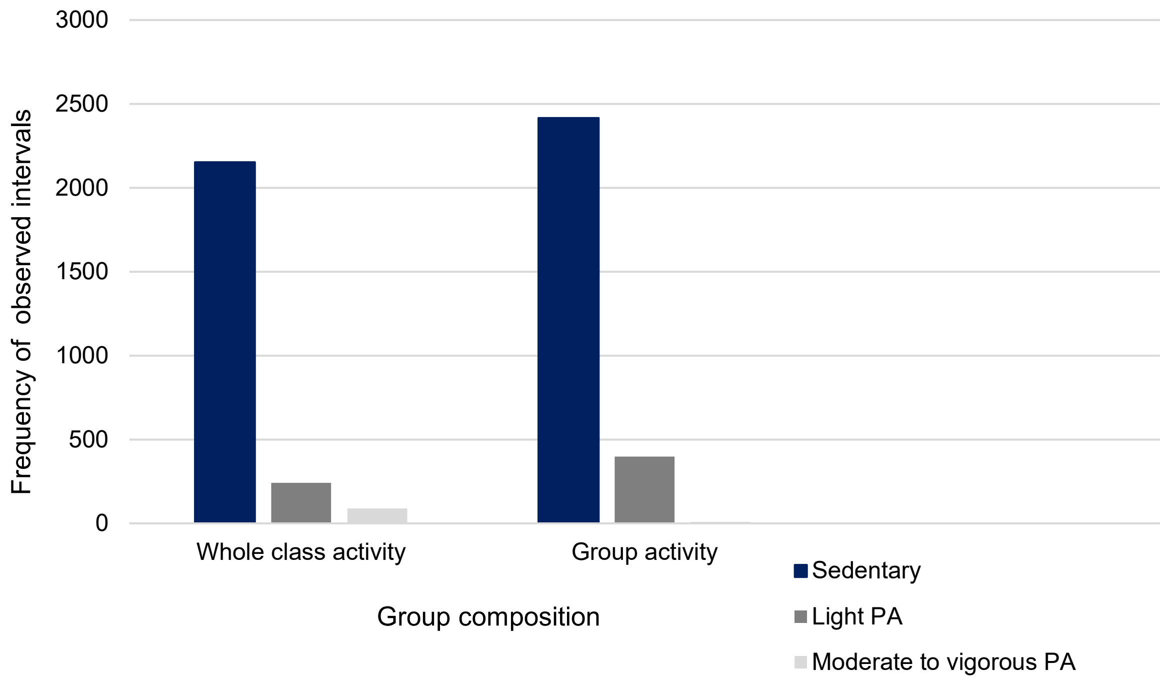


Figure 12: Frequencies of intervals observed in different PA intensity levels during whole class and group activities.

5.5.5 Transitions

In relation to the *location* category in the observations, *transitions* (e.g., from sports field to classroom) represented 1.1% of the total observed intervals and 25% of these transition intervals were sedentary (e.g., standing in line), 61.7% involved light PA (e.g., walking) and 13.3% involved MVPA (e.g., climbing stairs). In relation to the *instructional setting* category of observations, *change class* (i.e., indicating when the corresponding activity context category was coded as transition, snack break or classroom-based PA – non-academic) represented 5.6% of total observed intervals and 73.2% of these were sedentary, 21.8% involved light PA and 5% involved MVPA. In relation to the *activity context* category of observations, *transitions* (i.e., change in one activity context to another, excluding classroom-based PA and snack breaks) represented 2.5% of the total observed intervals and 63.1% of these were sedentary, 33.8% involved light PA and 3.1% involved MVPA (Table 17 and Table S3). The proportion of teacher-directed transitions and incidental transitions resulting in children undertaking light PA or MVPA (excluding observed intervals within PE, school sport and classroom-based PA – non-academic) was 4.2% and 6.7% respectively (Table 17). Results of the Pearson's Chi Square Test of Association conducted to examine the relationship between group composition and occurrence of incidental transitions indicated that when children completed activities in small groups (with or in the presence of peers), they were significantly more likely to engage in incidental transitions than when they completed activities as a whole class ($\chi^2 = 94.73$, $p < .001$, $\omega = .134$; Figure 13). However, teachers were not observed to direct children to move significantly more often during whole class activities than during group activities ($\chi^2 = 1.31$, $p = .253$).

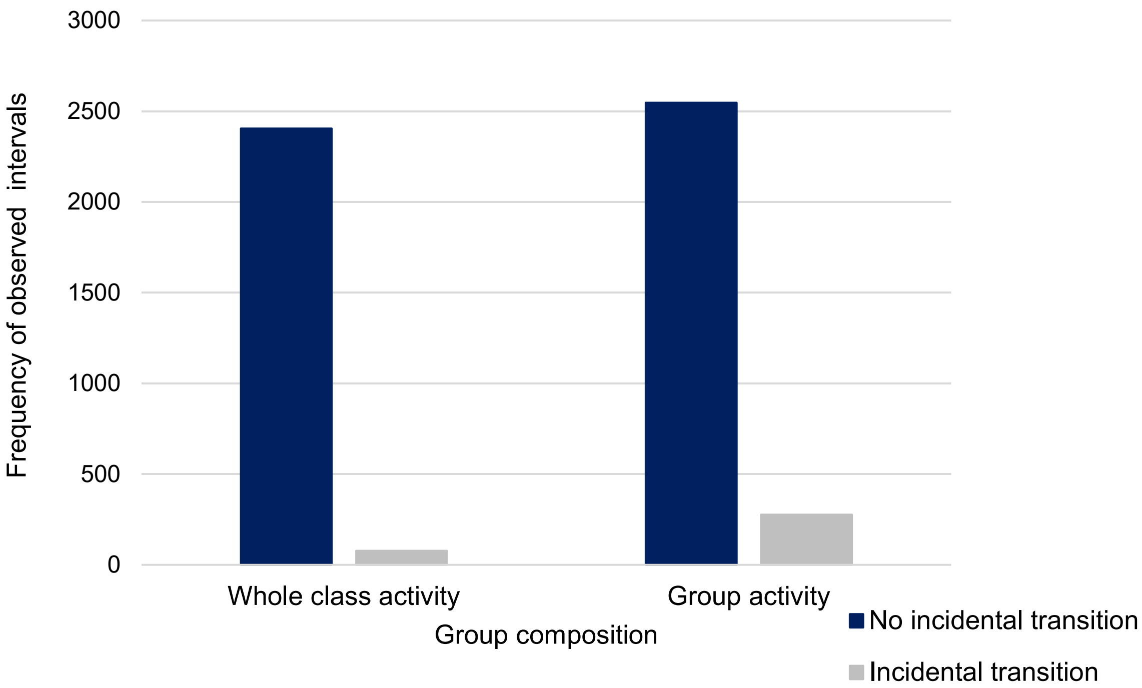


Figure 13: Frequency of incidental transitions observed during whole class and group activities.

5.6 Discussion

The aim of this study was to directly observe Year 1 children's PA and the context of their PA during school class time and identify opportunities to incorporate additional activity. Overall, the study findings provide evidence that although Year 1 children are currently being provided with some occasional opportunities to be active during school class time, children were observed to be most frequently participating in academic activities that were sedentary in nature. Several opportunities to incorporate additional PA during school class time were identified. These included both structured (e.g., classroom-based PA) and unstructured (e.g., incidental movement) opportunities.

5.6.1 Existing PA opportunities provided to Year 1 children during school class time

In Australia, the primary focus of learning in the early years of school is for children to develop essential skills in literacy and numeracy.[3] The focus on these core areas of learning in the Year 1 Australian Curriculum was evident in the present study as Year 1 participants engaged in academic activities primarily relating to English and mathematics for the majority of observation intervals. However, in line with other research conducted with children in the primary school setting,[240,247] findings from this study revealed that the nature of these academic activities was predominantly sedentary. For example, in the study by McIver et al.,[240] students in Kindergarten to Grade 5 were sedentary for the majority (84%) of observation intervals recorded using the OSRAC-E during the school day, with very few opportunities provided to children to accumulate MVPA throughout the school day.

In Australia it has been recommended that schools should ideally aim to deliver 150 minutes of organised PA to children each week.[16] It is noteworthy that in Australia, according to the Australian Curriculum, Assessment and Reporting Authority, the recommended time requirement for the subject Health and Physical Education (comprised of two interrelated strands including personal, social and community health, and movement and physical activity)[248] is up to 80 h/year (2 h per school week); however, this policy is not mandatory.[249] In this study, Year 1 children were observed being provided with several opportunities to engage in organised PA during school class time, including planned PE lessons, a sports carnival (which replaced the weekly PE lesson) and classroom-based PA, but the time allocated was limited. Although it was not possible to quantify the exact duration of organised PA accumulated by Year 1 participants during class time across the whole school week, in the current study one 60 min PE lesson was scheduled into the school class timetable each week (of which an estimated 37.7% or 22 min of observed class time was spent undertaking light PA or MVPA). During the four-week study period, no additional sport time was timetabled, and observations (Table 17) indicated that non-PE organised PA (i.e., classroom-based PA) was limited to 2.8% of observed class time, with this equating to an estimated 18 min per week.

In relation to the intensity levels of PA undertaken by children, participants were observed to achieve higher levels of MVPA during organised PA opportunities than during classroom academic lessons. Year 1 children's MVPA was most prevalent in PE lessons, with 21% of observation intervals during PE spent at this PA intensity. This finding is similar to that reported by McIver et al.,[240] who found children from Kindergarten to Grade 5 spent 15% of observed PE lessons in MVPA. As outlined in a comprehensive school physical activity program, one of the indicators of quality PE is for children to spend 50% of PE lessons being active.[138,139] In the present study, sedentary activities coded during PE lessons were explained by periods when children were sitting or standing still, listening to instructions being given by the PE teacher, or waiting for their turn. Furthermore, observed PE lessons involved children engaging in gross motor skills such as catching, throwing and kicking, which meant that activities were coded as 'stationary involving limb/trunk movement' but with no translocation (Table S4). Therefore, providing professional development and training to classroom teachers and specialist PE teachers outlining methods to increase Year 1 children's MVPA during PE lessons (e.g., incorporating higher intensity activities such as games that involve running and jumping) and strategies to minimise periods of inactivity may be important.[139,250] In future, it may be useful to validate the OSRAC-E against accelerometry to confirm whether MVPA coded using the OSRAC-E is correlated with levels of MVPA measured by accelerometry.

Although classroom-based PA was only observed on limited occasions (2.8% of the total time intervals), its presence during school class time provided evidence of how physically active lessons and PA breaks could be integrated into existing Year 1 class routines. The most popular types of classroom-based PA included PA breaks with a non-academic focus either delivered by the classroom teacher directly, or via the teacher using technology. Interestingly, the percentage of observed intervals that involved MVPA during teacher and technology-led PA breaks with a non-academic focus appeared to be higher than that observed during academic lessons, consistent with findings from experimental studies evaluating the impact of classroom-based PA interventions on children's MVPA.[251,252] However, as there were only a small number of observed intervals involving classroom-based PA, these results should be interpreted with caution. The higher percentage of observed intervals involving children engaging in MVPA during whole class activities compared to group activities was most likely due to teachers structuring PE lessons and classroom-based PA opportunities as whole-class activities, and thus all children were encouraged to engage in these activities at the same time. This likelihood is supported by the supposition of Russ et al.[239] that classroom-based PA directed by a teacher may result in more MVPA than light PA, whereas incidental PA that occurs in the classroom may involve more light PA. Teacher and technology-led physically active academic lessons were seldom observed in the current study (<0.5% of total observed intervals), suggesting either that classroom teachers were not familiar with this approach in the classroom or that there may be barriers for teachers trying to integrate PA into academic lessons with Year 1 children. Overall, these findings were similar to those reported by Russ et al.,[239] who reported during their pilot of the SOSMART tool that the median percentage of occurrence of non-academic and academic-infused movement within or between lessons was 2.2% (range 0-9.5%) and 0% (range 0-4%), respectively.

Interestingly, the majority of light PA recorded during observation intervals in the current study occurred during academic lessons. The most likely explanation for this was the number of teacher-directed and incidental transitions recorded during class activities or when changing classes from one instructional context to another, resulting in an accumulation of light PA. These findings are similar to those reported by Russ et al.,[239] who observed a higher frequency of incidental types of movement than structured active lessons and breaks, in children aged seven to eight years old. Notably, the findings in the present study also indicate that when children completed classroom activities in small groups, with, or in the presence of their peers they were more likely to engage in light PA than when activities were completed as a whole class. This could be attributed to the fact that children were more freely able to move around the classroom to collect supplies or to talk to the teacher or their peers when working at their own pace during group-based activities. Conversely, when children were engaged in activities as a whole class, it often involved the teacher giving instructions to children while they sat on the carpet, which meant children were concentrating on listening to the teacher and were not required to move about the classroom to access supplies.

5.6.2 Future opportunities to incorporate structured and unstructured PA opportunities into the regular school class schedule

Evidence of the existing PA opportunities being provided to Year 1 children during school class time means that it may be possible to build upon this current practice. This study revealed that although classroom-based PA was seldom included during school class time, the most frequently used method was the inclusion of PA breaks during transitions from one instructional context to another, which may indicate this was relatively easy to implement into the class routine. Observed PA breaks typically had a non-academic focus and were either delivered by the classroom teacher or using technology (i.e., online dance videos). Classroom teachers were rarely observed incorporating movement into academic lessons, which suggests there is potential to further explore utilisation of this method. An array of resources have been developed to support teachers who wish to provide PA breaks and physically active lessons and these may be useful in assisting teachers to implement classroom-based PA opportunities more often during school class time (see review by Webster et al.[146(p4)] for some examples of resources available).

The types of activities that resulted in MVPA during classroom-based PA included running and jumping on the spot (Table 18). Dance videos primarily involved children standing on one spot while copying the corresponding movements. Unless activities such as jumping or running on the spot were repeated, most often they were coded as stationary with limb/trunk movement, due to there being no translocation. It would be important to validate the PA intensity levels achieved during dance videos, using accelerometry, to confirm the level of PA intensity children are undertaking. Further investigation is also warranted to determine whether to target specific intensities of PA (e.g., MVPA) during activities and/or whether children will benefit from any form of movement and breaking up sedentary time.

While classroom-based PA is one approach for teachers to more formally structure PA opportunities into the school day, findings from this study have shed light on the need for teachers and schools to consider the role the environment (e.g., the physical layout of the classroom, access to outdoor open spaces) and social context (e.g., class group composition) may play in increasing unstructured PA opportunities during school class time. The frequency of children's incidental movement observed during classroom activities in the present study was related to the way the classroom teacher grouped children during those activities. This suggests that teachers may be able to influence the degree of children's incidental PA in the classroom by scheduling group activities that may in turn lead to children moving around the classroom more often. Furthermore, structuring the physical layout of the classroom in a way that encourages children to move during classroom activities in order to collect supplies, communicate with others or interact with equipment or resources may also lead to an accumulation of incidental

PA.[146,239] In addition, offering children a variety of different learning spaces and materials, for example, desks of different heights, may encourage children to regularly change position by kneeling, sitting or standing at different workstations during activities.

5.6.3 Limitations

It is important to acknowledge several limitations to this study. Firstly, the OSRAC-E direct observation tool has yet to be validated against other measures of PA such as accelerometry and thus recorded intensity levels of PA may have been over or underestimated. Research suggests that adopting multiple simultaneous approaches to measuring PA may lead to a more complete profile of children's PA.[60] For this study, permission was initially sought to assess children's PA using both accelerometry and direct observation to allow for this triangulation of data; however, approval to use accelerometers with study participants was not granted.

Another factor leading to a potential over or underestimation of PA intensity was that only a small number of participants were observed at one school, and these may differ from other children of the same age at the same or different schools. However, the observer did spend one whole school week with each Year 1 class over a four-week period and observe 34 different participants, and thus sampling was representative of the timetable (e.g., scheduled number of hours for English, mathematics, PE) and a range of children in the classes. Further limitations to the generalisability of the study findings include the fact that only one school agreed to participate, despite a more representative sample being invited. Nevertheless, given that teaching in all schools in Australia is guided by the Australian Curriculum[246] this observational study conducted in an Australian school provides a valuable indication of the extent to which PA may occur in Year 1 classrooms across many schools. To our knowledge, this study was the first to assess the frequency, type and context of Year 1 children's PA in Australia using the OSRAC-E. Whilst further research of this nature with larger sample sizes is warranted, this study provides valuable insight into existing classroom routines and PA practices, as a guide and catalyst for further research.

It is important to also acknowledge that some of the observation intervals occurred during assessment weeks designed to facilitate mid-year reporting of student grades. This meant that some activities such as English and mathematics small group rotations were not undertaken as planned, which may have resulted in an increase in sedentary time. However, these intervals represented less than 5% of the total number of observations. Furthermore, the primary school setting is dynamic and thus observation of children's PA was occasionally challenging, particularly during highly active periods when children were moving fast and there were many different activities occurring simultaneously. However, the advantage of the OSRAC-E being a focal child system meant that observer error due to environmental complexity was minimised, as long as the observer was able to view the focal child. Finally, all observation intervals were recorded by one observer. This may have subsequently resulted in observer bias leading to limitations in the generalisability of the findings. However, the observer had knowledge of, and experience in assessing children's PA levels and motor proficiency, along with specific professional experience delivering gross motor programs to Year 1 students within the primary school context.

5.7 Conclusion

The collective findings from this study advance current understanding of Year 1 children's PA and the context of this PA during school class time. The future opportunities available to incorporate PA into the regular class schedule were also identified. Overall findings revealed that Year 1 children were observed to be predominantly sedentary during school class time, undertaking limited amounts of light PA and MVPA, including organised and incidental PA. Implementing movement into academic lessons or during transitions between lessons (i.e., classroom-based PA) was identified as a key strategy to encourage children to be more active during school class time. Children's incidental PA may also be facilitated by scheduling group activities and/or structuring the physical layout of the classroom to encourage movement. Findings from this study may interest school principals, classroom teachers, specialist PE teachers and other policy makers interested in identifying ways to implement opportunities for children in the early years of primary school to be active during class time, as part of a whole-of-school approach to PA promotion. Findings are also relevant to health professionals working in schools who are qualified to promote children's health and wellbeing, as they may be able to support educators to implement these practices.[8]

[8] Please note that all references in this chapter are presented in the References section of the thesis

Table S3: Description of modified codes for Observational System for Recording Physical Activity in Children – Elementary School.

Observed categories	Observed codes[a]	Description
Location	Transition	When children move from an outdoor to an indoor location
Instructional setting	Change class	Teacher changed from one activity context to another (i.e., when the corresponding activity context category was coded as transition, snack break or classroom-based physical activity (teacher or technology-led with non-academic focus)
	Core learning lessons	English and mathematics. Inclusive of snack break and classroom PA (teacher or technology-led with academic focus)
	Other	Non-academic activities observed including morning roll call, free play, show and share, meditation/mindfulness and school sport (excluding PE)
Activity context	CBPA	PA observed in classroom (excluding PE and school sport)
	CBPA (Teacher led, non-academic)[b]	PA observed in classroom – delivered by the teacher, non-academic focus (i.e., PA break)
	CBPA (Teacher led, academic)[b]	PA observed in classroom – delivered by the teacher, academic focus (i.e., active lesson)
	CBPA (Technology led, non-academic)[b]	PA observed in classroom – delivered using technology (e.g., online dance video), non-academic focus
	CBPA (Technology led, academic)[b]	PA observed in classroom – delivered using technology (e.g., online dance video), academic focus
	PE/school sport	Activity observed during PE lessons. School sport: the school sports carnival was timetabled into the regular 1-hour PE lesson (i.e., replaced PE that one week)
	Snack	Eating fruit snack during break or while completing academic work
	Transition	Change in one activity context to another (excluding classroom-based PA and snack breaks)
Group composition	Whole class	Children complete an activity involving the whole class
	Group	Children complete an activity with or in the presence of a small group of peers
Transitions	Teacher-directed transition[b]	The teacher asked students to move from one area to another (i.e., carpet to desk), either to start an activity (i.e., collect supplies), or finish an activity (i.e., pack up learning materials) in preparation for a new activity
	Incidental transition[b]	The student engaged in physical activity, without receiving instruction from the teacher to do so (i.e., collecting learning materials, moving to speak to the teacher/peers)

CBPA: classroom-based PA; PA: physical activity; PE: physical education
[a] See McIver et al.[240] for original description of codes for observation categories
[b] See Russ et al.[239] for original description of codes for transitions

Table S4: Frequencies of observed intervals (and percentage of intervals) of physical activity opportunities provided during Year 1 school class time by physical activity intensity levels 1-5.

Observation categories	Observation codes	Observed intervals (% total)	Observed intervals (%) by physical activity intensity level						
			Stationary (Level 1)	Limbs (Level 2)	Sedentary (Levels 1 & 2)	Light (Level 3)	Moderate (Level 4)	Fast (Level 5)	MVPA (Levels 4 & 5)
Instructional setting	Change class*	298 (5.6)	166 (55.7)	52 (17.4)	218 (73.2)	65 (21.8)	3 (1)	12 (4)	15 (5.0)
	Physical Education	233 (4.4)	93 (39.9)	52 (22.3)	145 (62.2)	39 (16.7)	0 (0)	49 (21)	49 (21)
Activity context	CBPA*	151 (2.8)	53 (35.1)	69 (45.7)	121 (80.1)	17 (11.3)	3 (2)	9 (10.2)	13 (8.6)
	CBPA (Teacher-led, non-academic)*	50 (0.2)	21 (42.0)	20 (40)	41 (82)	2 (4)	1 (2.5)	6 (12)	7 (14)
	CBPA (Teacher-led, academic)*	10 (0.2)	3 (30.0)	7 (70)	10 (100)	0 (0)	0 (0)	0 (0)	0 (0)
	CBPA (Technology-led, non-academic)*	77 (1.5)	28 (36.4)	33 (42.9)	60 (77.9)	11 (14.3)	2 (2.6)	3 (3.9)	6 (7.8)
	CBPA (Technology-led, academic)*	14 (0.3)	1 (7.1)	9 (64.3)	10 (71.4)	4 (28.6)	0 (0)	0 (0)	0 (0)
	PE + sport	313 (5.9)	128 (40.9)	64 (20.4)	192 (61.3)	56 (17.9)	2 (0.6)	63 (20.1)	65 (20.8)
Group composition	Whole class*	2482 (46.8)	1676 (67.5)	478 (19.3)	2153 (86.7)	241 (9.7)	6 (0.2)	81 (3.3)	88 (3.5)
	Group*	2823 (53.2)	1559 (55.2)	858 (30.4)	2417 (85.6)	398 (14.1)	1 (0.0)	7 (0.2)	8 (0.3)

CBPA: classroom-based physical activity; PA: physical activity; PE: physical education.
Values may not add up to exactly 100% due to rounding.
Sedentary (stationary or limbs) = Level 1 code (stationary or motionless with no major limb movement or major joint movements) and Level 2 code (stationary with easy movement of limbs or trunk without translocation; Light PA = Level 3 code (translocation at a slow and easy pace); Moderate to vigorous PA = Level 4 code (translocation at a moderate pace) and Level 5 code (translocation at a fast or very fast pace) (See McIver et al.[240] for detailed description of activity level codes)
*See Table S3 for definitions of modified OSRAC-E codes

Chapter 6: Factors Influencing the Provision of Classroom-Based Physical Activity to Students in the Early Years of Primary School: A Survey of Educators

6.1 Preface

It was identified in **Study 2 (Chapter 5)** that classroom-based PA, particularly physically active lessons, was seldom observed being utilised by classroom teachers with Year 1 children during class time. Therefore, classroom-based PA was recommended as a potential method that teachers could employ to increase children's movement during class time. The study reported in this chapter concludes *Stage 2 (solution generation)* of the thesis framework and involved seeking feedback from Australian educators and school principals regarding the factors (barriers/facilitators) that would influence the provision of classroom-based PA to students in the early years of primary school. It has been reported in the implementation science literature that for school-based PA interventions to be more widely accepted and implemented, it is essential to explore the factors that may influence the implementation of school-based PA interventions under less controlled real world conditions.[51,145] Identification of contextual barriers and facilitators that may influence the implementation of classroom-based PA programs to students in the early years of primary school in Australia may inform the design of future studies evaluating the effectiveness of classroom-based motor skill programs on children's motor proficiency and academic outcomes. In this regard, potential barriers to effective implementation that have been identified early in the planning process may be addressed.

The cross-sectional study reported in this chapter was published in a peer-reviewed journal in 2020. The formatting of the original published manuscript has been amended to be consistent with the thesis style, and the citation for the published manuscript is as follows: https://link.springer.com/article/10.1007%2Fs10643-020-01076-y#citeas

Macdonald K, Milne N, Pope R, Orr R. Factors influencing the provision of classroom-based physical activity to students in the early years of primary school: a survey of educators. *Early Child Educ J.* 2020; 1-13. doi: 10.1007/s10643-020-01076-y under Creative Commons Attribution Licence (CC BY 4.0)

Two supplementary tables are referred to as Table S5 and Table S6 within this chapter. These tables can be found at the end of the chapter. The participant questionnaire can be found in Appendix C.

6.2 Abstract[9]

Evidence suggests that multiple factors affect implementation of school-based physical activity interventions. This survey study examined the factors that influence the provision of classroom-based physical activity to students in the early years of primary school in Australia. A social ecological approach guided questionnaire design and analysis. A 45-item online questionnaire was administered to Australian classroom teachers and assistant, deputy and school principals working with students in Prep/Kindergarten to Year 2. Descriptive analysis determined response frequencies and content analysis was used to identify common themes in open-ended responses. The survey response rate was 22%; 34 of the 75 participants answered at least 93% of the survey questions. Barriers to providing classroom-based physical activity include: insufficient time, limited training opportunities, limited resources, educator attitudes to physical activity, and their confidence. Proposed strategies to overcome barriers include the provision of training and resources to improve educator knowledge of the benefits of classroom-based physical activity for children's health and learning, and to improve their confidence in delivering classroom-based physical activity. Creating a supportive school culture towards physical activity through implementation of whole-of-school physical activity policies is recommended. Overall, the results of this study suggest that multiple strategies, targeted at the individual (i.e., educator) and organisational (i.e., school) levels, may be necessary to enable Australian schools to overcome perceived barriers to providing physical activity opportunities to students in the early years of school during class time. Findings from this research elucidate how Australian schools may be best supported to implement classroom-based physical activity programs, as part of a whole-of-school approach to physical activity promotion.

[9] The format of this abstract has remained consistent (i.e., unstructured) with those of the journal for which it was published

6.3 Background

The benefits of participation in regular physical activity (PA) for the physical and mental health of children and adolescents is widely reported in the literature.[20,82] However, low levels of PA continue to be reported globally.[253] In Australia, for example, current trends suggest that children and adolescents are not achieving the recommended levels of PA required for optimal health, with figures showing a concomitant decline in Australian children's aerobic and muscular fitness.[16,254] In addition, low levels of mastery over movement skills (e.g., object control and locomotor skills) have been reported in girls and boys by Grade 6.[254] Thus, identifying opportunities for children and adolescents to achieve the recommended 60 min of moderate-to-vigorous levels of PA each day is becoming increasingly important not only for their fitness and movement skill development, but also in the prevention of chronic disease.[21]

Schools are ideally positioned to establish health-promoting environments by providing multiple opportunities for students to be active each day. This may include providing PA opportunities before school, during school class time, during recess and lunch breaks; and after school, in addition to the inclusion of a regular physical education (PE) program.[138,139] This whole-of-school approach to PA promotion is known as a comprehensive school physical activity program (CSPAP).[138] The widespread implementation of CSPAPs in Australian schools is a key recommendation recently proposed to address rising concern over the PA trends of Australian children and adolescents.[16]

One approach for increasing students' activity levels during the school day, that may also improve educational outcomes, is scheduling active lessons and breaks during school class time, commonly known as classroom-based physical activity.[46,139,146] Classroom-based PA differs from PE and recess or lunch breaks in that it involves integrating movement into academic lessons or scheduling movement breaks during school class time, with or without an academic focus.[46,146] Preliminary findings from studies evaluating classroom-based PA interventions are favourable, with beneficial effects reported for both PA-related outcomes (e.g., motor skills, aerobic fitness and PA levels) and educational outcomes (e.g., improved academic performance, on-task behaviour).[43,45,46] However, evaluation of the practicalities of implementing classroom-based PA interventions in 'real-world' contexts is also essential to determine whether interventions can be successfully reproduced and sustained.[255] In fact, there is strong empirical evidence to suggest that multiple factors affect the implementation of health promotion and preventive interventions, including school-based PA interventions.[51,140]

A growing number of studies have investigated the various factors that may enable or hinder classroom teachers from implementing classroom-based PA programs during the school day.[256,257] A recently published systematic review by Michael et al.[258] synthesised the findings from 28 studies investigating facilitators and barriers to integrating movement in elementary classrooms. Findings revealed that factors influencing movement integration in elementary schools occurred primarily at the institutional (i.e., the school level) and intrapersonal (i.e., exist within the teacher) levels of a social ecological framework.[258] Factors influencing the implementation of movement opportunities at the interpersonal, community and public policy levels have been described less often,[51,258] which may be due to the fact that perspectives from classroom teachers, and not others, have been most frequently reported in the literature.

To date, the majority of studies investigating factors influencing the implementation of classroom-based PA interventions in the primary school setting have been conducted in North America, Europe and the United Kingdom (see review by Michael et al.[258]). A limited number of studies have been conducted in Australia across Prep/Kindergarten to Year 6[259,260] and Years 3 to 5.[261,262] However, in Australia, curriculum pressures and demands may differ across year levels of primary school. For example, national testing of numeracy and literacy in Australian schools commences in Year 3. Given that primary schools are in a position to positively influence children's PA behaviour as they commence school and that increased curriculum pressures associated with standardised testing commence in Year 3, this study focusses on the early years of primary school in Australia (i.e., Prep/Kindergarten to Year 2). Therefore, the aim of this study was to examine factors that influence the provision of classroom-based PA to students in the early years of primary school in Australia, within a social-ecological framework. Understanding the factors that may influence the implementation of classroom-based PA in the Australian context will allow for a more targeted approach to support for schools.[51]

6.4 Methods

6.4.1 Study design and participants

This study employed a cross-sectional survey design, using an online questionnaire to collect data from participants using Qualtrics software.[263] Study participants included Australian primary school staff who would be involved in the development, implementation and evaluation of classroom-based PA programs with students in the early years of primary school, if such PA programs were implemented at their school. Specifically, participants were eligible for inclusion in the study if they self-reported that they: (i) held an accredited teaching qualification; (ii) were eligible to work in Australian public, independent and/or Catholic primary schools; *and* (iii) taught the Foundation to Year 2 Australian Curriculum to students; *or* (iv) had responsibility as a school principal, deputy or assistant principal to supervise/oversee the delivery of the Foundation to Year 2 Australian Curriculum at their school. Ethics approval was obtained from the Bond University Human Research Ethics Committee (Protocol number KM03093). Research approval was also granted by the State Education Research Approval Process (Reference number: 2019177), the Queensland Department of Education (Reference number: 550/27/2157) and the ACT Education Directorate (Reference number: RES-1910).

6.4.2 Recruitment

Recruitment of participants occurred across two phases. Firstly, a Facebook page dedicated to the research study was created as a forum through which to invite eligible participants to complete the online questionnaire. This initial phase took place between February and March 2019. Secondly, following research approval from selected school jurisdictions, principals from primary schools in south east Queensland (n = 30), northern New South Wales (n = 3) and the Australian Capital Territory (n = 3) were invited via email to involve their school in the study. This second phase of recruitment occurred between June and September 2019. The school principals were known to the research team through existing professional networks. Following gatekeeper approval, an invitation to participate in the online questionnaire was circulated by the school principal to eligible staff members from the corresponding primary school. Prior to completion of the online questionnaire, prospective participants were required to confirm that they (i) met the eligibility requirements; (ii) had read and understood the participant information sheet and consent form; and (iii) provided their consent to take part in the questionnaire. All responses were anonymous.

6.4.3 Theoretical framework underpinning the questionnaire

Following a review of the relevant empirical literature, a social ecological approach was chosen as the theoretical framework through which to examine the contextual factors that may influence the provision of classroom-based PA to students in the early years of primary school.[51,140,257] A social ecological framework can be used to gain a comprehensive understanding of the factors that influence behaviour at the individual, interpersonal, organisation, community and public policy levels.[141,142] As such, a social ecological model takes into consideration not only the attributes of an individual, but also the social and environmental factors that may facilitate or inhibit the behaviour of an individual.[143,264]

6.4.4 Questionnaire

The online questionnaire was comprised of four main sections encompassing 45 items, including: Section 1 - Demographic information (7 items); Section 2 - Current use of classroom-based PA with students in Prep/Kindergarten to Year 2 in Australian primary schools (17 items); Section 3 - The factors which may influence the ability and/or willingness of primary school staff to provide PA opportunities to students in the classroom (19 items); and Section 4 - Major barriers for providing classroom-based PA to students in Prep/Kindergarten to Year 2 and suggestions for overcoming major barriers (2 items).

Section 1 of the questionnaire included information regarding the geographical location of the participants' school, the type of primary school (i.e., public, independent, Catholic), their number of years of teaching experience, whether their school had a CSPAP policy in place, and the participants' role/year level at the school.

Section 2 of the questionnaire included questions regarding whether participants had completed professional development (PD) and/or training on classroom-based PA and whether they currently provided classroom-based PA to students. At the beginning of this section, key definitions were provided for the terms PA, classroom-based PA, physically active lessons and PA breaks. A clear statement outlining that classroom-based PA is distinct from scheduled PE lessons was also provided. Participants were then asked about the frequency and methods of classroom-based PA utilised (e.g., physically active lessons vs PA breaks). For each method, participants were asked which key learning areas of the Foundation to Year 2 Australian Curriculum they incorporated active lessons into, along with how much time they allocated (in minutes), the types of PA (e.g., gross motor skills, cardiorespiratory fitness / strengthening/ flexibility activities) and the locations in which the PA occurred.

Section 3 of the questionnaire sought feedback from participants regarding 19 individual factors that may influence the ability of school staff to provide classroom-based PA to students in Prep/Kindergarten to Year 2. The factors included in Section 3 have been previously identified in the literature as potentially impacting the implementation process of health promotion and preventative interventions, including school-based PA interventions.[51,140] Participants were specifically asked whether they perceived these factors as barriers, facilitators or felt neutral about their influence, from the perspective of their role as a classroom teacher or principal. The 19 factors were categorised into four of the five levels within a social ecological framework; including (i) individual factors (i.e., staff beliefs and skills); (ii) interpersonal factors (i.e., relating to students and peers); (iii) organisational factors (i.e., school administration, environment, training/resources); and (v) public policy (i.e., state and national PA policies). Participants rated each factor in this section using a five-point Likert scale. Response options for each factor included 1 = strong barrier, 2 = barrier, 3 = neither, 4 = facilitator and 5 = strong facilitator.

Finally, Section 4 of the questionnaire included two open-ended questions, adapted from previous studies on this topic.[256,257] The purpose of the open-ended questions was to gain a deeper understanding of the main barriers that would influence the ability and/or willingness of staff at their school to provide classroom-based PA to students in Prep/Kindergarten to Year 2, along with any suggestions for overcoming these major barriers. Common themes from responses to open-ended questions were coded and categorised using content analysis, as described further below.[265]

The questionnaire was initially piloted with two primary school staff, including a specialist primary PE teacher and a classroom teacher to ensure questionnaire readability, relevance, clarity and validity.[266] The original questionnaire included six sections and 60 items. Based on feedback received during this pilot process, the questionnaire was modified and reduced to four sections and 45 items. To minimise the time requirement of the questionnaire, two sections were removed regarding the school PE program and school recess/lunch breaks, so that the focus was on classroom-based PA. Additionally, three items were removed regarding participants' perceptions of the proposed benefits of classroom-based PA for the health and learning outcomes of school students and the frequency of classroom-based PA. Finally, the Likert scale in Section 3 was modified from 7-points to 5-points. As proposed by Fink,[266] the responses to the pilot questionnaire were compared to the intended scope of the research questions in order to inform revisions that would maximise the external validity of the topics covered and the results generated.

6.4.5 Statistical analysis

Survey response rates were calculated based on methods recommended by the Institute for Social and Economic Research[267] and the American Association for Public Opinion Research[268] (rate definitions and formulae are provided in Table S5). Survey completion rates represented the percentage of respondents who completed (i.e., ≥ 93% of questionnaire answered) or partially completed (41-92% of questionnaire answered) the questionnaire, or where 'break-off' occurred (< 41% of questionnaire answered) in relation to the number of questions asked. For the first phase of recruitment, the number of people who received the invitation to participate in the questionnaire (eligibility unknown) was estimated using the metrics displayed on the study Facebook page dedicated to the present research study. The metrics included information on how many people had been reached, along with how many times the link to the questionnaire in the Facebook post had been clicked. As it was not possible to ascertain how many of the people who received notification about the questionnaire read it or thought they may be eligible to complete the questionnaire, the number of times the link to the questionnaire in the Facebook post was clicked was therefore used in subsequent calculations to represent the number of people who received the invitation to participate in the questionnaire (eligibility unknown) via social media. For the second phase of recruitment, the school cooperation rate, decline rate and non-contact rate were also calculated (see Table S5 for rate definitions and formulae).[268] The estimated number of emails distributed to school staff inviting them to participate was calculated based on the number of Prep/Kindergarten to Year 2 classroom teachers and assistant, deputy and school principals at each cooperating school.

Descriptive statistics were calculated for responses to all questions in Sections 1 to 3, and included (i) frequencies (%) for categorical data; and (ii) means and standard deviations (SD) for interval data.[230] For Section 3 data, calculation of frequencies (%) was based on a simplification of the 5-point Likert scale to a 3-point scale encompassing: facilitator (combining the 'strong facilitator' and 'facilitator' options), barrier (combining the 'strong barrier' and 'barrier' options) and neither. Using an inductive content analysis process, responses to open-ended questions in Section 4 were organised, coded, categorised and grouped into themes.[265] Themes were subsequently categorised into corresponding levels of the social ecological framework. To assist with the content analysis process, NVivo (Version 12) software program was used.[269] A second author reviewed the responses to open-ended questions and verified major themes and categories, with any differences resolved by discussion and consensus.

6.5 Results

6.5.1 Survey completion and response rates

Survey completion and response rates across the recruitment phases are summarised in Table 19.

Table 19: Summary of survey completion and response rates across the recruitment phases.

	Phase 1 (recruitment via social media)	**Phase 2 (recruitment via schools)**	**Total (recruitment via phase 1 and phase 2)**
Number of school principals invited (Phase 2)	N/A	*n* = 36	N/A
School cooperation rate	N/A	11% (*n* = 4)	N/A
School decline rate	N/A	3% (*n* = 1)	N/A
School non-contact rate	N/A	86% (*n* = 31)	N/A
Number of participants who received invitation	*n* = 142	*n* = 52	*n* = 194
Number of participants who commenced questionnaire	*n* = 61	*n* = 14	*n* = 75
Survey completion rate	46% (*n* = 28)	43% (*n* = 6)	45% (*n* = 34)
Survey partial completion rate	10% (*n* = 6)	14% (*n* = 2)	11% (*n* = 8)
Survey break-off rate	44% (*n* = 27)	43% (*n* = 6)	44% (*n* = 33)
Survey response rate	24%	15%	22%

(see Table S5 for rate definitions and formulae)

The survey response rate for the first phase of recruitment via social media, reflecting the proportion of the original 142 people who clicked on the survey Facebook post and subsequently completed or partially completed the survey, was calculated as 24%. The survey response rate for the second phase of recruitment, reflecting the proportion of the 52 invitees who completed or partially completed the survey, was calculated as 15%. The survey response rate across both phases of recruitment combined was calculated as 22%.

Review of data sets for the eight respondents who only partially completed the survey revealed that they had each only completed demographic questions and a few other questions, so that their data did not usefully inform the survey. On this basis, data from those eight partial survey responses were excluded from the further analyses reported below, leaving only data from the 34 respondents who completed at least 93% of the survey questions to be analysed, and so only these data are reflected in the results reported in subsequent sections.

6.5.2 Participant demographics

The demographic characteristics of participants included in the study, for the total sample and separately for classroom teachers and school principals are summarised in Table 20. The mean number of years of teaching experience reported by the 34 included participants was 19.41 ± 12.06 years (range 2-44 years). The majority of these participants (77%: *n* = 26) were classroom teachers, with the remaining participants having responsibility as either a school principal, deputy or assistant principal (23%: *n* = 8) to oversee the delivery of the Foundation to Year 2 Australian Curriculum at their school. The majority of participants worked at schools located on the east coast of Australia, including New South Wales (29%: *n* = 10), Queensland (29%: *n* = 10) and Victoria (21%: *n* = 7). Participants reported they worked at primary schools primarily located within major cities (38%: *n* = 13) or small regional areas (35%: *n* = 12). The majority of participants (79%: *n* = 23) worked at public schools. Only 41% (*n* = 14) of the participants reported they currently had a CSPAP in place at their school. Just under half the participants (47%: *n* = 16) reported having received professional development (PD) and/or training regarding the different methods of classroom-based PA (see Table S6). Participants reported having completed a mean of 24.75 ± 27.27 h (range 3-100 h) of PD/training in this topic area.

Table 20: Demographic characteristics of included participants, for total sample, classroom teachers and school principals.

Characteristic	Total (*n* = 34) Frequency (%)	Classroom teachers (*n* = 26) Frequency (%)	School principals (*n* = 8) Frequency (%)
Mean (SD) years of teaching experience	19.41 (12.06)	18.65 (12.31)	21.88 (11.66)
State/Territory			
Queensland	10 (29.4)	9 (34.6)	1 (12.5)
New South Wales	10 (29.4)	7 (26.9)	3 (37.5)
Victoria	7 (20.6)	5 (19.2)	2 (25)
South Australia	2 (5.9)	1 (3.8)	1 (12.5)
Western Australia	0 (0)	0 (0)	0 (0)
Australian Capital Territory	3 (8.8)	2 (7.7)	1 (12.5)
Northern Territory	2 (5.9)	2 (7.7)	0 (0)
Tasmania	0 (0)	0 (0)	0 (0)
Geographical location			
Major city	13 (38.2)	9 (34.6)	4 (50)
Large regional area	5 (14.7)	3 (11.5)	2 (25)
Small regional area	12 (35.3)	11 (42.3)	1 (12.5)
Remote area	2 (5.9)	1 (3.8)	1 (12.5)
Very remote area	2 (5.9)	2 (7.7)	0 (0)
School type			
Public	27 (79.4)	19 (73.1)	8 (100)
Catholic	3 (8.8)	3 (11.5)	0 (0)
Independent	3 (8.8)	3 (11.5)	0 (0)
Other	1 (2.9)	1 (3.8)	0 (0)
CSPAP			
No	14 (41.2)	11 (42.3)	3 (37.5)
Yes	14 (41.2)	12 (46.2)	2 (25)
Unsure	6 (17.6)	3 (11.5)	3 (37.5)
School role			
Classroom teacher	26 (76.5)		
Assistant principal	4 (11.8)		
Deputy principal	2 (5.9)		
School principal	2 (5.9)		
Year Level*			
Prep/Kindergarten	16		
Year 1	23		
Year 2	17		

CSPAP: comprehensive school physical activity program; School principals refers to assistant, deputy and school principals; SD: standard deviation.
*Participants could choose multiple response options and therefore frequencies do not add up to n=34

6.5.3 Current trends in classroom-based physical activity

The majority of participants who listed their role as classroom teacher (88%: *n* = 23) and school principal (75%: *n* = 6) reported current delivery of classroom-based PA to students at their school (additional data are provided in Table S6). The majority of participants delivered classroom-based PA at least three times per week, and this was consistent across all three year levels. Participants also reported using a combination of different methods of classroom-based PA, with physically active lessons most often integrated into the key learning areas of Health and Physical Education (which includes a theoretical component regarding health and wellbeing, and a practical component where students are provided with movement opportunities), mathematics and English. Physically active lessons typically lasted for 30 min or less and included a combination of motor skill, aerobic and flexibility activities and were undertaken inside the classroom or in the playground. Participants reported that PA breaks typically lasted 10 min or less, were predominantly delivered inside the classroom and also included a combination of motor skill, aerobic and flexibility activities. Participants reported they would be likely to continue to deliver both physically active lessons and active breaks (with and without an academic focus) in the future.

6.5.4 Factors influencing the provision of classroom-based physical activity

The responses reported by participants regarding the factors (barriers/facilitators) that may influence the provision of classroom-based PA programs to students in Prep/Kindergarten to Year 2 are outlined in Table 21. The majority of participants perceived factors categorised at the individual and public policy levels of the social ecological framework as facilitators to providing classroom-based PA (Table 21). However, in contrast to five of their peers and two-thirds of the classroom teachers who perceived their competence to plan and deliver classroom-based PA as a facilitator, three principals perceived their competence in this area as a barrier.

Table 21: Factors (barriers/facilitators) that may influence the provision of classroom-based PA programs to students in Prep/Kindergarten to Year 2.

Factors (categorised within levels of the social ecological framework)	Perceived as a barrier Frequency (%)			Perceived as a facilitator Frequency (%)			Perceived as neither barrier nor facilitator Frequency (%)		
	Total sample	CT	SP	Total sample	CT	SP	Total sample	CT	SP
Individual (intrapersonal) level									
Personal/professional									
Your perception of the need to provide CBPA at your school (*n* = 34)	3 (8.8)	2 (7.7)	1 (12.5)	**26 (76.5)**	**21 (80.8)**	5 (62.5)	5 (14.7)	3 (11.5)	2 (25)
Your perception of the benefits of providing CBPA at your school (*n* = 32)	2 (6.3)	1 (4.2)	1 (12.5)	**28 (87.5)**	**21 (87.5)**	**7 (87.5)**	2 (6.3)	2 (8.3)	0 (0)
Your perceived competence (self-efficacy) to plan and deliver CBPA at your school (*n* = 33)	7 (21.2)	4 (16)	**3 (37.5)**	**22 (66.7)**	**17 (68)**	5 (62.5)	4 (12.1)	4 (16)	0 (0)
Interpersonal level									
Student									
Disruptive student behaviour during or following CBPA (*n* = 34)	11 (32.4)	8 (30.8)	3 (37.5)	7 (20.6)	5 (19.2)	2 (25)	**16 (47.1)**	**13 (50)**	**3 (37.5)**
Improvement in student engagement during or following CBPA (*n* = 33)	2 (6.1)	2 (8)	0 (0)	**29 (87.9)**	**21 (84)**	**8 (100)**	2 (6.1)	2 (8)	0 (0)
Ability for all students with additional support/learning needs to participate in CBPA (*n* = 32)	5 (15.6)	4 (16.7)	1 (12.5)	20 (62.5)	14 (58.3)	**6 (75)**	7 (21.9)	6 (25)	1 (12.5)
Peer									
Attitudes and beliefs from peers towards CBPA at your school (*n* = 34)	8 (23.5)	5 (19.2)	**3 (37.5)**	17 (50)	13 (50)	4 (50)	9 (26.5)	8 (30.8)	1 (12.5)
Ability for staff to participate in peer observation of CBPA (*n* = 32)	4 (12.5)	1 (4.2)	**3 (37.5)**	18 (56.3)	13 (54.2)	5 (62.5)	10 (31.3)	**10 (41.7)**	0 (0)
Ability for staff to share ideas and resources for CBPA with colleagues (*n* = 32)	4 (12.5)	2 (8.3)	2 (25)	21 (65.6)	**16 (66.7)**	5 (62.5)	7 (21.9)	6 (25)	1 (12.5)
Organisational (institutional) level									
School administration									
Having sufficient time to schedule CBPA into the regular routine (*n* = 33)	**18 (54.5)**	**11 (44)**	**7 (87.5)**	12 (36.4)	11 (44)	1 (12.5)	3 (9.1)	3 (12)	0 (0)
Having a supportive school climate (including support from administration) (*n* = 32)	7 (21.9)	6 (25)	1 (12.5)	21 (65.6)	15 (62.5)	**6 (75)**	4 (12.5)	3 (12.5)	1 (12.5)
Compatibility of CBPA with school values (*n* = 32)	5 (15.6)	5 (20.8)	0 (0)	**22 (68.8)**	**16 (66.7)**	**6 (75)**	5 (15.6)	3 (12.5)	2 (25)
School environment									
The amount of space available inside the classroom (*n* = 33)	**15 (45.5)**	**11 (44)**	**4 (50)**	13 (39.4)	10 (40)	3 (37.5)	5 (15.2)	4 (16)	1 (12.5)
The amount of space available outside in the playground (*n* = 32)	7 (21.9)	7 (29.2)	0 (0)	**22 (68.8)**	**16 (66.7)**	**6 (75)**	3 (9.4)	1 (4.2)	2 (25)
Training / support									
The provision of PD/training to staff to ensure they have the necessary knowledge & skills to provide PA opportunities in the classroom (*n* = 33)	10 (30.3)	6 (24)	**4 (50)**	20 (60.6)	16 (64)	4 (50)	3 (9.1)	3 (12)	0 (0)
Availability of quality resources, including examples of developmentally appropriate methods of CBPA (*n* = 32)	9 (28.1)	7 (29.2)	2 (25)	18 (56.3)	14 (58.3)	4 (50)	5 (15.6)	3 (12.5)	2 (25)
Public policy level									
Policy									
Reading an evidence-based research article from an esteemed educational journal that describes how PA may enhance children's learning (*n* = 33)	1 (3)	1 (4)	0 (0)	**25 (75.8)**	**19 (76)**	**6 (75)**	7 (21.2)	5 (20)	2 (25)
Awareness and knowledge of Australia's Physical Activity and Sedentary Behaviour Guidelines that recommend children aged 5-12 years should accumulate at least 60 min of MVPA every day (*n* = 32)	2 (6.3)	2 (8.3)	0 (0)	**24 (75)**	**18 (75)**	**6 (75)**	6 (18.8)	4 (16.7)	2 (25)
Awareness and knowledge of Australia's National Physical Activity Policy recommending that primary schools provide students with 120 to 150 min of PE and organised physical activity each week (*n* = 29)	4 (13.8)	3 (13.6)	1 (14.3)	19 (65.5)	**16 (72.7)**	3 (42.9)	6 (20.7)	3 (13.6)	**3 (42.9)**

CBPA: classroom-based PA; CT: classroom teacher (*n* = 26); MVPA: moderate to vigorous physical activity; PD: professional development; PE: physical education; SP: assistant, deputy or school principal (*n* = 8); Barrier (bold represents >33% responses were perceived as a barrier), Facilitator (bold represents > 66.6% responses were perceived as a facilitator), Neither barrier nor facilitator (bold represents > 33.3% responses were perceived as neither barrier nor facilitator

At the interpersonal level of the social ecological framework, the strongest facilitator of classroom-based PA reported by participants was observing an improvement in student engagement during or following classroom-based PA. The ability for staff to share ideas and resources for classroom-based PA and the ability for students with additional support/learning needs to participate in classroom-based PA were also largely perceived as facilitators. Just over half the total participants listed attitudes and beliefs from their peers towards classroom-based PA (n = 17) and the ability to participate in peer observation (n = 18) as facilitators. However, three principals listed these latter factors as barriers. Almost half of participants (n = 16) listed observing disruptive student behaviour as neither a barrier nor a facilitator, while a third of participants (n = 11) listed disruptive student behaviour as a barrier.

Organisational level factors including having a supportive school climate, compatibility of classroom-based PA with school values and the amount of space available outside in the playground were predominantly perceived as facilitators. However, participant responses regarding other organisational level factors were mixed, including having sufficient time to schedule classroom-based PA into the regular routine, the amount of space available inside the classroom, the provision of training, and availability of resources. For example, having sufficient time and space inside the classroom were identified as barriers (n = 18, n = 15, respectively) more frequently than as facilitators (n = 12, n = 13, respectively). However, the provision of training and availability of quality resources were identified more frequently as facilitators (n = 20, n = 18, respectively) than as barriers (n = 10, n = 9, respectively).

Responses from principals and classroom teachers were on the whole very similar. However, from the perspective of principals, having sufficient time to schedule classroom-based PA into the regular routine was the strongest barrier to providing classroom-based PA, with the amount of space available inside the classroom and provision of PD/training also perceived as barriers by half (n = 4) of school principals. The perceived benefits of classroom-based PA and observed improvements in student engagement were the strongest facilitators reported by principals.

6.5.5 Major barriers for providing classroom-based physical activity and proposed solutions

A total of 28 of the 34 participants answered the open-ended survey question regarding major barriers to implementing classroom-based PA and 24 of them offered potential solutions. A total of seven themes emerged for the major barriers identified by participants for providing classroom-based PA to students in the early years of primary school (Table 22).

Table 22: Themes of major barriers for providing classroom-based PA and proposed solutions.

Theme	Social ecological level	References (Total) (*n* = 28)	References (CT) (*n* = 20)	References (SP) (*n* = 8)
Barriers (*n* = 28)				
Insufficient time	Organisational	24	17	7
Staff attitudes, knowledge, beliefs	Individual	16	11	5
Lack of training, resources, equipment	Organisational	14	10	4
Lack of space inside classroom	Organisational	7	5	2
Student characteristics	Interpersonal	4	3	1
School ethos	Organisational	5	4	1
School policy	Organisational	2	2	0
No barriers		2	1	1
Weather		1	1	0
Proposed solutions (*n* = 24)				
Provision of training and resources	Individual, organisational	16	11	5
Scheduling CBPA into regular routine	Organisational	9	4	5
Administration support	Organisational	7	5	2
School PA policies	Organisational	5	5	0
Funding	Organisational	3	2	1
Engaging with parents/community	Community	3	1	2
Collaboration with peers	Interpersonal	3	2	1
Access to facilities	Organisational	2	2	0
No solution suggested		1	1	0

CBPA: classroom-based PA; CT: classroom teacher; SP: assistant, deputy or school principal

Five themes were categorised as organisation-level factors, including:

(i) insufficient time (*n* = 24 references):

'Time would be seen as a barrier with pressures of curriculum unfortunately.' (Participant 23).

(ii) lack of training, resources and equipment (*n* = 14 references):

'*Not having adequate resources easily accessible or organised'* (Participant 2).

(iii) lack of space inside the classroom (*n* = 7 references).

(iv) school ethos (*n* = 5 references):

'*NAPLAN focus; Academic results focus; school ethos for academic excellence only'* (Participant 25); and

(v) school policies (*n* = 2 references).

One theme was categorised as an individual-level factor, and related to staff attitudes, knowledge, beliefs and confidence (*n* = 16 references):

'*Knowledge and awareness of the evidence of the benefits of physical activity for children'* (Participant 2).

One final theme was categorised as an interpersonal-level factor and related to student characteristics, including disruptive behaviour (*n* = 4 references). Themes relating to major barriers were consistent between classroom teachers and principals.

A total of eight themes emerged for solutions proposed by participants for overcoming the major barriers identified for providing classroom-based PA to students in the early years of school. Six themes were categorised as organisation-level solutions, including:

(i) the provision of training, resources and equipment relating to classroom-based PA (*n* = 16 references):

'*Providing readings and data related to the benefits of physical activity and the links with student engagement. If executive staff can see the link with engagement they are more likely to consider this encouragement and support'* (Participant 27);

(ii) scheduling classroom-based PA into the regular routine (*n* = 9 references):

'*Make it a routine; Live life well @ school initiatives; make a school culture of health, nutrition and physical activity'* (Participant 11).

(iii) administration support (*n* = 7 references):

‘*Administrators to model 'in class' physical activity when conducting staffroom in services; Talk the talk encourage and support any increased activity for staff and students. Promote whole school fitness*’ (Participant 3);

(iv) school PA policies (*n* = 5 references):

‘*National curriculum requirement that has all children engage in classroom physical movement/kinaesthetic activities for 60 minutes every day built into the daily timetable’* (Participant 25).

(v) funding (*n* = 3 references); and

(vi) access to facilities (*n* = 2 references).

One participant shed light on the impact that school policy and education/training may have on minimising perceived barriers:

‘*We are required to provide children with physical activity on a daily basis, so there are no barriers as it is a requirement’. ‘We aim to engage in a movement break every 20 minutes. This approach was recommended to me by a physiotherapist I worked with and is also supported by the occupational therapists. This is supported by evidence-based research. When children are provided with regular opportunities to move, it increases their focus and concentration, therefore having a positive impact on their learning’* (Participant 13).

Another solutions theme, collaboration with peers, related to interpersonal-level factors:

‘*Mentoring from confident skilled staff. Sharing best practice. Cooperative planning’* (Participant 10).

One final theme related to community level factors was the suggestion to engage with parents/communities by increasing their awareness of the benefits of school PA programs (*n* = 3 references):

‘getting the community on board’ (Participant 27).

6.6 Discussion

The aim of this study was to examine factors that influence the provision of classroom-based PA to students in the early years of primary school in Australia, within a social ecological framework. Based on self-report data from the participant sample, there was evidence to suggest that, at the time of this study, classroom teachers in Australia were providing some PA opportunities to students in Prep/Kindergarten to Year 2 during school class time, including both physically active lessons and PA breaks. However, variability in the frequency, duration, and type of PA included in active lessons and breaks was evident.

Overall, the factors that participants reported as influencing the provision of classroom-based PA to students in the early years of primary school related primarily to the organisational level (i.e., occur at school level) and individual level (i.e., exist within the participant themselves) of influence within a social ecological framework. However, several other factors, relating to the interpersonal, community, and public policy levels of influence, were also highlighted. These findings are important as they suggest that multiple strategies, particularly targeted at the individual and organisational levels, may need to be employed to support Australian schools in overcoming the perceived barriers that currently exist to providing PA opportunities to students in the early years of school during class time.

Findings from the present study revealed that Australian classroom teachers and assistant, deputy and school principals perceive organisational (or school) level factors, including insufficient time and a lack of training, resources and space to be the major barriers to providing classroom-based PA to students in the early years of school. These findings are in agreement with institutional barriers to movement integration in elementary classrooms identified in the systematic review by Michael et al.,[258] which also included time, availability of resources, space and administrative support.[258] However, findings reported in that review were from studies conducted predominantly in the United States. Several studies conducted in Australia[259-262] have also reported insufficient time as a major barrier to implementing classroom-based PA and this related to difficulties scheduling PA opportunities into the regular school class routine due to an already crowded curriculum. However, this is the first study to seek feedback from school staff regarding the factors influencing the provision of classroom-based

PA to children specifically in the early years of school in Australia. In contrast, knowledge of the factors (barriers/facilitators) influencing the provision of classroom-based PA to children in the early years of school identified in the present study can guide the design of future classroom-based interventions with these year groups.

The most commonly reported solutions for overcoming barriers at the organisation level reported by participants in the present study included the provision of training, resources and equipment, scheduling classroom-based PA into the regular school routine and having support from school administrators. This suggests that creating a school culture where PA promotion is valued and supported may be essential. Furthermore, school principals that perceive PA as being important for students' health and learning, may be in a position to influence the extent to which government PA policies are implemented and monitored in their individual schools.[270]

Individual level factors, including staff attitudes, knowledge, beliefs and confidence, were also perceived by participants in the current study to be influential barriers to providing classroom-based PA. The solution proposed by participants of providing training and resources to school staff may overcome these barriers. Given that participants reported that perceived need for and benefits of providing classroom-based PA were strong facilitators of implementation of classroom-based PA (in quantitative responses), this suggests that if school staff (teachers and principals) do not understand the value and benefits of classroom-based PA, they may be less likely to advocate for these opportunities to be provided. Therefore, providing school staff with evidence-based articles or training regarding the relationships between children's PA, health and learning may improve their knowledge of the rationale and benefits of classroom-based PA. This may be particularly important for school principals, given that in the current study it was this group that most strongly perceived the benefits of classroom-based PA to be a facilitator of classroom-based PA. In addition, the provision of training to school staff, that includes practical information on how to schedule classroom-based PA into the regular routine, along with examples and resources on classroom-based PA, may help to increase staff confidence. This may be a priority area in which to focus support, given that teacher confidence has been identified in several other studies as being an influential facilitator in determining whether movement opportunities will be provided to children throughout the school day.[258,259]

At the interpersonal level (i.e., student and peer factors), only one third of participants perceived observing disruptive student behaviour as a barrier to providing classroom-based PA, whereas almost half the participants reported perceiving it as neither a facilitator nor barrier. This finding is in contrast to other studies conducted in Australia where behavioural challenges with students in Prep/Kindergarten to Year 6 have been reported as a barrier for implementing short PA breaks into the school day.[260,261] Notably, one of the strongest facilitators for providing classroom-based PA (in quantitative responses) identified by participants in this study was observing an improvement in student engagement during or following classroom-based PA. This suggests that educating school principals and classroom teachers on the ability for classroom-based PA to result in improved education behaviours, such as student engagement, may be another key element of training.[258] Solutions aimed at improving staff collaboration, including sharing ideas and resources relating to classroom-based PA with peers, may also be useful.

Several participants made reference to the importance of engaging with the wider school community, which has been highlighted as a key component of a CSPAP.[138] Participants suggested that having assistance from external organisations to run school-based PA programs, along with increasing parents' awareness of the benefits of school PA programs would be beneficial in supporting schools to run such programs. The importance of educating families on the benefits of PA has previously been reported in the literature.[139]

The influence that public policy may have on the provision of classroom-based PA was also highlighted in this study. Participants reported that evidence-based readings and having knowledge and awareness of PA and sedentary behaviour guidelines, as well as national school PA and PE policies would be facilitators to providing classroom-based PA. The implementation of whole-of-school PA policies was also proposed by several participants. This suggests that teachers may be receptive to receiving more direction from school principals around the implementation and monitoring of school and national PA policies – an observation that has been reported in other studies examining this topic.[139,270]

6.6.1 Limitations

It is important to acknowledge a number of limitations to the present study. Firstly, a major limitation is that only a small number of participant responses were available for analysis. Therefore, given this small sample size, the study results are unable to be generalised to all school jurisdictions in Australia but may nevertheless usefully inform future research on this topic. It is worth noting the social ecological factors (facilitators/barriers) identified in the present study are consistent with those reported in studies conducted internationally[258] and in Australia.[259] Secondly, the majority of participants who self-reported they were classroom teachers were currently delivering classroom-based PA to students in Prep/Kindergarten to Year 2. Therefore, the perceived barriers and facilitators for providing classroom-based PA from classroom teachers that do not currently provide classroom-based PA in Australia remain largely unknown. However, study findings do provide insight from classroom teachers who have already tried and tested classroom-based PA and are thus able to provide realistic suggestions on overcoming barriers they may have encountered. Thirdly, the wording in Section 3 of the questionnaire may have been ambiguous to participants, and this may explain the mixed results, particularly in relation to training/support factors. However, it was possible to triangulate the responses provided in Section 3 with open-ended responses to gain a deeper understanding of the factors (facilitators and barriers) influencing the provision of classroom-based PA to students in the early years of school. In fact, during the qualitative content analysis process, there was evidence of having achieved data saturation in open-ended responses in that no new knowledge and/or themes emerged as the number of responses analysed increased.[271]

Although participants were provided with the definitions of classroom-based PA in the questionnaire, including that it is distinct from scheduled PE lessons, several participants ticked that they integrated movement into the key learning area health and physical education (HPE). Given that in Australia, HPE is considered a key learning area and comprises both theoretical and practical components, we are unable to be certain that participants meant that they incorporated movement into the theoretical component of the HPE subject, though the definitions provided to them at the start of the questionnaire make it most likely they were discussing classroom-based PA and not scheduled PE classes. One final limitation of this study was that although staff attitudes, knowledge and beliefs were identified as an important barrier in open-ended responses (Table 21), these attitudes and beliefs were not explored in any depth. Therefore, further exploration of classroom teacher beliefs regarding whether they believe increasing movement and/or reducing sedentary time during the school day may be beneficial to student learning outcomes and learning behaviours would be a valuable addition to future studies in this area.

6.7 Conclusion

The widespread implementation of whole-of-school approaches to PA promotion in Australian schools is a key recommendation made recently to address current trends of physical inactivity in Australian children and young people.[16,254] Providing students in the early years of primary school with opportunities to be active throughout the school day through the provision of classroom-based PA programs may be one way to optimise both PA-related and education outcomes. However, the findings of the present study suggest that multiple barriers exist for providing classroom-based PA to students in the early years of school in Australia. Key barriers that were identified included insufficient time, limited training opportunities and resources and individual school staff characteristics, including attitudes towards PA and confidence to implement the activities. To enhance the ability for primary school staff to provide classroom-based PA to students in the early years of school in Australia, strategies need to be implemented primarily at the individual (i.e., teacher/principal) and organisation (i.e., school) levels, whilst also considering the influence that government policies and families may have on this practice. Creating a school culture where school administrators value PA and implement whole-of-school PA policies that support scheduling PA opportunities into the regular routine may help to overcome identified barriers. The provision of training and resources should also be prioritised to improve staff knowledge regarding the benefits of classroom-based PA on children's PA, health, and learning as well as improve staff confidence in delivering such PA. Findings from this research will contribute to guiding how to best support Australian schools to implement classroom-based PA programs and may interest school staff and policy makers committed to implementing a whole-of-school approach to PA promotion.[10]

[10] Please note that all references in this chapter are presented in the References section of the thesis

Table S5: Survey completion and response rates: Rate definition and formulas.

Abbreviation	Definition
C	Completion rate. Number of completed surveys (≥ 93% of questionnaire answered)
DEC	Declined. The number of school principals that received the invitations but declined to participate
O	Other non-response
P	Partial completion rate. Number of partial surveys completed (41-92% of the questionnaire answered)
B	Break off rate. Number of surveys where 'break-off' occurred (less than 41% of questionnaire answered)
SAP	School agreed participation. The number of school principals that agreed to participate in the study
SNC	School non-contact. Following circulation of the invitation to school principals, no response was received
T_E	Emails distributed. The number of emails distributed to school staff, inviting them to participate in the questionnaire
T_L	Links clicked. The number of times the link to the questionnaire in the Facebook post was clicked
$T_L + T_E$	Total invitations distributed. The number of people who received the invitation to participate in the questionnaire (including links clicked via social media and emails distributed via school setting)

School cooperation rate

The school cooperation rate is the proportion of all school principals that were invited to involve their school in the study and agreed to involve their school.

$$\text{School cooperation rate} = \frac{SAP}{SAP + DEC + SNC}$$

$$\text{School decline rate} = \frac{DEC}{SAP + DEC + SNC}$$

$$\text{School non-contact rate} = \frac{SNC}{SAP + DEC + SNC}$$

Survey response rate

The percentage of respondents who completed or partially completed the survey in relation to the number invited to participate.

$$\text{Survey response rate (recruitment via social media)} = \frac{C + P}{T_L}$$

$$\text{Survey response rate (recruitment via schools)} = \frac{C + P}{T_E}$$

$$\text{Survey response rate (both phases of recruitment)} = \frac{C + P}{T_L + T_E}$$

Sources: Lynn et al.[267] and The American Association for Public Opinion[268]

Table S6: Current trends in classroom-based physical activity with students in the early years of primary school in Australia.

Item	Frequency (%)
Professional development	
No	17 (50)
Yes	16 (47.1)
Unsure	1 (2.9)
Source of PD training*	
None	18
Undergraduate program	5
Postgraduate program	2
Professional development (school)	9
Professional development (external provider)	13
PD hours completed (Mean ± SD, range)	24.75 ± 27.27 (range 3-100 hours)
Do you currently provide CBPA	
No	5 (14.7)
Yes	29 (85.3)
Frequency of CBPA delivered per week	
Prep/Kindergarten (*n* = 29)	
N/A	12 (41.4)
1-2 times	4 (13.8)
3-5 times	9 (31)
>5 times	4 (13.8)
Year 1 (*n* = 29)	
N/A	10 (34.5)
1-2 times	5 (17.2)
3-5 times	7 (24.1)
>5 times	7 (24.1)
Year 2 (*n* = 28)	
N/A	11 (39.3)
1-2 times	5 (17.9)
3-5 times	6 (21.4)
>5 times	6 (21.4)
Methods of CBPA* (*n* = 34)	
Physically active lessons	15
PA break (academic focus)	16
PA break (non-academic focus)	24
Other	1
Key Learning Areas*	
None	5
English	10
Mathematics	15
Science	2
Humanities	2
Arts	7
Technologies	1
Health & Physical Education	17
Languages	0

Item	Frequency (%)
Physically active lessons	
Duration (*n* = 29)	
Unsure	2 (6.9)
<10 min	11 (37.9)
11-20 min	7 (24.1)
21-30 min	6 (20.7)
31-40 min	1 (3.4)
41-50 min	2 (6.9)
Type of PA*	
None	6
Unsure	1
Motor skills	21
Cardio-respiratory fitness	24
Strengthening	12
Flexibility	19
Other	2
Location of PA*	
N/A	5
Unsure	2
Inside	25
Hallway	1
Playground	20
Other	5
Physical activity breaks	
Duration (*n* = 29)	
Unsure	1 (3.4)
None provided	1 (3.4)
1-5 min	9 (31)
6-10 min	13 (44.8)
11-15 min	3 (10.3)
16-20 min	1 (3.4)
26-30 min	1 (3.4)
Type of PA*	
N/A	5
None provided	2
Motor skills	21
Cardio-respiratory fitness	18
Strengthening	7
Flexibility	18
Other	2
Location of PA*	
N/A	5
Unsure	2
Inside	26
Hallway	0
Playground	13
Other	4
Future methods of CBPA likely to use	
Methods of CBPA*	
Physically active lessons	24
PA break (academic focus)	22
PA break (non-academic focus)	24
Other	3

Item	Frequency (%)
Key Learning Areas	
None	1
English	18
Mathematics	27
Science	12
Humanities	8
Arts	11
Technologies	3
Health & Physical Education	28
Languages	7

N = 34 unless otherwise specified
CBPA: classroom-based physical activity; PA: physical activity; PD: professional development
* Asterisk means that participants could choose multiple options for responses and therefore frequencies do not add up to *N* = 34

Chapter 7: Evaluation of a 12-week Classroom-Based Gross Motor Program Designed to Enhance Motor Proficiency, Mathematics and Reading Outcomes of Year 1 School Children: A Pilot Study

7.1 Preface

It was identified in *Stage 1 (problem definition)* of the thesis framework that a limited number of studies had evaluated the impact of classroom-based PA interventions, particularly motor skill interventions, on children's motor proficiency and academic outcomes **(Systematic review, Chapter 3)**. Findings from *Stage 2 (solution generation)* of the thesis framework sought to explore whether early primary school classrooms in Australia could be feasible settings to implement PA opportunities during class time and revealed that classroom-based PA may be a method that educators could potentially utilise to increase children's movement opportunities.

Stage 3 (solution testing) of the thesis framework aimed to specifically explore whether classroom-based motor skill programs could be utilised as a strategy to support children's motor proficiency and academic outcomes. The opportunity to conduct research alongside the Tweed Healthy Schools Project (THSP), a school-based participatory action project, formed the basis of *Stage 3* of the thesis framework. This meant that the proposed 'solution tested', a 12-week classroom-based gross motor program, was conducted with Year 1 children under real world conditions representative of the conditions in which solutions would be applied. As an exploratory study, the purpose was to evaluate a novel program conducted in a complex school environment that could potentially inform the design of a more robust, larger evaluation in the future. Noting the benefits of conducting the research in a real word context of the primary school setting, the constraints and limitations are acknowledged and discussed.

While the factors influencing the provision of classroom-based PA to students in the early years of primary school were explored with educators (Chapter 6), the 12-week program that was evaluated alongside the THSP was designed and delivered by a registered physiotherapist, with assistance from physiotherapy and exercise science university students, in collaboration with the classroom teachers. This approach allowed for less disruption to classroom teachers and aimed to inform the design of future studies, with a view to mitigate the barriers previously identified, including insufficient time, limited training opportunities and limited resources (Chapter 6). Given the health promoting schools framework recognises the importance of schools forming partnerships with the wider school community (i.e., 'community links & partnerships'), it provides a suitable framework for the involvement of allied health professionals in this study in supporting educators and schools to promote children's motor skill development and overall health and wellbeing.

The pilot study reported in this chapter was published in a peer-reviewed journal in 2021. The formatting of the original accepted manuscript has been amended to be consistent with the thesis style. Copyright permission has been obtained from the publisher and the citation for the published manuscript is as follows: http://link.springer.com/article/10.1007/s10643-021-01199-w

Macdonald K, Milne N, Pope R, Orr R. Evaluation of a 12-week classroom-based gross motor program designed to enhance motor proficiency, mathematics and reading outcomes of year 1 school children: a pilot study. *Early Child Educ J.* 2021; 1-12. doi: 10.1007/s10643-021-01199-w. Copyright © 2021. Reproduced with permission from Springer Nature.

Two supplementary tables are referred to as Table S7 and Table S8 within this chapter. These tables can be found at the end of the chapter. An additional supplementary table (Table S9) summarising the development of the 12-week classroom-based gross motor program can be found in Appendix D.

7.2 Abstract[11]

This study explored whether Year 1 school children exposed to a 12-week classroom-based gross motor program progressed differently to Year 1 children undertaking their regular school program in motor proficiency, mathematics and reading outcomes. Fifty-five Australian Year 1 school children (25 boys, 30 girls, mean age = 6.77±0.40 years) were exposed to either (i) their normal school program (Class N) or (ii) a 12-week program comprised of gross motor circuits and physically active: a) reading lessons (Class R) or b) mathematics lessons (Class M). Motor proficiency and academic performance in mathematics and reading were assessed using the Bruininks-Oseretsky Test of Motor Proficiency – 2nd Edition and the Wechsler Individual Achievement Test – 2nd Edition – Australian Standardised Edition, respectively. Differences in outcomes between classes following the 12-week program were assessed. Mean change scores for the mathematics composite were significantly greater for participants in Class R (9.61 ± 5.62, p = .001) and Class M (7.57 ± 5.79, p = .019) than for participants in Class N (0.76 ± 8.00). Mean change scores for reading (11.54 ± 7.51, p = .017) and total motor composites (6.12 ± 5.07, p = .034) were also significantly greater for participants in Class M than Class N (4.47 ± 3.50 and 0.82 ± 4.38, respectively). A 12-week classroom-based gross motor program may be beneficial for motor skill development and academic outcomes in Year 1 school children. This pilot evaluation may usefully inform future experimental studies to further investigate whether classroom-based motor skill programs have a beneficial effect on motor proficiency and academic outcomes in children in the early years of primary school.

[11] The format of this abstract has remained consistent (i.e., unstructured) with those of the journal for which it was accepted for publication.

7.3 Background

In response to rising concern over high levels of physical inactivity in children and young people globally, schools have been identified as ideal settings to positively influence children's physical activity (PA) behaviour.[138,139] During the early years of primary school, educators play an integral role in promoting the holistic development of children, including their ongoing physical development.[3] To facilitate children's motor skill development and promote positive attitudes towards PA, educators can provide opportunities for children to be active during the regular classroom routine.[138] However, several barriers to providing PA opportunities to primary school children have been previously identified including insufficient time due to competing academic demands and a busy classroom curriculum as well as limited access to training opportunities and resources.[131,258,272] Thus, given these barriers, educators may feel reluctant to incorporate movement opportunities into the school day. Yet, in addition to the well-established physical health and psychological benefits of PA,[82,85] cognition and academic performance have also been found to be positively associated with PA in children and adolescents.[30,34] The prospect that PA may be beneficial for children's health and learning may be of considerable interest to the public health and education sectors, however, further evidence is required to support a *causal* relationship between PA, cognition and academic performance in children.[34]

The provision of PA opportunities to students during the school day has been identified as a key component of whole-of-school approaches to PA promotion.[16,138,139] Classroom-based PA is one approach used to incorporate PA into the regular school routine and involves integrating movement into academic lessons (or physically active lessons) and/or scheduling PA breaks during regular class time with, or without, an academic focus.[138] In relation to classroom-based PA interventions, a growing number of experimental studies have reported a positive impact of physically active lessons on academic performance, including mathematics and reading outcomes.[42,218,273-275] Conversely, mixed findings have been reported by studies investigating the use of PA breaks in the classroom, without an academic focus, on academic performance.[30,46] There also appears to be considerable variability in the type of PA undertaken by students in classroom-based PA interventions, with programs involving aerobic activities, motor skill training, strength and/or flexibility training, or a combination of activities involving varying degrees of cognitive engagement.[227] The majority of classroom-based PA interventions reported in the literature have included predominantly aerobic or cognitively engaging aerobic activities, with fewer studies specifically evaluating the impact of cognitively engaging motor skill programs.[32,227]

Furthermore, while studies have typically investigated the effectiveness of classroom-based PA programs on children's overall PA levels,[44-46] few studies have investigated the impact of such programs on motor proficiency outcomes.[227] Given proficiency in movement skills may be associated with both health[9,89] and academic outcomes,[47,227] investigating motor proficiency as an outcome in classroom-based PA programs is warranted. Finally, studies investigating the impact of physically active lessons on academic outcomes have been primarily conducted with students in primary school years 2 to 6, with a limited number of studies conducted with students in the early years of primary school.[218,275] Therefore, the aim of this study was to explore whether Year 1 school children exposed to a 12-week classroom-based gross motor program comprised of gross motor circuit training and physically active reading or mathematics lessons progressed differently to Year 1 children undertaking their regular school program in motor proficiency, mathematics and reading outcomes.

7.4 Methods

7.4.1 Study design

This pilot study was conducted alongside the Tweed Healthy Schools Project (THSP), a school-based, interprofessional clinical placement program for university health professional students. The THSP was planned and initiated prior to the conceptualisation of this study and involved subsequent implementation of classroom-based gross motor skill activities into two separate Year 1 classes at one school. The present study was conceptualised because of the opportunity presented by the THSP for accompanying evaluation research. This study involved evaluating specific outcomes among children in the two Year 1 classes that participated in the THSP and in another Year 1 class at a separate but demographically similar school, which had not implemented the THSP and thus constituted a comparison class. On this basis, the present study was exploratory in nature, in which outcomes associated with exposure or non-exposure to THSP activities were evaluated in the form of a pilot study. Thus, it is important to acknowledge from the outset that a key limitation of the study design is that it was not possible to infer whether any differences that were observed between the three classes in academic performance and motor proficiency outcomes were due to the 12-week gross motor program. Rather, as an exploratory study, the purpose was to evaluate a novel program conducted in a complex school environment that could potentially inform the design of a more robust, larger evaluation in the future.[276]

7.4.2 Setting and study participants

The two schools from which participants were drawn were public primary schools in the northern region of New South Wales, Australia. All students enrolled in the three mainstream Year 1 classes (n = 64) were invited and eligible to participate in the study. Two of the three Year 1 classes were from one school and the other Year 1 class was from another but demographically similar school undertaking the same Year 1 Australian Curriculum.[246] Written parental consent was provided for 55 students (25 boys, 30 girls, mean age = 6.77±0.40 years, range 5.42-7.75 years) (Table 23). Since the THSP activities were implemented at a class level, independently of the study, the children whose parents did not provide consent received the same exposure to the 12-week classroom-based program as their classmates but did not participate in outcome testing for the study.

Table 23: Demographic profile of Year 1 study participants by class.

Characteristic		**Class N (*n* = 17) n (%)**	**Class R (*n* = 19) n (%)**	**Class M (*n* = 19) n (%)**
Sex	Boys	8 (47.1)	10 (52.6)	7 (36.80)
	Girls	9 (52.9)	9 (47.4)	12 (63.2)
Ethnicity (using BOT-2 classifications)	White	15 (88)	15 (79)	18 (95)
	Other	2 (12)	4 (21)	1 (5)
ICSEA	965	0 (0)	19 (100)	19 (100)
	1011	17 (100)	0 (0)	0 (0)

BOT-2: Bruininks-Oseretsky Test of Motor Proficiency – 2nd Edition; ICSEA: Index of Community Socio-Educational Advantage (ICSEA average = 1000)[229];
Class N: regular Year 1 class; Class R: gross motor circuit + physically active reading lessons; Class M: gross motor circuit + physically active mathematics lessons

Prior to being invited to participate in the study, all children were already enrolled in their pre-existing Year 1 school classes. These pre-existing classes had been allocated under normal school procedures (Class N) or the THSP (Classes R and M), and independent of the research, to be exposed to either (i) their normal Year 1 school program (Class N); or (ii) a 12-week classroom-based program comprised of gross motor circuit training (4x15 min/week) and gross motor activities integrated into: a) reading lessons (Class R) (4x10 min/week) or b) mathematics lessons (Class M) (3x15 min/week). Figure 14 depicts the flow of participants through the study. Ethics approval was obtained from the Bond University Human Research Ethics Committee (Protocol number: RO1836), and research approval was provided by the State Education Research Approval Process in New South Wales, Australia (Reference number: 2014075).

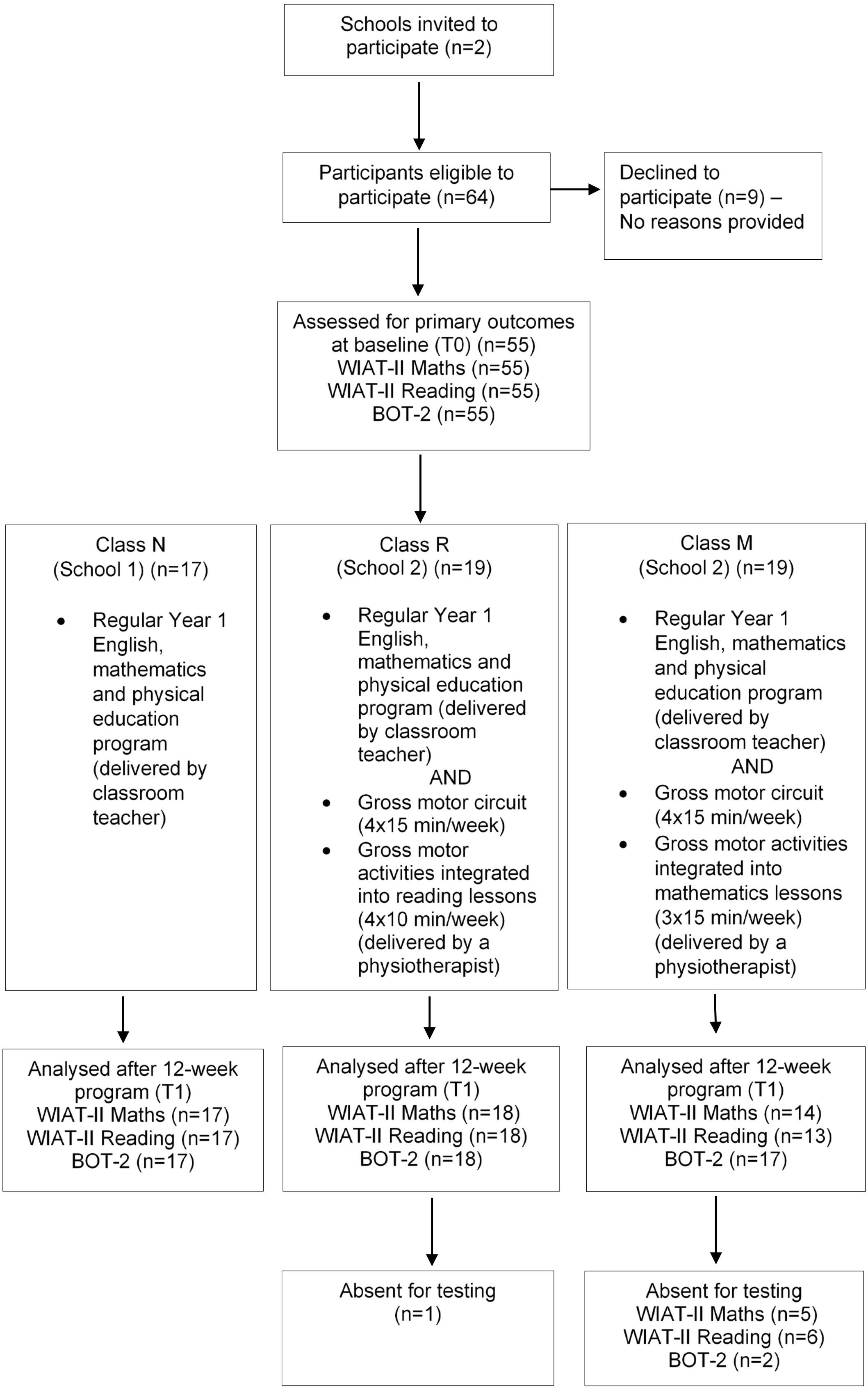


Figure 14: Flow of participants through study.

7.4.3 Outcome measures

7.4.3.1 Demographics

Age, sex, ethnicity, and school Index of Community Socio-Educational Advantage (ICSEA) were recorded for each participant (Table 22). Relevant medical history was also recorded for participants, based on questionnaires completed by each parent.

7.4.3.2 Motor proficiency

Motor proficiency was assessed using the Bruininks-Oseretsky Test of Motor Proficiency – 2nd Edition (BOT-2) Complete Form.[59] The BOT-2 is a standardised tool that measures the motor proficiency of people aged four to 21 years.[59] The BOT-2 is comprised of eight subtests (fine motor precision, fine motor integration, manual dexterity, upper limb coordination, bilateral coordination, balance, running speed and agility and strength) which combine to yield four motor area composites (fine manual control, manual coordination, body coordination and strength and agility). The total point scores of individual items were converted to scale scores for the eight subtests and standard scores for four motor area composites. A total motor composite standard score was then calculated from the sum of standard scores for each motor area composite. A total motor composite standard score between 40 to 60 (±10) is considered 'average' motor proficiency.[59] For each assessment item, age and sex-specific norms were used to interpret the scores. The BOT-2 is considered a valid and reliable motor assessment tool for use in children and adolescents.[59,74] High values have been reported for the total motor composite for internal consistency reliability ($\alpha = 0.95$) and test-retest reliability ($r = 0.86$) in children aged 4-7 years and for interrater reliability ($r = 0.98$) in individuals aged 4-21 years.[59,74] Scores from the BOT-2 are also able to discriminate between particular age groups and/or diagnosis groups (e.g., Developmental Coordination Disorder, Autism Spectrum Disorder).[59,74]

7.4.3.3. Academic performance in mathematics and reading

Academic performance was assessed using the Wechsler Individual Achievement Test – 2nd Edition – Australian Standardised Edition (WIAT-II Australian).[112] The WIAT-II Australian is a standardised test that assesses achievement across the academic areas of reading, mathematics, written language and oral language composites in people aged four to 85 years.[112] For the present study, the mathematics and reading composites were administered. The mathematics composite was comprised of the numerical operations and maths reasoning subtests. The reading composite was comprised of the word reading, pseudoword decoding and reading comprehension subtests. Age-based (using years and months) standard scores were calculated for each subtest, mathematics and reading composite. A standard score between 90 to 110 (±15) is considered 'average' achievement.[112] The WIAT-II Australian is considered a reliable and valid academic achievement test.[112] Strong age-based internal consistency reliability for the reading (.98-.99) and mathematics composites (.92-.95) have been reported in children aged six and seven years.[112] High age-based test-retest reliability has also been reported for the reading (.96) and mathematics composites (.96).[112] Administration of the WIAT-II Australian is restricted to Allied Health (including physiotherapists) or Special Education professionals.[228]

7.4.4 Procedure

During the third school term in 2014, baseline (T0) motor proficiency and academic performance assessments were administered during the regular school day. Participants were re-assessed during the fourth school term following the 12-week program (T1). At T0 and T1, the BOT-2 Complete Form, which took approximately 40-60 min per participant, was administered by physiotherapy and exercise science university students, under the training and supervision of a registered physiotherapist. The WIAT-II Australian test took approximately 45 to 60 min per participant and was administered by a registered physiotherapist with experience working with children.

7.4.5 12-week classroom-based gross motor program

The Year 1 classroom-based gross motor program was delivered to Classes R and M for a total of 12 weeks during the third and fourth school terms in 2014. The program was comprised of two components, (i) a gross motor skills circuit without an academic focus and (ii) physically active lessons incorporated into either mathematics or reading lessons with an academic focus. The program was designed and delivered by a registered physiotherapist, with assistance from physiotherapy and exercise science university students. The scope and sequence of the Year 1 mathematics and English curriculum for the third and fourth school terms were provided by the classroom teachers of Classes R and M to inform planning of physically active lessons. Planned gross motor activities were then integrated into academic lessons based on their alignment with the weekly academic focus.

7.4.5.1 Gross motor skills circuit

Throughout the 12-week program, students in Classes R and M engaged in a 15 min gross motor circuit four days per week, delivered at the beginning of the school day before academic classes commenced. The session was conducted with students in small groups of four to six rotating through eight different circuits. The circuits included activities that promoted gross motor skill development (Table 24).[70,277] The focus during each session was on quality of movement, with feedback provided to Year 1 students regarding their technique as appropriate. Each week, gross motor activities were also varied and progressed as student abilities allowed, in order to engage and continuously challenge students during sessions and consistent with the principles of variability of practice.[48]

Table 24: Example gross motor activities included in morning circuit.

Circuit	Example Activities
Balance/proprioception	Walking along a line (heel-toe, eyes open/closed), activities on balance pods, balance beam, balance obstacle course
Vestibular	Rolling sideways along gym mat, spinning around on spot
Hand/eye and hand/foot coordination	Balloon throwing, underarm/overarm throwing at targets, kicking balls, throwing/catching activities
Bilateral coordination	Moving body over/under hurdles, crawling up, over and through objects
Locomotor/agility	Hopping into hoops, jumping on lily pads, skipping rope, leaping activities
Spatial awareness games	Builders and bulldozers game, airplanes and airports, rob the nest, stuck in the mud
Strength	Animal walks (e.g., bear/crab walk), using scooter board
Letter/number run	Pick up letter/number and run to order letters A-Z or numbers 1-20 between cones

7.4.5.2 Physically active reading and mathematics lessons

Four days per week, students in Class R engaged in movement-based reading and spelling activities incorporated into their allocated reading group rotation (four to six students per group), which lasted 10 min (Table 25). Sessions took place in a designated outdoor area, adjacent to the classroom. Three days per week, students in Class M engaged in a 15 min movement-based mathematics activity (Table 25). Sessions took place either inside the classroom, school hall, or in a designated outdoor area.

Table 25: Example gross motor activities integrated into reading and mathematics groups.

Academic area	Academic focus	Activities
Reading	Sound/verb of the week; blending sounds; sight words; rhyming words	Using sidewalk chalk, ribbons and sand outdoors to draw letters of the week. Alphabet mat activities (e.g., throw bean bag underarm, walk, jump, hop, leap to different letters to spell out each word) Verb of the week action song to music Make rhyming words while throwing ball in a circle
Mathematics	Number line; 2D/3D shapes in environment; addition, subtraction, multiplication, division; time	Activities on outdoor number line; friends of 10 Using objects / own bodies to make 2D shapes (e.g., square, triangle, rectangle) "What's the time Mr Wolf?" game. Children dance to song, when music stops, children are asked to form groups of 2, 3, 4. Subtraction game using ball to roll underarm at skittles, then count how many skittles are left

7.4.6 Statistical analysis

The Statistical Package for the Social Sciences (SPSS) (Version 26)[230] was used to conduct all statistical analyses for this study. To explore whether there were any significant changes in mean scores for total motor, mathematics and reading composites between baseline measurement (T0) and measurement following the 12-week program (T1) *within* each of the three classes, paired samples t-tests were performed, using an alpha level of .05 and two-tailed tests of significance. Where extreme outliers were evident in the change scores, these were noted and removed prior to conducting the paired samples t-tests. The effect size for paired samples t-tests was calculated using Cohen's d. According to Cohen,[231] an effect size (d) of .2 can be considered small, .5 can be considered medium and .8 can be considered large. To determine whether there were significant differences in mean scores at T0 and mean change scores (T1-T0) *between* the three classes for total motor, mathematics and reading composite scores, one-way analyses of variance (ANOVA) with Bonferroni post hoc tests were performed, using an overall alpha level of .05 and two-tailed tests of significance. Where extreme outliers were evident in the data without other violations of the assumptions underpinning ANOVA, these outliers were noted and removed prior to conducting the ANOVA. Where assumptions regarding equality of variances were violated, a Welch statistic was reported and post hoc comparisons were performed using the Games Howell test, using an alpha level of .05. Independent samples Kruskal Wallis tests with pairwise comparisons (significance values adjusted by Bonferroni correction for multiple tests) were performed instead of ANOVA where assumptions of normality were not met in the data. To determine the effect size for one-way ANOVA analyses, eta squared (η^2) was calculated. Finally, Pearson's correlation analyses were conducted to examine relationships between mean change scores in motor proficiency and academic outcomes for the total sample. *A priori* statistical power calculations conducted using G*Power software[232] indicated that a sample size of 54 participants spread across three classes would provide 70% statistical power to detect an effect size consistent with f(V) of 0.4 (a large effect size) in one-way ANOVA.

7.5 Results

A total of 64 children were invited to take part in the study. At T0, data were collected for 55 study participants (*n* = 25 boys, mean age = 6.81±0.31 years, range 6.25-7.42 years; *n* = 30 girls, mean age = 6.74±0.46 years, range 5.42-7.75 years). Due to absences on the testing days and the timing of assessments at T1 coinciding with the end of the final school term for the year, complete data were only available for 52 participants for motor proficiency outcomes, 49 participants for mathematics outcomes and 48 participants for reading outcomes.

7.5.1 Baseline motor proficiency and academic performance (T0)

The mean and standard deviation (SD), as well as the median, for total motor, mathematics and reading composite scores for each class at baseline (T0) and following the 12-week program (T1) are presented in Table 26. At T0, results of independent-samples Kruskal-Wallis analyses (used due to violations of assumptions underpinning ANOVA) indicated there were no significant differences between the three classes in medians of any of the composite scores.

Table 26: Results from paired t-tests assessing between baseline (T0) and post-test (T1) mean scores for motor proficiency, mathematics and reading outcomes.

Outcome	Class N (*n* = 17)			Class R (*n* = 18)			Class M (BOT-2 *n* = 17; WIAT-II maths *n* = 14; WIAT-II reading *n* = 13)		
	Baseline Mean (SD) Median#	Post Test Mean (SD)	p-value (ES)	Baseline Mean (SD) Median#	Post Test Mean (SD)	p-value (ES)	Baseline Mean (SD) Median#	Post Test Mean (SD)	p-value (ES)
Motor proficiency									
Total motor composite[a]	53.88 (5.95) 53.00#	54.71 (5.98)	.449 (0.19)	55.11 (11.93) 53.00#	60.44 (8.93)	.008* (0.71)	46.41 (11.94) 49.00#	52.53 (13.66)	<.001**(1.21)
Mathematics ability									
Mathematics composite[b]	100.88 (16.58) 101.00#	101.65 (16.58)	.699 (0.10)	91.39 (10.96) 89.00#	101.00 (12.60)	<.001**(1.71)	97.00 (17.52) 93.00#	104.57 (14.63)	<.001**(1.31)
Reading ability									
Reading composite[b]	103.47 (14.48)[c] 103.00#	107.93 (15.90)[c]	<.001**(1.27)[c]	95.61 (16.87) 91.00#	102.33 (19.53)	<.001**(1.30)	96.23 (15.53) 91.50#	107.77 (19.68)	<.001**(1.54)

Class N: regular Year 1 class; Class R: gross motor circuit + physically active reading lessons; Class M: gross motor circuit + physically active mathematics lessons.
[a] Motor proficiency assessed by BOT-2: Normative sample standard score (M = 50, SD = 10, range = 20-80); Scores adjusted for chronological age (in years and months) and sex.
[b] Mathematics and reading ability assessed by WIAT-II Australian: Normative sample standard score (M = 100, SD = 15, range = 40-160). Scores adjusted for chronological age (in years and months).
[c] Values for paired samples t-tests were calculated after removal of two extreme outliers (evident in change scores) in Class N.
#Median reported as Independent-samples Kruskal-Wallis analyses conducted at baseline (due to violations of assumptions underpinning ANOVA).
Class N (*n* = 17); Class R (*n* = 19); Class M (BOT-2, WIAT-II maths *n* = 19; WIAT-II reading *n* = 18).
**p* ≤ .05; ** *p* ≤.001; ES: effect size was calculated using Cohen's d (.2 = small; .5 = medium; .8 = large)

7.5.2 Changes in motor proficiency and academic performance scores (T1-T0)

7.5.2.1 Differences between pre-test and post-test scores for each class

Analyses conducted using paired samples t-tests revealed that from T0 to T1 participants in Classes R and M demonstrated significant improvements in mean scores for the mathematics ($p < .001$), reading ($p < .001$) and total motor ($p < .008$ and $p < .001$ respectively) composites (Table 26). Similarly, once two extreme outliers in reading composite change scores (T1-T0) were removed for Class N, it was evident that the mean score for the reading composite significantly improved in Class N (though less than in the other classes) from T0 to T1 ($p < .001$; Table 26). However, mean scores for the mathematics and total motor composites in Class N did not change significantly from T0 to T1 (Table 26). Results from supplementary paired t-tests examining changes between baseline (T0) and post-test (T1) in scores for subtests of motor proficiency, mathematics and reading outcomes are presented for completeness in Table S7 but did not form part of the primary analyses of the study.

7.5.2.2 Differences in mean change scores between classes from T0 to T1

Mathematics outcomes

One-way ANOVA analyses revealed significant differences between the three classes in mean change scores for the mathematics composite, $F(2, 46) = 8.48$, $p = .001$, $\eta^2 = .269$. Post hoc comparisons indicated mean change scores for the mathematics composite were greater for participants in Class R ($p = .001$) and Class M ($p = .019$) than for participants in Class N (Table 27). For completeness, results from one-way ANOVA comparing differences in mean change scores for subtests of motor proficiency, mathematics and reading outcomes are outlined in Table S8 but did not form part of the primary analyses of the study.

Table 27: Results from one-way analyses of variance comparing differences in mean change scores for motor proficiency, mathematics and reading outcomes between Class R, Class M and Class N.

Outcome	Class N (*n* = 17) Mean change ± SD from T0 to T1 (95% CI)	Class R (*n* = 18) Mean change ± SD from T0 to T1 (95% CI)	Class M (*n* = 17) (BOT-2 *n* = 17; WIAT-II maths *n* = 14; WIAT-II reading *n* = 13) Mean change ± SD from T0 to T1 (95% CI)	Mean difference ±SE between Class N and Class R (95% CI)	p-value	Mean difference ±SE between Class N and Class M (95% CI)	p-value
Motor proficiency							
Total motor composite[a]	0.82 ±4.38 (-1.43, 3.07)	5.33±7.54 (1.58, 9.08)	6.12±5.07 (3.51, 8.73)	-4.51±1.98 (-9.43, 0.41)	.082	-5.29±2.01 (-10.28, -0.31)	.034*
Mathematics ability							
Mathematics composite[b]	0.76±8.00 (-3.35, 4.88)	9.61±5.62 (6.82, 12.40)	7.57±5.79 (4.23, 10.91)	-8.85±2.23 (-14.38, -3.31)	.001**	-6.81±2.38 (-12.71, -0.90)	.019*
Reading ability							
Reading composite[b]	4.47±3.50 (2.53, 6.41)[c]	6.72±5.18 (4.15, 9.30)	11.54±7.51 (7.00, 16.08)	-2.26±1.52 (-6.00, 1.49)[c]	.312[c]	-7.07±2.27 (-12.92, -1.23)[c#]	.017*[c]

Class N: regular Year 1 class; Class R: gross motor circuit + physically active reading lessons; Class M: gross motor circuit + physically active mathematics lessons
[a] Motor proficiency assessed by BOT-2: Normative sample standard score (M = 50, SD = 10, range = 20-80); Scores adjusted for chronological age (in years and months) and sex.
[b] Mathematics and reading ability assessed by WIAT-II Australian: Normative sample standard score (M = 100, SD = 15, range = 40-160); Scores adjusted for chronological age (in years and months).
[c] Values were calculated after removal of two extreme outliers in Class N (due to violations of assumptions underpinning ANOVA).
[#] Post hoc comparisons were performed using the Games Howell test (due to violations underpinning equality of variances).
*$p \leq .05$; **$p \leq .001$

Reading outcomes

Once two extreme outliers in reading composite change scores (T1-T0) were removed for Class N, one-way ANOVA analyses revealed significant differences between classes in mean change scores for the reading composite, Welch's F(2, 25.009) = 5.009, *p* = .015, η^2 = .216. Post hoc comparisons performed using the Games Howell test indicated mean change scores for the reading composite were greater for participants in Class M than Class N (*p* = .017) (Table 27).

Motor proficiency outcomes

One-way ANOVA analyses revealed significant differences between classes in mean change scores for the total motor composite, F(2, 49) = 4.06, *p* = 0.23, η^2 = .142. Post hoc comparisons indicated mean change scores for the total motor composite were greater for participants in Class M than Class N (*p* = .034) (Table 27).

7.5.3 Relationships between mean change scores for motor proficiency and academic outcomes

Weak to moderate positive correlations were found between mean change scores for the total motor composite and mathematics composite (*r* = .227, *p* = .117) and reading composite (*r* = .426, *p* = .003) for the total sample, indicating that 5% and 20% of mathematics and reading change scores respectively could be explained by changes in motor proficiency.

7.6 Discussion

The aim of this pilot study was to explore whether Year 1 school children exposed to a 12-week classroom-based gross motor program comprised of gross motor circuit training and physically active reading or mathematics lessons progressed differently to Year 1 children undertaking their regular school program in motor proficiency, mathematics and reading outcomes. Several key findings were evident. Firstly, participants in both Year 1 classes that undertook either the mathematics- or reading-focussed 12-week classroom-based gross motor program demonstrated significantly greater improvements in mean change scores for the mathematics composite than participants in the regular Year 1 program. However, only participants exposed to the 12-week classroom-based gross motor program comprised of gross motor circuit training and physically active mathematics lessons demonstrated significant improvements in mean change scores in reading and total motor composites when compared to participants in the regular Year 1 program. Due to the constraints of the pilot study design, it is not possible to determine whether differences in outcomes between classes could be solely attributed to the classroom-based gross motor program. However, these findings provide some preliminary evidence that a classroom-based PA program comprised of gross motor activities may be beneficial for motor skill development and academic outcomes in children in the early years of primary school and, thus a robust, larger scale study may be warranted to verify these findings.

7.6.1 Classroom-based gross motor programs and mathematics, reading and motor proficiency outcomes

The results from this study are in line with findings from systematic reviews by Fedewa and Ahn[29] and Singh et al.,[34] which reported beneficial effects of PA interventions on the mathematics performance of children. The results are also consistent with findings from experimental studies that have reported a positive impact of physically active lessons on the mathematical skills of primary school students.[42,218,273-275,278,279] Studies reporting beneficial effects of physically active lessons on mathematics outcomes share common parameters with the program outlined in the present study in that physically active lessons were delivered for a minimum duration of 10 min, at a frequency of at least three times per week over a minimum period of six weeks. Importantly though, in previous studies, it has been difficult to ascertain the type of PA undertaken in physically active lessons, as many studies have described the intensity of PA undertaken (i.e., moderate-to-vigorous), but they have not necessarily reported the exact type of PA undertaken (e.g., aerobic activity, flexibility, strength, motor skill tasks). The classroom-based program delivered in this study comprised a combination of gross motor activities with an academic focus (i.e., physically active reading or mathematics lessons) and without an academic focus (i.e., gross motor circuit). However, the intensity of PA undertaken by students during sessions was not recorded, as the focus during gross motor circuits was on quality of movement, along with variation and progression of activities. Additionally, the aim during physically active lessons was to match gross motor activities with the focus of learning for the week. Therefore, a direct comparison of findings from this study, which was focussed on the type of PA undertaken, with findings of experimental studies that have evaluated physically active lessons based on exercise intensity is not possible. Nevertheless, interestingly, and consistent with the findings from our study, improvements in the mathematical skills of Year 1 school students have also been reported in several experimental studies that implemented gross motor-enriched mathematics activities[218] or specialised motor skill programs[178,220,225] during the school day.

The evidence regarding the impact of PA interventions on language outcomes, including reading, in children and adolescents has been less conclusive in the literature.[34] The results from the present study are consistent with the mixed findings regarding the effects of classroom-based PA programs on reading outcomes. For example, several experimental studies have reported improvements in reading performance following physically active lessons with children aged 5 years[219] and 8-10 years.[42,280] However, other studies have reported no significant differences between intervention and control groups following physically active lessons.[278,279,281-283] This inconsistency in findings may be explained by variability in study design and PA intervention parameters, along with the methodological quality of studies investigating classroom-based PA to date.[46]

Significant improvements were found in total motor composite scores for participants exposed to physically active mathematics lessons when compared to participants exposed to their regular Year 1 program. These results are similar to findings from other studies conducted with students in the early years of primary school that have reported significant improvements in children's gross motor skills following motor-enriched physically active lessons,[218,219] motor skill training,[220] or developmental movement programs.[178] Although it is not possible to explain the underlying cause for the observed findings, Pesce and colleagues[48] have suggested that improvements in motor coordination may be one of the mechanisms underlying changes in cognitive performance. Beck et al.[218] also reported in their study that the effects of a 6-week program of motor-enriched learning activities on the mathematical performance of Year 1 school children could be partially explained by changes in visuo-spatial short-term memory and gross motor coordinative skills.

To date, school-based PA interventions involving motor skill training have been delivered by classroom teachers,[218,219] physical education teachers[220] or researchers.[178,225] A meta-analysis by Fedewa and Ahn[29] found that children appeared to benefit from PA interventions regardless of who was directing the intervention. However, no previous studies have reported findings from classroom-based gross motor skill programs that have been designed and delivered by a physiotherapist, with assistance from physiotherapy and exercise science university students. Physiotherapists are allied health professionals trained to design, implement and evaluate age-appropriate programs to facilitate motor development, motor control and motor planning.[284] As such, there may be a role for physiotherapists to contribute to future multidisciplinary research investigating the impact of motor skill interventions on children's motor proficiency and academic outcomes in the early years of primary school.

7.6.2 Limitations

As previously acknowledged, due to the constraints of only being able to undertake accompanying evaluation research alongside the THSP, a key limitation in the design of this pilot study is that it is not possible to infer that the differences observed between the three classes in academic performance and motor proficiency outcomes were due to the 12-week classroom-based gross motor program. This was due to the fact that the three classes came from two different schools and were comprised of different groups of children, and each class had a different teacher, and these factors may have influenced the findings. However, to minimise risk of confounding, the two classes at the school where the THSP was being implemented and the comparison class at another school were matched as closely as possible in that both were public primary schools located in the same geographical region and exposed to the same Year 1 Australian Curriculum. Additionally, correlation analyses examining relationships between mean change scores in motor proficiency and academic performance suggested that the more total motor proficiency scores improved, the more academic scores improved. This finding may lend credence to the likelihood that the classroom-based gross motor program (which can be expected to develop motor proficiency beyond age-related changes that would occur in the absence of additional gross motor training, which are already factored into BOT-2 scores) contributed 5% and 20% to the observed improvements in mathematics and reading scores respectively and thus improvements may not be explained by school/teacher/class differences alone. Another limitation is that there was greater loss to follow up for participants in Class M for academic outcomes, which may have impacted findings. Additionally, as the classroom-based program delivered in this study involved gross motor activities with and without an academic focus incorporated into the regular school day, we are unable to determine whether one or both of these components may be associated with the observed findings.

7.6.3 Practical implications for early childhood educators

A growing body of evidence suggests that motor skill development is positively associated with both health-related and academic outcomes.[9,82,227] Thus, the early years of primary school may represent an ideal time to support children's ongoing motor skill development through the implementation of classroom-based motor skill programs, such as the one outlined in the present study. Several strategies have been recommended to train and support educators to overcome existing barriers to providing classroom-based PA to children during class time.[258,272] Key strategies may include the provision of training and resources to educators to increase their knowledge and awareness of the benefits of classroom-based PA on children's health and learning and to improve their confidence and competence in delivering classroom-based PA through targeted training.[258,272]

7.7 Conclusion

This pilot study provides an example of a novel 12-week classroom-based gross motor program, designed and delivered by a physiotherapist with assistance from physiotherapy and exercise science university students. Key findings suggest that a 12-week classroom-based gross motor program comprised of gross motor circuit training and physically active mathematics or reading lessons, may be beneficial for Year 1 children's motor skill development and academic outcomes, particularly their mathematical skills. However, given the exploratory nature of this pilot study, further experimental studies are recommended to verify whether classroom-based motor skill programs have a beneficial effect on motor proficiency, mathematics and reading outcomes of children in the early years of primary school.[12]

[12] Please note that all references in this chapter are presented in the References section of the thesis

Table S7. Results from paired t-tests assessing differences between baseline (T0) and post-test (T1) mean scores for subtests of motor proficiency, mathematics and reading outcomes.

Outcome	Class N (*n* = 17)			Class R (*n* = 18)			Class M (BOT-2 *n* = 17; WIAT-II maths *n* = 14; WIAT-II reading *n* = 13)		
	Baseline Mean (SD) Median	**Post Test Mean (SD)**	**p-value (ES)**	**Baseline Mean (SD) Median**	**Post Test Mean (SD)**	**p-value (ES)**	**Baseline Mean (SD) Median**	**Post Test Mean (SD)**	**p-value (ES)**
Motor proficiency									
Fine motor precision[a]	14.53 (2.60) 14.00[#]	13.65 (3.67)	.418 (-0.20)	14.33 (4.04) 13.00[#]	12.33 (3.52)	.054 (-0.48)	12.39 (4.53) 13.00[#]	11.17 (4.94)	.165 (-0.34)
Fine motor integration[a]	17.18 (2.63) 17.00[#]	14.00 (2.57)	<.001**(-1.61)	17.00 (4.06) 17.00[#]	16.17 (2.55)	.368 (-0.22)	14.17 (5.71) 14.00[#]	13.83 (4.68)	.699 (-0.09)
Fine manual control[b]	51.71 (5.15) 52.00[#]	46.94 (5.52)	.002*(-0.88)	51.61 (8.46) 51.00[#]	48.11 (4.66)	.052 (-0.49)	46.11 (10.91) 47.00[#]	44.17 (9.69)	.228 (-0.29)
Manual dexterity[a]	16.35 (2.45)	18.06 (2.38)	.005*(0.79)	15.06 (3.59)	17.39 (2.64)	.010*(0.68)	12.11 (4.91)	15.89 (5.56)	<.001**(1.02)
Upper limb coordination[a]	17.29 (5.30)	19.12 (5.07)	.078 (0.46)	17.83 (6.50)	21.44 (4.50)	.001**(0.94)	13.78 (6.36)	17.39 (7.74)	<.001**(1.18)
Manual coordination[b]	54.29 (7.61)	59.24 (7.00)	.004*(0.82)	54.06 (9.80)	60.78 (7.33)	<.001**(1.31)	45.56 (10.79)	54.72 (13.89)	<.001**(1.26)
Bilateral coordination[a]	19.06 (2.02)[d] 19.00[#]	18.38 (2.83)[d]	.077(-0.47)[d]	18.06 (4.25) 19.00[#]	20.83 (2.90)	.002*(0.86)	15.94 (4.80) 18.00[#]	17.89 (4.80)	.001**(0.89)
Balance[a]	15.94 (3.72)	16.29 (3.10)	.686 (0.10)	17.11 (4.48)	18.28 (4.27)	.168 (0.34)	14.41 (3.76)	15.76 (4.19)	.021*(0.62)
Body coordination[b]	55.47 (6.34)	55.88 (6.69)	.773 (0.07)	56.72 (10.09)	61.72 (7.09)	.006*(0.73)	51.00 (10.39)	54.82 (10.88)	.004*(0.82)
Running speed and agility[a]	16.94 (2.93)	18.00 (2.12)	.114 (0.41)	18.17 (4.67)	19.22 (4.04)	.305 (0.25)	14.94 (5.37)	17.29 (5.58)	.009*(0.72)
Strength[a]	14.47 (3.79) 16.00[#]	15.29 (4.07)	.226 (0.31)	14.50 (4.85) 13.00[#]	18.83 (5.14)	.001**(0.97)	12.28 (5.96) 12.00[#]	14.78 (6.15)	.004*(0.78)
Strength and agility[b]	51.00 (6.10)	52.94 (5.99)	.080 (0.45)	52.72 (10.74)	59.17 (10.52)	.011*(0.67)	46.65 (10.45)	52.59 (12.03)	<.001**(1.11)
Mathematics ability									
Maths reasoning[c]	100.53 (18.66) 103.00[#]	104.47 (15.51)	.233 (0.30)	90.44 (11.46) 89.00[#]	100.61 (11.26)	<.001**(1.52)	94.86 (17.35) 91.00[#]	104.29 (14.80)	<.001**(1.67)
Numerical operations[c]	99.29 (15.11)	96.88 (16.51)	.295 (-0.26)	91.94 (11.05)	100.00 (12.86)	<.001**(1.11)	97.29 (16.97)	102.36 (14.76)	.036* (0.63)
Reading ability									
Pseudoword decoding[c]	103.41 (15.15)	101.24 (17.28)	.133 (-0.38)	94.29 (14.59)[e]	98.53 (15.21)[e]	.001**(1.01)[e]	93.54 (14.22)	99.85 (16.33)	.002*(1.08)
Word reading[c]	105.19 (15.73)[f]	108.88 (14.19)[f]	.003*(0.90)[f]	98.78 (17.68)	101.72 (16.48)	.018*(0.62)	100.07 (15.40)	104.71 (15.06)	<.001**(1.24)
Reading comprehension[c]	104.00 (9.83)	111.94 (11.14)	<.001**(1.11)	93.39 (12.11)	104.11 (16.70)	<.001**(1.22)	97.00 (10.71)	113.69 (14.88)	<.001**(1.59)

Class N: regular Year 1 class; Class R: gross motor circuit + physically active reading lessons; Class M: gross motor circuit + physically active mathematics lessons.

[a] Motor proficiency assessed by BOT-2: Normative scale score (M = 15, SD = 5, range = 1-35). Scores adjusted for chronological age (in years and months) and sex.

[b] Motor proficiency assessed by BOT-2: Normative sample standard score (M = 50, SD = 10, range = 20-80). Scores adjusted for chronological age (in years and months) and sex.

[c] Mathematics and reading ability assessed by WIAT-II Australian: Normative sample standard score (M = 100, SD = 15, range = 40-160); Scores adjusted for chronological age (in years and months).

[d] Values for paired samples t-tests were calculated after removal of one extreme outlier in Class N.

[e] Values for paired samples t-tests were calculated after removal of one extreme outlier in Class R.

[f] Values for paired samples t-tests were calculated after removal of one extreme outlier in Class N.

[#] Median reported as Independent-samples Kruskal-Wallis analyses conducted at baseline (due to violations of assumptions underpinning ANOVA). Class N (*n* = 17); Class R (*n* = 19); Class M (BOT-2, WIAT-II maths *n* = 19, WIAT-II reading *n* = 18)

**p* ≤ .05; ***p* ≤ .001

ES: effect size was calculated using Cohen's d (.2 = small; .5 = medium; .8 = large)

Table S8. Results from one-way analyses of variance comparing differences in mean change scores for subtests of motor proficiency, mathematics and reading outcomes between Class R, Class M and Class N.

Outcome	Class N (n = 17) Mean change ±SD from baseline (95% CI)	Class R (n = 18) Mean change ±SD from baseline (95% CI)	Class M (BOT-2 n = 17; WIAT-II maths n = 14; WIAT-II reading n = 13) Mean change ±SD from baseline (95% CI)	Mean difference ±SE between Class N and Class R (95% CI)	p-value	Mean difference ±SE between Class N and Class M (95% CI)	p-value
Motor proficiency							
Fine motor precision[a]	-0.88±4.37 (-3.13, 1.37)	-2.00±4.10 (-4.04, 0.04)	-1.22±3.57 (-3.00, 0.55)	1.12±1.36 (-2.25, 4.49)	1.00	0.34±1.36 (-3.03, 3.71)	1.00
Fine motor integration[a]	-3.18±1.98 (-4.19, -2.16)	-0.83±3.82 (-2.73, 1.07)	-0.33±3.60 (-2.12, 1.46)	-2.34±1.02 (-4.88, 0.19)[#]	.074	-2.84±0.97 (-5.26, -0.43)[#]	.019*
Fine manual control[b]	-4.76±5.41 (-7.55, -1.98)	-3.50±7.12 (-7.04, 0.04)	-1.94±6.59 (-5.22, 1.33)	-1.27±2.18 (-6.66, 4.13)	1.00	-2.82±2.12, (-8.21, 2.57)	.603
Manual dexterity[a]	1.71±2.17 (0.59, 2.82)	2.33±3.43 (0.63, 4.04)	3.78±3.72 (1.93, 5.63)	-0.63±1.08 (-3.30, 2.05)	1.00	-2.07±1.08 (-4.75, 0.61)	.183
Upper limb coordination[a]	1.82±3.99 (-0.23, 3.87)	3.61±3.82 (1.71, 5.51)	3.61±3.05 (2.09, 5.13)	-1.79±1.23 (-4.83, 1.26)	.457	-1.79±1.23 (-4.83, 1.26)	.457
Manual coordination[b]	4.94±6.05 (1.83, 8.05)	6.72±5.13 (4.17, 9.27)	9.17±7.29 (5.54, 12.79)	-1.78±2.11 (-7.00, 3.43)	1.00	-4.23±2.11 (-9.44, 0.99)	.150
Bilateral coordination[a]	-0.69±1.45 (-1.46, 0.08)[d]	2.78±3.25 (1.16, 4.39)	1.94±2.18 (0.86, 3.03)	-3.47±0.85 (-5.58, -1.35)[d#]	.001**[d]	-2.63±0.63 (-4.18, -1.08)[d#]	.001**[d]
Balance[a]	0.35±3.53 (-1.46, 2.17)	1.17±3.43 (-0.54, 2.87)	1.35±2.18 (0.23, 2.47)	-0.81±1.05, (-3.43, 1.80)	1.00	-1.00±1.07, (-3.65, 1.65)	1.00
Body coordination[b]	0.41±5.79 (-2.56, 3.39)	5.00±6.83 (1.60, 8.40)	3.82±4.68 (1.42, 6.23)	-4.59±1.98 (-9.50, 0.32)	.074	-3.41±2.00 (-8.39, 1.57)	.287
Running speed and agility[a]	1.06±2.61 (-0.28, 2.40)	1.06±4.24 (-1.05, 3.16)	2.35±3.28 (0.67, 4.04)	0.00±1.17 (-2.90, 2.90)	1.00	-1.29±1.19 (-4.23, 1.65)	.842
Strength[a]	0.82±2.70 (-0.56, 2.21)	4.33±4.47 (2.11, 6.56)	2.50±3.19 (0.92, 4.08)	-3.51±1.20 (-6.48, -0.54)	.015*	-1.68±1.20 (-4.65, 1.29)	.505
Strength and agility[b]	1.94±4.28 (-0.26, 4.14)	6.44±9.64 (1.65, 11.24)	5.94±5.36 (3.19, 8.69)	-4.50±2.50 (-10.75, 1.74)[#]	.190	-4.00±1.66 (-8.10, 0.10)[#]	.057
Mathematics ability							
Maths reasoning[c]	3.94±13.12 (-2.81, 10.69)	10.17±6.70 (6.84, 13.50)	9.43±5.65 (6.16, 12.69)	-6.23±3.55 (-15.11, 2.66)[#]	.207	-5.49±3.52 (-14.32, 3.35)[#]	.284
Numerical operations[c]	-2.41±9.18 (-7.13, 2.31)	8.06±7.25 (4.45, 11.66)	5.07±8.09 (0.40, 9.74)	-10.47±2.77 (-17.36, -3.58)	.001**	-7.48±2.96 (-14.84, -0.13)	.045*
Reading ability							
Pseudoword decoding[c]	-2.18±5.67 (-5.09, 0.74)	4.24±4.21 (2.07, 6.40)[e]	6.31±5.84 (2.78, 9.83)	-6.41±1.80 (-10.88. -1.94)[e]	.003*[e]	-8.48±1.93 (-13.29, -3.68)[e]	<.001**[e]
Word reading[c]	3.69±4.08 (1.51, 5.86)[f]	2.94±4.77 (0.57, 5.32)	4.64±3.73 (2.49, 6.80)	0.74±1.47 (-2.90, 4.39)[f]	1.00[f]	-0.96±1.56 (-4.83, 2.92)[f]	1.00[f]
Reading comprehension[c]	7.94±7.16 (4.26, 11.62)	10.72±8.81 (6.34, 15.10)	16.69±10.52 (10.34, 23.05)	-2.78±2.97 (-10.16, 4.60)	1.00	-8.75±3.23 (-16.79, -0.71)	.029*

Class N: regular Year 1 class; Class R: gross motor circuit + physically active reading lessons; Class M: gross motor circuit + physically active mathematics lessons.
[a] Motor proficiency assessed by BOT-2: Normative scale score (M = 15, SD = 5, range = 1-35). Scores adjusted for chronological age (in years and months) and sex.
[b] Motor proficiency assessed by BOT-2: Normative sample standard score (M = 50, SD = 10, range = 20-80). Scores adjusted for chronological age (in years and months) and sex.
[c] Mathematics and reading ability assessed by WIAT-II Australian: Normative sample standard score (M = 100, SD = 15, range = 40-160). Scores adjusted for chronological age (in years and months).
[#] Post hoc comparisons were performed using the Games Howell test (due to violations underpinning equality of variances)
[d] Values were calculated after removal of extreme outlier in Class N (due to violations of assumptions underpinning ANOVA).
[e] Values were calculated after removal of extreme outlier in Class R (due to violations of assumptions underpinning ANOVA).
[f] Values were calculated after removal of extreme outlier in Class N (due to violations of assumptions underpinning ANOVA).
*p ≤ .05; **p ≤ .001

Chapter 8: Discussion

8.1 Summary of key findings and implications of this doctoral program of research

The overall objectives of this doctoral program of research were to (i) investigate relationships between motor proficiency and academic performance in mathematics and reading in children in the early years of primary school in Australia; and (ii) explore whether early primary school classrooms in Australia are feasible settings to implement physical activity, particularly motor skill programs, as a strategy to promote children's motor proficiency and academic outcomes.

The six-stage model for the development and evaluation of health promotion programs proposed by Nutbeam[52] guided the overarching framework used to address the thesis objectives and study aims, with three of the six stages utilised to complete this program of research. Key findings and potential implications from the studies investigated across the three stages of this program of research are outlined below.

8.1.1 Stage 1: Problem definition

Stage 1 of this doctoral program of research commenced with a **Narrative review of the literature (Chapter 2),** which provided the context and rationale for undertaking this program of research. Findings from the narrative review revealed that schools can establish health-promoting environments that support children's health and physical activity (PA) behaviour.[139] Therefore, Australian primary schools may be ideal settings to implement strategies that support children's ongoing physical development in order to overcome current trends, including low levels of PA, physical fitness and motor skill proficiency.[16,254] The early years of primary school were specifically identified as an opportune time to intervene given one in five children in their first year of school in Australia are considered developmentally at risk or vulnerable on the physical health and wellbeing domain.[4] Evidence to support relationships between children's motor proficiency, health-related physical fitness and participation in PA was presented, providing the justification for focussing on motor proficiency as one of the core aspects of children's physical development to promote within the early years of primary school. Following a comprehensive narrative review of the literature, consistent evidence was found to support positive relationships between PA, cognition and academic performance in children and adolescents. However, inconclusive evidence to support a beneficial effect of PA interventions, including classroom-based PA interventions, on children's cognition and overall academic performance was apparent. The first stage of this program of research further narrowed the focus of the broad topic of PA, cognition and academic performance, by specifically examining relationships between motor proficiency and academic outcomes, which had been identified as a gap in the existing body of literature.

A **Systematic review (Chapter 3)** was undertaken to identify, critically appraise, and synthesise the findings of studies examining relationships between motor proficiency and academic performance in mathematics and reading in typically developing school-aged children and adolescents. The collective findings from 51 observational studies included in the review revealed that significant positive relationships exist between academic performance in mathematics and reading and both fine motor proficiency (specifically fine motor integration and total fine motor scores) and gross motor proficiency (specifically upper limb coordination, speed and agility and total gross motor scores) in school-aged children and adolescents. However, insufficient evidence was found to support relationships between academic outcomes and several components of gross motor proficiency (specifically bilateral coordination and strength) and total motor proficiency scores (i.e., a combination of fine and gross motor proficiency) due to a limited number of studies assessing these specific outcomes. Considerable variability was also evident between studies regarding the outcome measures used to assess motor proficiency and academic outcomes. Finally, preliminary evidence from four experimental studies suggested that school-based motor skill interventions may be beneficial for children's mathematics and reading skills. However, it was concluded that further research is required to confirm these findings given the limitations in the methodological quality of the experimental studies included in the review.

8.1.1.1 Key findings from Stage 1

Key findings and implications (in italics) from Stage 1 of this doctoral program of research include:

- The physical development of Australian children needs to be prioritised given existing trends of low levels of PA, aerobic and muscular fitness and motor skill proficiency **(Narrative review, Chapter 2).**

- Children's motor skill proficiency is positively associated with health-related outcomes including cardiorespiratory fitness and participation in PA and inversely associated with weight status **(Narrative review, Chapter 2).**
- Positive relationships between PA, cognition and academic performance in children and adolescents were consistently reported in the literature. However, there is currently inconclusive evidence to support a beneficial effect of PA interventions, including classroom-based PA interventions, on children's cognition and overall academic performance **(Narrative review, Chapter 2).**
- In school-aged children and adolescents, significant positive relationships exist between academic performance in mathematics and reading and fine motor proficiency (specifically fine motor integration and total fine motor scores) and gross motor proficiency (specifically upper limb coordination, speed and agility and total gross motor scores). Relationships between the components of gross motor proficiency and academic outcomes have been investigated less frequently in the literature and thus further research to support associations between these variables is necessary. School-based motor skill interventions may be beneficial for children's mathematical and reading skills; however, further research is required to verify these findings **(Systematic review, Chapter 3).**
- *Evidence suggests that motor proficiency is positively associated with both health-related*[9-12] *and academic outcomes,*[227] *thus the early years of primary school may represent an ideal time to target children's motor skill development through the implementation of school-based motor skill programs.*

8.1.2 Stage 2: Solution generation

Stage 2 of this doctoral program of research aimed to further address the gaps in the literature identified in the **Narrative review (Chapter 2)** and **Systematic review (Chapter 3)** and involved exploring potential solutions to support the physical development of Australian children, particularly their motor skill development, during the early years of primary school.

Relationships between academic outcomes and gross motor composite scores had predominantly been investigated by studies included in the **Systematic review (Chapter 3)**, with fewer studies examining relationships between the individual components of gross motor proficiency. Therefore, the aim of **Study 1 (Chapter 4)** was to examine associations between fine and gross motor proficiency and academic performance in mathematics and reading with the cohort of 55 Year 1 children involved in the school-based participatory action project, the Tweed Healthy Schools Project (THSP). Baseline data for the Year 1 cohort was analysed prior to the commencement of the 12-week classroom-based gross motor program (described in **Study 4, Chapter 7**).

When examining relationships between fine and gross motor proficiency and academic outcomes **(Study 1, Chapter 4)**, results from baseline data analysis demonstrated that fine motor integration was the only component of motor proficiency that explained significant variance in mathematics and reading composite scores of Year 1 children. These findings were consistent with those reported more generally across school-aged children in studies included in the **Systematic review (Chapter 3)**. Further, findings were in line with research conducted with Year 1 children in other countries, including South Africa,[182] the United Kingdom,[181] and the United States of America.[184] Results also revealed a moderate positive association between overall motor proficiency (i.e., a combination of the components of fine and gross motor proficiency) and mathematical skills in Year 1 children. This was consistent with the findings from the **Systematic review (Chapter 3)** where weak positive associations were reported in studies using the BOT-2 (Short Form) to assess motor proficiency.[173,182,189] However, in **Study 1 (Chapter 4)**, relationships between the components of gross motor proficiency and mathematics and reading outcomes in Year 1 children did not reach statistical significance after adjusting for multiple comparisons. Whilst a lack of significant findings between the components of gross motor proficiency and academic outcomes is in contrast to those reported in the **Systematic review (Chapter 3)**, the components of gross motor proficiency that were most strongly related to academic outcomes (i.e., running speed and agility and upper limb coordination) were consistent, along with the strength of the association (i.e., weak). Findings from this study are relevant to early childhood educators and paediatric health professionals who are qualified to assess and facilitate children's motor proficiency (e.g., physiotherapists and occupational therapists). Educators may benefit from professional development and training to increase their knowledge regarding associations between children's motor proficiency and academic outcomes and to increase their capacity to identify early, for further investigation, any children with poorly developed or delayed motor skills.

The second, solution generation stage of this program of research also involved exploring whether early primary school classrooms in Australia are feasible settings to implement PA, specifically motor skill programs, as a strategy to promote children's motor proficiency and academic outcomes. The frequency, type and context of children's PA during school class time in Australia was unknown. Furthermore, limited objective data existed regarding how often educators implement classroom-based PA in the early years of primary school and which methods (i.e., physically active lessons and/or breaks) were being utilised. Therefore, it was necessary to determine existing PA practices of children in the early years of primary school in Australia during class time. Thus, the aim of **Study 2 (Chapter 5)** was to directly observe Year 1 children's PA and the context of their PA during school class time and identify opportunities to incorporate additional activity.

Findings revealed that Year 1 children were observed to be predominantly sedentary during school class time, undertaking limited amounts of light and moderate to vigorous PA (MVPA). Few studies had previously utilised direct observation tools to assess primary school children's PA during class time; however, findings from **Study 2 (Chapter 5)** were consistent with studies by McIver et al.[240] and Russ et al..[239] Results also demonstrated that Year 1 children spent limited time participating in organised PA, including classroom-based PA and incidental PA. However, when children completed activities in small groups, they were significantly more likely to engage in incidental PA than when they completed activities as a whole class. This was similar to findings reported by Russ et al..[239] Notably, classroom-based PA, particularly incorporating movement into academic lessons (i.e., physically active lessons) was rarely observed to be utilised by classroom teachers and was thus identified as a potential strategy to incorporate PA into the regular class routine. Overall, both structured (classroom-based PA) and unstructured (incidental PA) movement opportunities were identified as potential strategies to encourage children to be more active during school class time. Results from this study provide a detailed account of existing PA practices and contexts in a sample of Year 1 children in Australia. Thus, findings are relevant to classroom teachers, specialist physical education (PE) teachers, school principals and other policy makers interested in identifying ways to provide PA opportunities to children in the early years of school during class time. Findings are also relevant to health professionals working in schools who are qualified to provide health education, advice and support to promote children's health and wellbeing, as they may be able to support educators to implement these practices.

Having identified in **Study 2 (Chapter 5)** that classroom-based PA was a potential method that teachers could employ to increase movement during class time, but was seldom being utilised, **Study 3 (Chapter 6)** involved seeking feedback from Australian educators and school principals regarding the factors (barriers/facilitators) that would influence the provision of classroom-based PA to students in the early years of primary school (i.e., Prep/Kindergarten to Year 2). Evidence from the implementation science literature[51] recommends that researchers utilise a multi-level ecological framework to understand implementation of school-based PA interventions. Therefore, a social ecological approach was used to examine these factors (barriers/facilitators) and subsequently guided questionnaire design and analysis in this study.

Insufficient time, limited training opportunities, limited resources, educator attitudes to PA, and their confidence to implement PA within the school setting were the key barriers identified by educators and school principals to providing classroom-based PA to students in the early years of school in Australia. The provision of training and resources to improve educator knowledge of the benefits of classroom-based PA for children's health and learning, and to improve their confidence in delivering classroom-based PA through targeted training were the main strategies recommended to overcome the identified barriers. These results suggest that to overcome the existing perceived barriers for providing classroom-based PA to students in the early years of school during class time, multiple strategies will need to be employed, targeting both educators and the school (at an organisational level). These findings were consistent with those previously reported both internationally[258] and across different school year levels in Australia.[259-262] However, unlike previous studies, this study **(Chapter 6)** sought feedback from school staff regarding the factors influencing the provision of classroom-based PA to children specifically in the early years of school (i.e., Prep/Kindergarten to Year 2) in Australia. Feedback from school staff working with children in Prep/Kindergarten to Year 2 was considered important, given increased curriculum pressures associated with standardised testing commence in Year 3 in Australian primary schools. Overall, findings from this study are relevant to school staff, including classroom teachers, specialist PE teachers, school principals as well as school policy makers who are interested in implementing classroom-based PA as part of a whole-of-school approach to PA promotion (i.e., a comprehensive school physical activity program). Findings are also relevant to health professionals working in schools who may be able to support educators to implement these practices, given their expertise in promoting children's health and wellbeing.

8.1.2.1 Key findings from Stage 2

Key findings and implications (in italics) from Stage 2 of this doctoral program of research include:

- In a sample of Year 1 children in Australia, overall motor proficiency was related to their mathematical skills. Fine motor integration skills were predictive of mathematical and reading skills **(Study 1, Chapter 4).** *A role may exist for paediatric health professionals who are trained to assess and facilitate children's motor proficiency (e.g., physiotherapists and occupational therapists) to assist educators to identify early, for further investigation, any child with poorly developed or delayed motor skills.*
- A sample of Year 1 children in Australia were observed to be predominantly sedentary during school class time, undertaking limited amounts of light and moderate to vigorous PA, including organised and incidental PA. Opportunities to incorporate additional PA during class time were identified and included implementing movement into academic lessons or during transitions between lessons, as well as encouraging children's incidental PA **(Study 2, Chapter 5).** *Educators need to be trained and supported to provide structured and unstructured movement opportunities to children during school class time. Training could occur through entry-level curriculum and/or via professional development opportunities.*
- Barriers to providing classroom-based PA to students in the early years of primary school in Australia include insufficient time, training opportunities, resources and educator attitudes and confidence. Proposed solutions to overcome barriers include the provision of training and resources to educators, including education regarding the benefits of classroom-based PA **(Study 3, Chapter 6).** *Multiple strategies need to be employed at the individual (educator)*

and organisational (school) level to overcome existing barriers to providing classroom-based PA programs to students in the early years of primary school in Australia.

8.1.3 Stage 3: Solution testing

Stage 3 of this doctoral program of research involved exploring whether classroom-based motor skill programs (i.e., the solution tested), may be beneficial for children's motor proficiency and academic outcomes; a gap that had been identified in the literature. **Study 4 (Chapter 7)** was thus designed as an exploratory pilot study delivered under the real world conditions of the THSP, a school-based participatory action project. The study investigated whether Year 1 school children exposed to a 12-week classroom-based gross motor program, comprised of gross motor circuit training and physically active reading or mathematics lessons, progressed differently to Year 1 children undertaking their regular school program in motor proficiency, mathematics and reading outcomes.

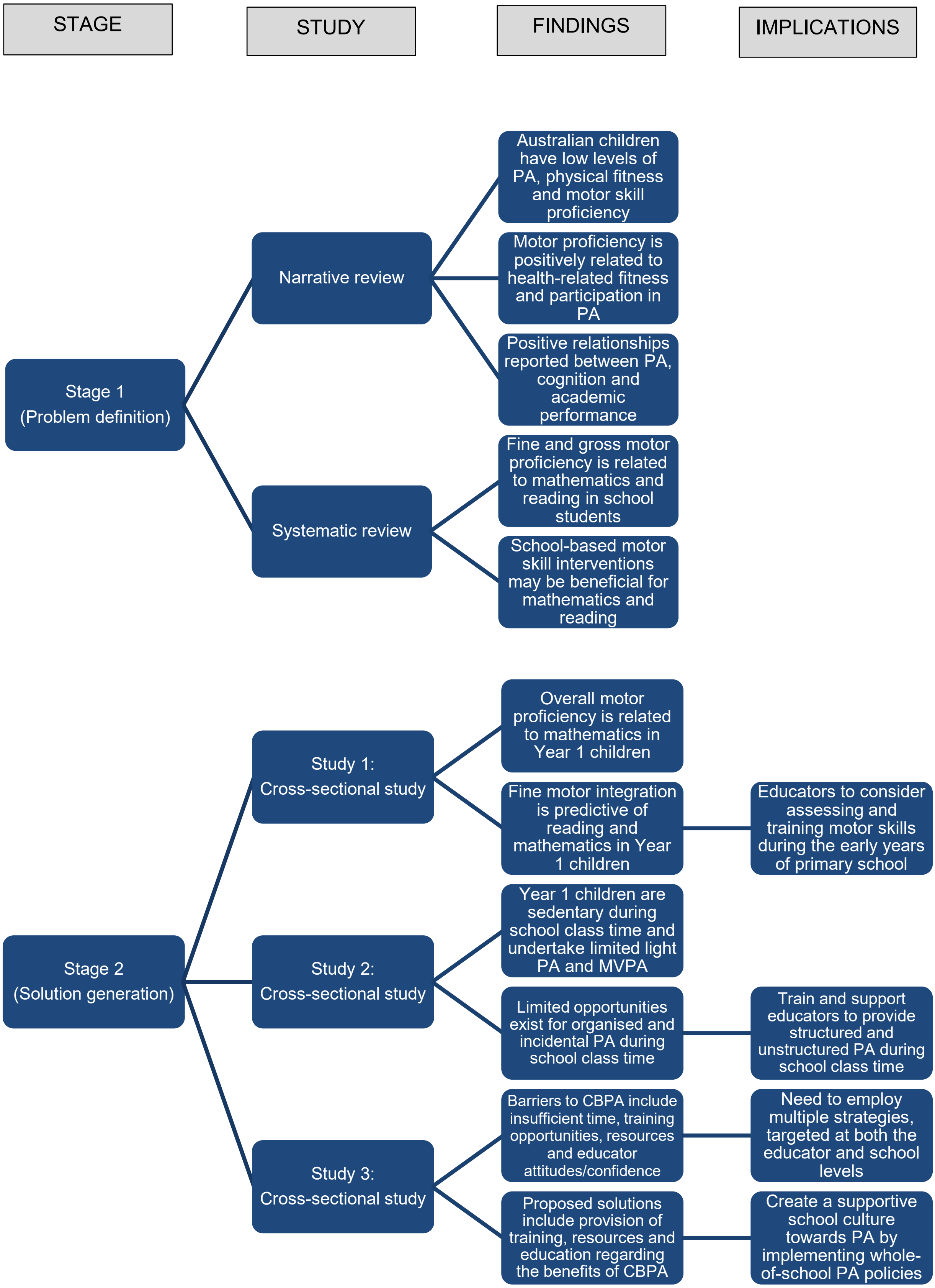
Key findings revealed that mean change scores for the mathematics composite were significantly greater for Year 1 participants exposed to the 12-week classroom-based gross motor program than for Year 1 participants undertaking their regular school program. Given the exploratory nature of this study and limitations within the study design, it was concluded that further robust experimental studies are recommended to verify whether classroom-based motor skill programs have a beneficial effect on motor proficiency and academic outcomes in children in the early years of primary school. However, findings from the pilot evaluation may usefully inform the design of future experimental studies. Despite the limitations in the pilot design of **Study 4 (Chapter 7)**, results were consistent with findings from several systematic reviews[29,34] and experimental studies,[42,218,273-275,278,279] which have reported beneficial effects of PA interventions, including physically active lessons, on children's mathematical outcomes. Results were also consistent with the mixed findings in the literature reported for reading outcomes.[34] Several experimental studies have also previously reported significant improvements in the gross motor skills of children in the early years of primary school following school-based motor skill interventions including motor enriched physically active lessons,[218,219] a motor skill training program[220] and a developmental movement program[178] **(Systematic review, Chapter 3).** These findings were consistent with the improvements in children's total motor proficiency reported in the pilot study. The 12-week classroom-based gross motor program outlined in **Study 4 (Chapter 7),** involved gross motor circuit training (i.e., incorporating additional PA into the school day) as well as physically active reading and mathematics lessons (i.e., adapting the school curriculum). The physically active lessons incorporated gross motor skills, which differed from the aerobic types of activities included in the classroom-based PA interventions most frequently reported in the literature. Motor proficiency was also chosen as an outcome measure which is in contrast to other studies that primarily evaluated subjectively/objectively measured PA as the main PA-related outcome following classroom-based PA interventions. Finally, a point of difference from previous studies was that this 12-week classroom-based gross motor program was designed and delivered by a registered physiotherapist, with assistance from supervised physiotherapy and exercise science students. Findings from this study are relevant to school staff (e.g., classroom teachers, specialist PE teachers) and health professionals working in schools who are qualified to design and evaluate developmentally appropriate motor skill programs (e.g., physiotherapists and occupational therapists).

8.1.3.1 Key findings from Stage 3

Key findings and implications (in italics) from Stage 3 of this doctoral program of research include:

- In a sample of Year 1 children in Australia, participation in a 12-week classroom-based gross motor program was associated with improvements in their motor proficiency and academic outcomes, particularly their mathematical skills **(Study 4, Chapter 7).** *Findings from this pilot study will usefully inform, and justify the benefits of, larger, more robust experimental studies in this field.*

Figure 15 provides a diagrammatic summary of the key findings and practical implications across the three stages of the program of research.


STAGE
STUDY
FINDINGS
IMPLICATIONS
Stage 1 (Problem definition)
Narrative review
Australian children have low levels of PA, physical fitness and motor skill proficiency
Motor proficiency is positively related to health-related fitness and participation in PA
Positive relationships reported between PA, cognition and academic performance
Systematic review
Fine and gross motor proficiency is related to mathematics and reading in school students
School-based motor skill interventions may be beneficial for mathematics and reading
Stage 2 (Solution generation)
Study 1: Cross-sectional study
Overall motor proficiency is related to mathematics in Year 1 children
Fine motor integration is predictive of reading and mathematics in Year 1 children
Educators to consider assessing and training motor skills during the early years of primary school
Study 2: Cross-sectional study
Year 1 children are sedentary during school class time and undertake limited light PA and MVPA
Limited opportunities exist for organised and incidental PA during school class time
Train and support educators to provide structured and unstructured PA during school class time
Study 3: Cross-sectional study
Barriers to CBPA include insufficient time, training opportunities, resources and educator attitudes/confidence
Need to employ multiple strategies, targeted at both the educator and school levels
Proposed solutions include provision of training, resources and education regarding the benefits of CBPA
Create a supportive school culture towards PA by implementing whole-of-school PA policies

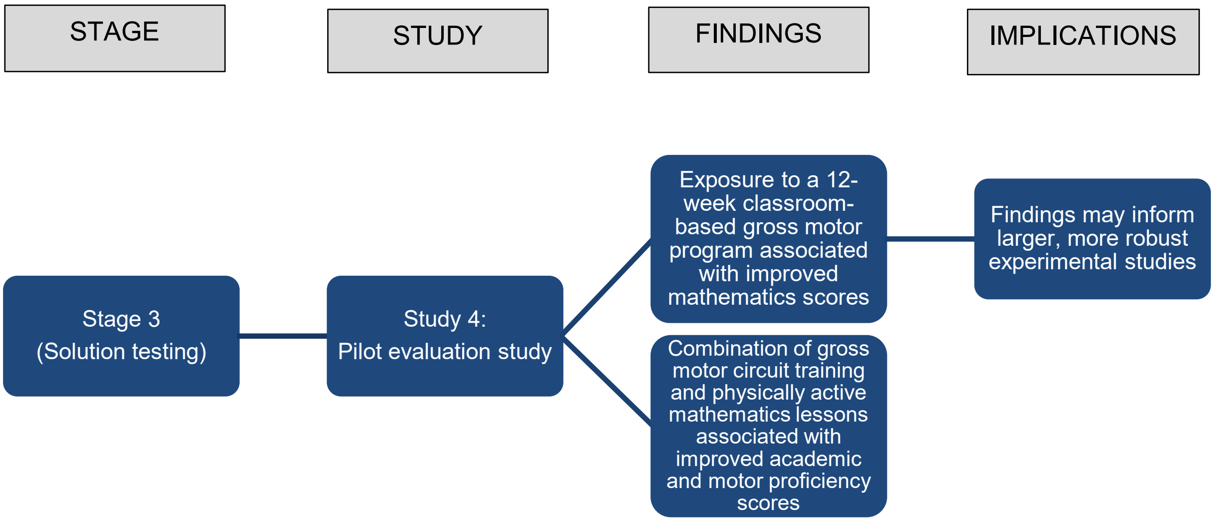


Figure 15: Key findings and practical implications of this doctoral program of research.

Figure 16 summarises the potential implications of the findings from this doctoral program of research for specific audiences, including schools, educators, children in the early years of school and their caregivers as well as allied health professionals working in schools who are qualified to assess and facilitate children's motor proficiency and promote children's health and wellbeing.

Health professionals working in schools who are trained to assess and facilitate children's motor proficiency and promote their health and wellbeing

- Assist educators with the early identification of children with poor or delayed motor skills, as this may also impact their academic performance.
- Contribute to the design, implementation and evaluation of age-appropriate motor skill programs to facilitate motor development, motor control and motor learning.
- Support schools to identify and implement opportunities for children to be active during the school day.

Educators

Provision of training and resources to:

(i) Increase knowledge and awareness of:

- benefits of PA on children's mental, physical, social, emotional and academic outcomes
- 24-hour movement guidelines

(ii) Improve competency and confidence

- Provision of CBPA examples to trial
- Collaboration and sharing of resources between staff

Schools

- Review strategies, policies and practices currently in place regarding the use of a health promoting schools framework and comprehensive school physical activity programs.
- Outcomes of research may guide pedagogical approaches used in the early years of primary school and inform future topics for professional development.

Children and their caregivers

- Early identification of difficulties with motor skills.
- Participation in motor skill training programs.
- Increase PA levels and reduce sitting time through structured and unstructured PA opportunities in the classroom.

Figure 16: Potential implications of doctoral program of research for health professionals, schools, educators, children and their caregivers.

8.2 Significance of this program of research to the wider research community

The motivation and drive behind the rapidly expanding field of research examining relationships between PA, cognition, and academic performance in children and adolescents is ultimately to investigate how children can be offered the best possible start to life to prosper physically, cognitively, emotionally, and socially throughout their lives. Consequently, relationships between PA, cognition, and academic performance have been investigated across multiple disciplines, including by exercise and cognition researchers and developmental neuroscientists. Relationships between motor and cognitive development and links between motor proficiency and academic outcomes have also been examined by early childhood education researchers. This doctoral program of research has been conducted through the lens of a registered physiotherapist in Australia, whose background knowledge and skillset are guided by research on motor development, motor learning and motor control. Therefore, given the multidisciplinary nature of this field of research, the breadth of literature from the perspective of all disciplines has been considered in this program of research. The key disciplines involved in the broad field of research relevant to the thesis topic are summarised in Figure 17. As outlined in Section 8.1, the findings of this program of research complement and build upon the existing body of literature.

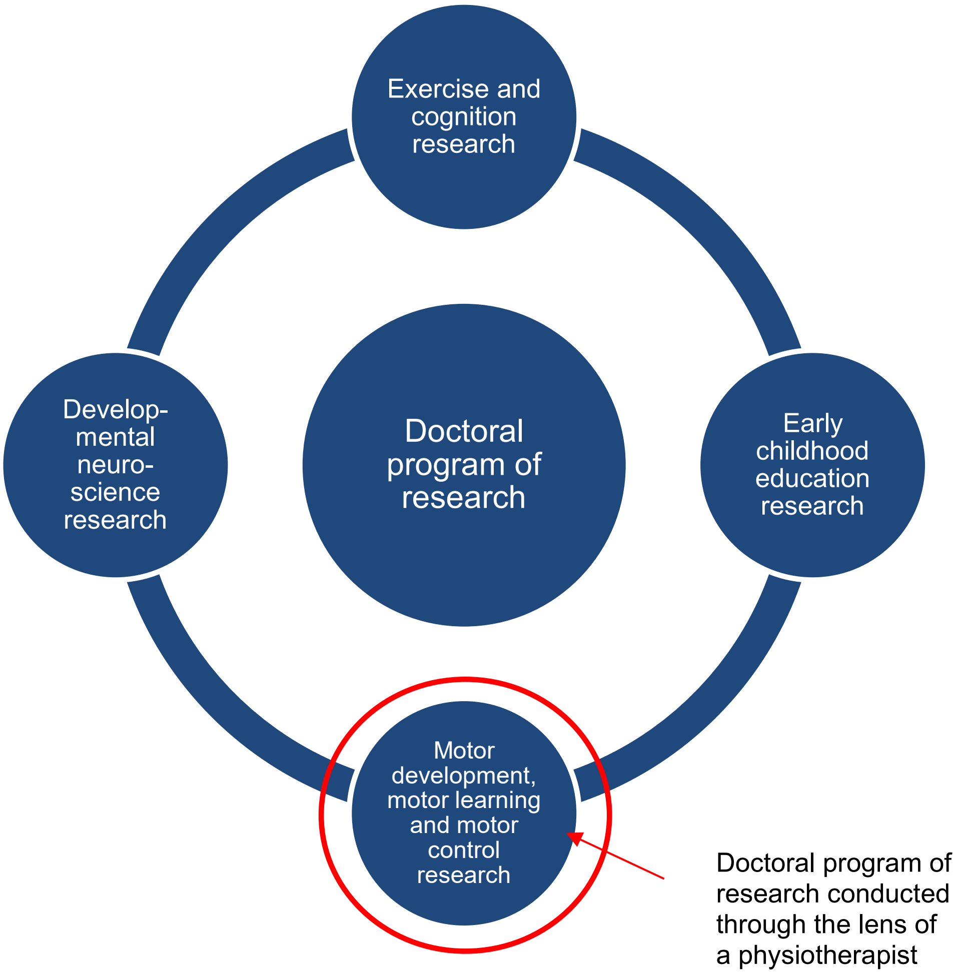


Figure 17: Key disciplines involved in the broad field of research.

8.3 Significance of this program of research to the allied health professional community

The health promoting schools (HPS) framework recognises the importance of schools forming partnerships with the wider school community (i.e., 'community links & partnerships', Figure 18) and advocates for the health and education sectors to work together to support children's health and education outcomes.[25]

Figure 18: Components of the health promoting schools framework used in Australia.[133]

Findings from this program of research highlight a potential partnership that Australian primary schools could forge with allied health professionals to promote and support children's motor skill development during the early years of school, along with their overall health and wellbeing. Therefore, the collective findings from this program of research are also relevant to allied health professionals working within the school setting (e.g., physiotherapists, occupational therapists, speech-language pathologists, dietitians, exercise physiologists and exercise scientists) and may guide current and future practices, as outlined further below.

8.3.1 Evolving role of allied health professionals working within the school setting

School-based therapy service delivery methods in Australia have traditionally involved providing direct (e.g., assessment/intervention) and indirect support (e.g., education to teachers/caregivers) to students eligible to access services, as well as building the capacity of school staff through the provision of professional development and training.[134] However, there is evidence that school-based therapy models of service delivery are evolving in Australia. For example, the use of school-wide / universal approaches to service delivery by school-based therapists has been recently recognised in Queensland government schools.[134] Similarly, government schools in New South Wales may utilise their budget to directly engage allied health professionals (e.g., physiotherapists, occupational therapists, speech-language pathologists and exercise physiologists) to provide services within the school setting to students with or without a disability.[135] The provision of allied health services must to be linked to learning outcomes and may include small group activities, whole-of-class and school-wide initiatives, as well as staff professional development.[135]

Internationally, there is also evidence that school-based therapy service delivery models are shifting towards more universal approaches to service provision. For example, in Canada, the Partnering for Change (P4C) model of service delivery has been described as '*an innovative, collaborative, evidence-informed model that uses a needs-based, tiered approach to provide rehabilitation services for children with special needs in schools*.'[285] In this model, the tiered approach involves the provision of (i) school-wide and classroom support for all children; (ii) more specialised services for groups of children considered at risk; and (iii) individualised treatment for children with more complex needs.[286] The P4C model has been evaluated as a school-based occupational therapy service delivery model for children with Developmental Coordination Disorder,[286] but is yet to be evaluated as a model of service delivery for other school-based therapy services.

Overall, in addition to the existing role of allied health professionals working in schools, there may be an evolving role to extend the traditional method of service delivery from providing support (direct and/or indirect) for individual students, to employing whole-of-class and whole-of-school activities thereby supporting schools, educators and all children. The potential implications of this program of research for allied health professionals working in schools were summarised in Figure 15. These key implications are explained in further detail below.

8.3.2.1 Provide training to educators to facilitate earlier identification of children with poorly developed or delayed motor skills

Findings from this doctoral program of research indicate that educators may benefit from training and support to identify early, for further investigation and management, any children with poorly developed or delayed motor skills as they transition to primary school. The detailed paediatric training that physiotherapists and occupational therapists obtain during their entry-level professional education makes them suitably qualified to assume the role of collaborating with educators to facilitate earlier identification of children in the early years of primary school with poorly developed or delayed motor skills. Essential content areas that are recommended for entry-level professional physiotherapy education include (i) the selection and implementation of age-appropriate assessment techniques related to motor development and function, and (ii) the selection and implementation of age-appropriate intervention techniques related to strengthening, motor development, motor control and motor planning.[284] Similarly, occupational therapists working with children require specific knowledge and skills in relation to child development, occupations of children (school work, play/leisure and self- care), assessment and outcome measurement, goal setting and evidence-based interventions.[287]

8.3.2.2 Contribution to the design, implementation and evaluation of age-appropriate motor skill programs to facilitate motor development, motor control and motor learning

Findings from this doctoral program of research also indicate that beyond the regular Health and Physical Education (HPE) Australian Curriculum, classroom-based motor skill programs could potentially be implemented with children in the early years of primary school in Australia. School-based motor skill programs aim to facilitate children's motor proficiency by delivering structured, developmentally appropriate motor skill activities during the school day.[13,14] Specialist PE teachers have the knowledge and skillset[288] to work with classroom teachers to assist them to plan and deliver developmentally appropriate classroom-based motor skill activities. However, primary schools in some states and territories in Australia (e.g., New South Wales) may not employ specialist PE teachers.[130] Therefore, allied health professionals working in schools who are suitably qualified to design, implement and evaluate programs that improve children's motor development, motor control and motor planning (e.g., physiotherapists, occupational therapists)[284] may be well-positioned to collaborate with educators and provide professional development, training and support as required.

8.3.2.3 Provision of training and resources to educators and school staff to support children's overall health and wellbeing

A key role of allied health professionals including physiotherapists, occupational therapists and exercise physiologists is to promote the health and wellbeing of individuals and populations, including school children.[137,287,289-294] The collective expertise and training of allied health professionals make them suitably qualified to work with school staff (e.g., educators, specialist PE teachers, school principals) to promote children's health and wellbeing. Strategies may include (i) increasing knowledge and awareness of the benefits of PA on children's mental, physical, social, emotional and academic outcomes and the Australian 24-hour movement guidelines; (ii) providing support and training to improve educator competence and confidence to deliver classroom-based PA; (iii) identifying and implementing opportunities for children to be active during the school day; and (iv) reviewing strategies, policies and practices currently in place regarding the use of a health promoting school framework and comprehensive school physical activity program.

In summary, in addition to schools, educators and caregivers, findings from this program of research may be directly relevant to allied health professionals working in schools who are qualified to assess and facilitate children's motor proficiency and promote their overall health and wellbeing. In Australia, given existing school-based therapy models of service delivery, physiotherapists and occupational therapists may best suit this purpose.

8.4 Summary of strengths and limitations of doctoral program of research

A number of steps were taken to ensure sound methodological quality was applied to the systematic review and four studies included in this doctoral program of research, whilst recognising both the benefits and restrictions of conducting research under the real-world conditions of a school setting. Although outcome evaluations of school-based PA interventions delivered in controlled settings are crucial for determining efficacy, research suggests that when these interventions are subsequently delivered under real world conditions, their success may be limited.[145] Thus, a focus of this program of research was to conduct studies under real world conditions using a social ecological approach that recognises the interplay of individual, social and environmental factors that may affect implementation.[143,264]

8.4.1 Study design and sample size

Several study designs were employed in this program of research to address the thesis objectives and study aims including a systematic review, three cross-sectional studies and an exploratory pilot study.

The **Systematic review (Chapter 3)** identified several gaps in the existing literature, which guided the four studies included in this program of research. The systematic review was conducted in accordance with PRISMA guidelines,[157] which is the study's most notable strength. In addition, a total of 55 peer-reviewed studies were included in the review, representing findings from a large sample of typically developing school-aged children and adolescents from over 20 different countries. The methodological quality of each study was also assessed using a modified Downs and Black tool,[159] which subsequently guided the interpretation of the summary levels of evidence. Key limitations of the **Systematic review (Chapter 3)** include the fact that findings were synthesised from studies with predominantly cross-sectional, longitudinal and quasi-experimental designs, with a limited number of experimental studies with robust study designs eligible for inclusion. The use of a single reviewer for the article screening and selection process may also have introduced selection bias. It was also challenging to clearly compare and interpret the findings across studies due to the considerable heterogeneity of the outcome measures used between studies to assess motor proficiency and academic performance in mathematics and reading.

Study 1 (Chapter 4), Study 2 (Chapter 5) and Study 3 (Chapter 6) followed the 'Strengthening the Reporting of Observational Studies in Epidemiology' (STROBE) guidelines[295] to ensure adequate reporting of the cross-sectional study designs employed. However, a notable limitation of utilising a cross-sectional study design is that data is only collected at a single point in time and results cannot infer causality when examining relationships between variables.

It was acknowledged from the outset that a major limitation of the design of **Study 4 (Chapter 7)** was that due to the constraints of undertaking evaluation research alongside the Tweed Healthy Schools Project (THSP); a school-based participatory action project, it was not possible to infer whether differences observed between the three Year 1 classes in academic performance and motor proficiency were solely due to the 12-week classroom-based gross motor program. As the three classes came from two different schools, were comprised of different groups of children, and each class had a different teacher, these factors may have influenced the findings as they may well influence future implementation of such a program. Additionally, as the classroom-based program delivered in this study involved gross motor activities with and without an academic focus incorporated into the regular school day, we are unable to determine whether one or both of these components may be associated with the observed findings. However, in order to minimise risk of confounding, the two classes at the school where the THSP was implemented and the comparison class at the additional school were matched as closely as possible. Both schools were public primary schools located in the same geographical regions and the same Year 1 Australian Curriculum was delivered to all three classes. The advantage, on the other hand, of conducting this exploratory pilot study was that findings could be used to inform the design of a future study which is larger with more robust evaluation methods whilst embedded in the real-world context of the school environment.[276]

Finally, the small sample size of the cohorts of Year 1 children **(Study 1, Chapter 4; Study 2, Chapter 5; Study 4, Chapter 7)** may limit the generalisability of the study findings reported in this program of research to children in all school jurisdictions in Australia. However, teaching in all schools in Australia is guided by the Australian Curriculum which was implemented to Year 1 children participating in the studies and thus this curriculum is likely similar to that delivered in a large proportion of other Australian schools. The most significant limitation of **Study 3 (Chapter 6)** was that only a small number of participant survey responses were available for analysis. Therefore, the generalisability of the study findings to educators and school principals in all school jurisdictions in Australia may be limited.

8.4.2 Outcome measures

The outcome measures selected to assess children's PA, motor proficiency and academic performance in the studies included in this doctoral program of research were chosen following a thorough review of the literature on the topic and careful consideration of the reliability and validity of the tools.

For **Study 1 (Chapter 4)** and **Study 4 (Chapter 7)**, motor proficiency and academic performance were measured using the BOT-2[59] and the WIAT-II Australian[112] which were chosen for utilisation in the doctoral program of research as they are internationally recognised, valid and reliable standardised assessments tools for measuring motor proficiency[74] and academic performance, respectively. However, given the limited time and resources available to conduct multiple assessments within the school setting, it was not possible to assess children's health-related physical fitness or cognitive function as outcomes in **Study 1 (Chapter 4)** or **Study 4 (Chapter**

7). Therefore, future observational studies should ideally assess the relationship between the components of both health-related physical fitness and motor proficiency, and academic performance. Similarly, future experimental studies could further investigate whether classroom-based PA interventions with cognitively engaging aerobic activities or cognitively engaging gross motor skill activities or both are more beneficial for children's academic performance.

One of the main strengths of **Study 2 (Chapter 5)** was that in assessing Year 1 children's PA using the OSRAC-E direct observation tool, a social ecological approach was employed to understand the contextual factors influencing children's PA behaviour during school class time. Furthermore, approximately 44 hours of observation data were collected, representative of the Year 1 timetable at the selected school. A key limitation was that the OSRAC-E direct observation tool has yet to be validated against other measures of PA such as accelerometry, thus the recorded intensity levels of PA may have been over or underestimated. However, it is important to note that the design of the study was modified to assess children's PA during school class time using direct observation only, as the school research jurisdiction did not approve the original plan to assess children's PA using both accelerometers and direct observation as accelerometers were considered to be an 'invasive device'.

A social ecological approach was also used to guide the questionnaire design and analysis of **Study 3 (Chapter 6).** This enabled a greater understanding of the individual, interpersonal, organisational, community and policy level factors that may influence the provision of classroom-based PA to children in the early years of primary school in Australia. The design of the questionnaire was also informed by the implementation science literature regarding school-based PA interventions. Early identification of barriers and facilitators to the implementation of classroom-based PA interventions can subsequently be used to inform the design and implementation of future interventions. Implementation science research suggests this approach may be used to maximise successful translation of interventions into real world contexts.[296]

Finally, whilst this doctoral program of research was undertaken by a registered physiotherapist using a health promotion framework, a strength of this research includes the breadth of literature reviewed which is important considering the multidisciplinary contributions to this field of research. Additionally, being immersed in the school setting **(Study 1, Chapter 4; Study 2, Chapter 5; Study 4, Chapter 7)** afforded deeper insight into the school culture and classroom schedules. This assisted in developing a better understanding of competing demands for students and educators, along with knowledge of policies and priorities in school settings. These understandings have subsequently enabled the researcher to identify ways in which not only physiotherapists, but other allied health professionals working in schools more generally, can best support educators and schools to optimise children's health and educational outcomes.

8.5 Key lessons learned through undertaking research in schools

To guide other researchers wishing to undertake future research within the school setting, the following section provides a summary of key lessons learned whilst undertaking the research studies described in previous chapters, along with the key factors to consider when planning future research within the school setting.

8.5.1 Ethics approval and approval to conduct research in schools

In addition to seeking ethical approval for each of the studies included in this program of research from the Bond University Human Research Ethics Committee, research approval from selected school research jurisdictions in Australia was sought. Each school research jurisdiction differs in their priorities for research being conducted within schools and it is essential to investigate this prior to submitting an application. For **Study 2 (Chapter 5)** and **Study 3 (Chapter 6)**, permission was sought to conduct research in schools across multiple jurisdictions, which differed between states/territories as well as school sectors (e.g., Independent, Catholic and public schools). For **Study 2 (Chapter 5)** this was not a centralised process and applications had to be individually submitted for states and school sectors in accordance with the application guidelines. However, for **Study 3 (Chapter 6)**, a centralised process to conduct research in schools in more than one jurisdiction (sector, state or territory) in Australia was introduced and required the completion of a National Application Form for approval to conduct research in schools.

There were also differences between school research jurisdictions in relation to the extent of support provided for the proposed study methods. For example, in **Study 4 (Chapter 7)**, permission was sought for participants to wear Sensewear monitors (accelerometers) to assess children's PA levels. To analyse data collected by the

Sensewear monitors, participants' height and weight was required. However, the measurement of participants' height and weight was not supported by the school research jurisdiction. Consequently, only parent-reported height and weight could be used in analyses of children's PA levels using Sensewear monitors. Thus, a decision was made to exclude this important data, given the threats to reliability and validity. A similar event occurred for **Study 2 (Chapter 5)**, when seeking permission to assess participants' PA levels. The initial design of the study included monitoring participants' PA levels using accelerometry (ActiGraph), and triangulating and contextualising the data on activity levels with direct observation using the OSRAC-E. However, the use of accelerometry was considered 'invasive' and its use was subsequently not supported by the school research jurisdiction. Therefore, the design of the study was modified to assessing children's PA using direct observation only, which limited the timeframe in which children's PA could be assessed and may have impacted the validity of this data.

8.5.2 Recruitment of schools and study participants

Recruitment of schools and participants for each study proved challenging if a previously established relationship with school principals did not exist. This was one of the challenges encountered during recruitment of participants for **Study 2 (Chapter 5)**, where despite inviting 53 schools to participate in the study, only one school principal agreed to participate. Similarly, in **Study 3 (Chapter 6)**, 36 school principals, identified through existing networks, were invited to participate in the survey study. However, one school principal declined the invitation, and 31 school principals did not respond. Recruiting prospective participants via social media for the survey also proved to be difficult. The challenges encountered when trying to recruit schools may be due to the large number of competing demands that schools face, with many external organisations making requests to conduct research in schools.[145,296] Consequently, schools have been required to develop research priorities to assist them in making decisions around which research projects to support.[297]

It is thus recommended that prior to seeking ethical approval and approval to conduct research in schools, it is important to identify and consult with school principal/s who may be interested in participating in the proposed research study. These early conversations are pivotal in shaping the design and methodology of the research study. This is particularly relevant to any school-based PA interventions as early stakeholder engagement is essential to firstly undertake a needs assessment and secondly, to anticipate and plan for any barriers to implementing the proposed intervention. For example, when undertaking a needs assessment, it is important to discuss with key stakeholders (i.e., school principals, classroom teachers, specialist PE teachers) what current practice at the school entails (e.g., HPE program, organised PA opportunities), along with gaining an understanding of which existing policies are in place (e.g., comprehensive school physical activity program, PA policy, health and wellbeing policies) and how the proposed research may be able to assist their school in addressing existing research priorities.

Similarly, as part of the intervention planning process, it is essential to observe existing practices. For example, if possible, it would be beneficial to spend time observing classroom routines in schools that one may be planning to undertake research, including behaviour management strategies as this will assist in a greater understanding of competing curriculum pressures for both teachers and students. This will also prepare researchers to be flexible to potential changes that may occur during the study as there may be multiple and ongoing changes to proposed timetables due to absences, school assemblies, special days, sports carnivals, assessment and school sport all of which add challenges to implementing robust study designs in school-based research.

8.6 Future investigations

8.6.1 Future classroom-based gross motor programs

Future classroom-based gross motor skill interventions would ideally need to form part of the school's comprehensive school physical activity program that is nested within a broader health promoting schools framework. In isolation and without a school culture that supports children's PA promotion, a classroom-based motor skill intervention may not successfully be adopted, implemented or scaled up.

The recently published PRACTical planning for Implementation and Scale-up (PRACTIS) guide[296] may be consulted to plan a larger, more robust classroom-based gross motor skill intervention with children in the early years of primary school. Four key steps are outlined in the PRACTIS guide including; (i) Step 1: Characterise the parameters of the implementation setting; (ii) Step 2**:** Identify and engage key stakeholders across multiple levels within the delivery system(s); (iii) Step 3: Identify contextual barriers and facilitators to implementation; and (iv) Step 4: Address potential barriers to effective implementation. The social ecological approach used in **Study 3 (Chapter 6)** to identify contextual barriers and facilitators to implementing classroom-based PA to children in the early years of primary school aligns well with the steps outlined in the PRACTIS guide and will usefully inform future classroom-based gross motor skill interventions. Table 28 provides an example of intervention parameters that could be considered in future experimental studies.

Table 28: Example intervention parameters for future experimental studies.

Parameter	
Design	Cluster randomised controlled trial
Sample size	Power size to be determined
Intervention population	School children in Prep/Kindergarten to Year 2
Implementers	Researchers in collaboration with classroom teachers/specialist physical education teachers
Type of PA	Cognitively engaging motor skill program (i.e., tasks that requires motor and problem solving skills/mental engagement)
Theoretical background[48]	Motor learning Principles of variability of practice (complexity, novelty, diversity, effort and successfulness)
Intensity	Not specified
Duration[78]	Minimum of 12 weeks
Frequency	Minimum of three times per week
Outcome measures	**Educational outcomes:** • Academic performance (e.g., measured using standardised mathematics and reading tests, classroom behaviour) • Cognition (e.g., executive function – working memory, inhibition, cognitive flexibility) **PA-related outcomes** • Motor proficiency (e.g., measured using standardised product and/or process-oriented assessment tools) • Health-related physical fitness (e.g., cardiorespiratory fitness) • Physical activity (accelerometery, direct observation)
Groups[34]	1. Intervention group: combines PA with academic content. 2. Non-active control group: only receives the same academic content as intervention group 3. Active control group: only receives the PA component
Participant moderators	Age, sex, socioeconomic status, weight status, relevant medical history
Psychosocial mediators[8,40]	Mood, social belonging, self-esteem, self-efficacy, perceived competence
Process evaluation	Program compliance (attendance) Dimensions of feasibility[260,298] (1) acceptability (e.g., satisfaction) (2) demand (e.g., intention to use) (3) implementation (e.g., success or failure of execution) (4) practicality (e.g., ability of participants to carry out the activity) (5) integration (e.g., fit with infrastructure) (6) adaptation (e.g., degree to which similar outcomes are obtained with a modified format)

Parameter	
	(7) expansion (e.g., potential success of a previously tested activity in a new context) (8) limited efficacy testing (e.g., preliminary effects of the program tested with a small sample)

8.6.2 Expanded role of allied health professionals working within the school setting

Another potential line of enquiry extending from this doctoral program of research relates to further exploring the role of allied health professionals working within the school setting (e.g., physiotherapists, occupational therapists, speech language pathologists, dietitians, exercise physiologists and exercise and sport scientists) in supporting children's health and education outcomes. Further evaluation of school-based participatory action projects involving partnerships between schools, allied health professionals and caregivers is thus warranted. As highlighted in Section 8.3.2, there may be an evolving role for qualified allied health professionals currently working within the school setting to extend the traditional method of service delivery from working with individual students, to employing whole-of-class and whole-of-school initiatives that support health and education outcomes in children of all abilities. Therefore, tiered models of service delivery (e.g., the P4C model) could be evaluated as a model of service delivery for other school-based therapy services, including school-based physiotherapy services both in Australia and internationally.[13]

[13] Please note that all references in this chapter are presented in the References section of the thesis on page 255

Chapter 9: Conclusion

9.1 Key Findings and Conclusions

Findings in relation to the first thesis objective of this doctoral program of research revealed that in a small cohort of Year 1 children in Australia, children's motor proficiency, particularly fine motor integration, was positively associated with their mathematical and reading skills. Observation of existing PA practices during school class time at one primary school in Australia revealed that Year 1 children were predominantly sedentary, undertaking limited amounts of light and moderate to vigorous levels of PA. Incorporating movement into academic lessons and/or during transitions between lessons (i.e., classroom-based PA) was identified as a potential strategy to encourage Year 1 children to be more active during class time. Survey findings indicated that Australian educators and school principals were amenable to providing classroom-based PA to students in the early years of primary school, however, multiple strategies were recommended to train and support school staff in order to do so. Given that motor skill development is considered crucial for other areas of children's development and is positively associated with health-related physical fitness and participation in PA, classroom-based motor skill interventions were identified as a potential solution to promote children's motor proficiency and academic outcomes during the early years of primary school. Participation in a 12-week classroom-based gross motor program, specifically a combination of gross motor circuits and physically active mathematics lessons, was associated with improvements in motor proficiency and academic outcomes in a small sample of Year 1 school children in Australia. In relation to the second thesis objective, these collective findings suggest that early primary school classrooms in Australia may indeed be feasible settings to implement PA, particularly classroom-based motor skill programs, as a strategy to promote children's motor proficiency and academic outcomes, in particular their mathematical outcomes.

Future studies employing more rigorous outcome and process evaluations are required to confirm findings from the exploratory work conducted as part of this doctoral program of research. Key findings can be used to guide schools, educators and caregivers regarding how to best support children's motor proficiency and academic outcomes in the early years of primary school. Specifically, given motor proficiency is positively associated with both academic and health-related outcomes it may be beneficial for educators to implement programs that target children's motor skill development during the early years of primary school. Consistent with the ethos of a health promoting schools framework, findings from this program of research also advocate for schools to consider forming partnerships with paediatric allied health professionals (qualified to assess and facilitate children's motor proficiency and promote children's health and wellbeing), as they may be ideally positioned to support educators to implement these practices.

9.2 Summary of key findings in this thesis

1. Current trends suggest that Australian children are demonstrating low levels of PA, aerobic and muscular fitness and motor skill proficiency. Evidence suggests children's motor skill proficiency is positively associated with health-related outcomes including cardiorespiratory fitness and participation in PA and inversely associated with weight status **(Stage 1).**
2. Significant positive relationships exist between fine and gross motor proficiency and academic performance in mathematics and reading in school-aged children and adolescents. School-based motor skill interventions may be beneficial for children's mathematical and reading skills, however, insufficient evidence currently exists **(Stage 1).**
3. In a small cohort of Year 1 children in Australia, children's overall motor proficiency was related to their mathematical skills and fine motor integration skills were predictive of their mathematical and reading skills **(Stage 2).**
4. Both structured (e.g., implementing movement into academic lessons and/or during transitions between lessons – i.e., classroom-based PA) and unstructured (incidental PA) movement opportunities were identified as potential strategies to encourage Year 1 children to be more active during school class time **(Stage 2).**
5. Multiple strategies need to be employed at the individual (educator) and organisational (school) level to overcome existing barriers (i.e., lack of training, resources and insufficient time) to providing classroom-based PA programs to students in the early years of primary school in Australia. Proposed solutions to overcome barriers include the provision of training and resources to educators, including education regarding the benefits of classroom-based PA **(Stage 2).**

6. Given that motor skill proficiency is positively associated with both health-related and academic outcomes, the early years of primary school may represent an ideal time to target children's motor skill development through the implementation of classroom-based motor skill programs. In a sample of Year 1 children in Australia, participation in a 12-week classroom-based gross motor program was associated with improvements in motor proficiency and academic outcomes, particularly their mathematical skills. Findings from this pilot study may inform larger, more robust experimental studies on this topic **(Stage 3).**
7. In addition to schools, educators and caregivers, findings from this doctoral program of research are relevant to allied health professionals working in schools who are qualified to assess and facilitate children's motor proficiency and promote their overall health and wellbeing.

References

1. Moore T. *Early Childhood and Long Term Development: The Importance of the Early Years.* Perth: Australian Research Alliance for Children and Youth; 2006.
2. Australian Government Department of Education Employment and Workplace Relations for the Council of Australian Governments. *Belonging, Being and Becoming: The Early Years Learning Framework for Australia.* Canberra: Commonwealth of Australia; 2009.
3. Ministerial Council on Education Employment Training and Youth Affairs. *Melbourne Declaration on Educational Goals for Young Australians.* Melbourne: Ministerial Council on Education, Employment, Training and Youth Affairs; 2008.
4. Commonwealth of Australia. *Australian Early Development Census National Report 2018: A Snapshot of Early Childhood Development in Australia.* Canberra: Department of Education and Training; 2019.
5. Piek JP, Hands B, Licari MK. Assessment of motor functioning in the preschool period. *Neuropsychol Rev.* 2012;22(4):402-413. doi:10.1007/s11065-012-9211-4.
6. Adolph KE, Franchak JM. The development of motor behavior. *Wiley Interdiscip Rev Cogn Sci.* 2017;8(1-2):e1430. doi:10.1002/wcs.1430.
7. Adolph KE, Hoch JE. Motor development: Embodied, embedded, enculturated, and enabling. *Annu Rev Psychol.* 2019;70:141-164. doi:10.1146/annurev-psych-010418-102836.
8. Hulteen RM, Morgan PJ, Barnett LM, Stodden DF, Lubans DR. Development of foundational movement skills: a conceptual model for physical activity across the lifespan. *Sports Med.* 2018;48(7):1533-1540. doi:10.1007/s40279-018-0892-6.
9. Lubans DR, Morgan PJ, Cliff DP, Barnett LM, Okely AD. Fundamental movement skills in children and adolescents. *Sports Med.* 2010;40(12):1019-1035. doi:10.2165/11536850-000000000-00000.
10. Cattuzzo MT, dos Santos Henrique R, Ré AHN, et al. Motor competence and health related physical fitness in youth: a systematic review. *J Sci Med Sport.* 2016;19(2):123-129. doi:10.1016/j.jsams.2014.12.004.

11. Holfelder B, Schott N. Relationship of fundamental movement skills and physical activity in children and adolescents: a systematic review. *Psychol Sport Exerc.* 2014;15(4):382-391. doi:10.1016/j.psychsport.2014.03.005.
12. Logan SW, Robinson LE, Getchell N, Webster EK, Liang L-Y, Golden D. Relationship between motor competence and physical activity: a systematic review. *Res Q Exerc Sport.* 2014;85(S1):A14.
13. Logan S, Robinson LE, Wilson A, Lucas W. Getting the fundamentals of movement: a meta‐analysis of the effectiveness of motor skill interventions in children. *Child Care Health Dev.* 2012;38(3):305-315. doi:10.1111/j.1365-2214.2011.01307.x.
14. Eddy LH, Wood ML, Shire KA, et al. A systematic review of randomized and case‐controlled trials investigating the effectiveness of school‐based motor skill interventions in 3‐to 12‐year‐old children. *Child Care Health Dev.* 2019;45(6):773-790. doi:10.1111/cch.12712.
15. Morgan PJ, Barnett LM, Cliff DP, et al. Fundamental movement skill interventions in youth: a systematic review and meta-analysis. *Pediatrics.* 2013;132(5):e1361-e1383. doi:10.1542/peds.2013-1167.
16. Active Healthy Kids Australia. *Muscular Fitness: It's Time for a Jump Start. The 2018 Active Healthy Kids Australia Report Card on Physical Activity for Children and Young People.* Adelaide: Active Healthy Kids Australia; 2018.
17. Hardy LL, Merom D, Thomas M, Peralta L. 30-year changes in Australian children's standing broad jump: 1985–2015. *J Sci Med Sport.* 2018;21(10):1057-1061. doi:10.1016/j.jsams.2018.04.005.
18. Fraser BJ, Blizzard L, Tomkinson GR, et al. The great leap backward: changes in the jumping performance of Australian children aged 11− 12-years between 1985 and 2015. *J Sports Sci.* 2019;37(7):748-754. doi:10.1080/02640414.2018.1523672.
19. Hardy L, Mihrshah S, Drayton B, Bauman A. *NSW Schools Physical Activity and Nutrition Survey (SPANS) 2015: Full Report.* Sydney: NSW Department of Health 2016.
20. World Health Organization. Physical activity. World Health Organization Web site: http://www.who.int/dietphysicalactivity/pa/en/ Published 2017. Accessed May 3, 2018.

21. Aubert S, Barnes JD, Abdeta C, et al. Global Matrix 3.0 physical activity report card grades for children and youth: results and analysis from 49 countries. *J Phys Act Health.* 2018;15:S251-S273. doi:10.1123/jpah.2018-0472.
22. UNICEF. Primary education. UNICEF Web site. https://data.unicef.org/topic/education/primary-education/. Published 2019. Accessed October 11, 2020.
23. OECD. Education at a Glance 2014: OECD Indicators. OECD iLibrary Web site:. http://dx.doi.org/10.1787/eag-2014-en. Published 2014. Accessed October 11, 2020.
24. Langford R, Bonell C, Jones H, et al. The WHO health promoting school framework for improving the health and well-being of students and their academic achievement. *Cochrane Database Syst Rev.* 2014;4 doi:10.1002/14651858.CD008958.pub2.
25. World Health Organization, United Nations Educational Scientific and Cultural Organization. *Global Standards for Health Promoting Schools: Concept Note.* WHO; 2018.
26. Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Rep.* 1985;100(2):126-131.
27. Howie EK, Pate RR. Physical activity and academic achievement in children: a historical perspective. *J Sport Health Sci.* 2012;1(3):160-169. doi:10.1016/j.jshs.2012.09.003.
28. Sibley BA, Etnier JL. The relationship between physical activity and cognition in children: a meta-analysis. *Pediatr Exerc Sci.* 2003;15(3):243-256. doi:10.1123/pes.15.3.243.
29. Fedewa AL, Ahn S. The effects of physical activity and physical fitness on children's achievement and cognitive outcomes: a meta-analysis. *Res Q Exerc Sport.* 2011;82(3):521-535. doi:10.1080/02701367.2011.10599785.
30. Donnelly JE, Hillman CH, Castelli D, et al. Physical activity, fitness, cognitive function, and academic achievement in children: a systematic review. *Med Sci Sports Exerc.* 2016;48(6):1197-1222. doi:10.1249/MSS.0000000000000901.
31. Castelli DM, Centeio EE, Hwang J, et al. VII. The history of physical activity and academic performance research: informing the future. *Monogr Soc Res Child Dev.* 2014;79(4):119-148. doi:10.1111/mono.12133.

32. Vazou S, Pesce C, Lakes K, Smiley-Oyen A. More than one road leads to Rome: a narrative review and meta-analysis of physical activity intervention effects on cognition in youth. *Int J Sport Exerc Psychol.* 2016;17(2):153-178. doi:10.1080/1612197X.2016.1223423.
33. de Greeff JW, Bosker RJ, Oosterlaan J, Visscher C, Hartman E. Effects of physical activity on executive functions, attention and academic performance in preadolescent children: a meta-analysis. *J Sci Med Sport.* 2018;21(5):501-507. doi:10.1016/j.jsams.2017.09.595.
34. Singh AS, Saliasi E, Van Den Berg V, et al. Effects of physical activity interventions on cognitive and academic performance in children and adolescents: a novel combination of a systematic review and recommendations from an expert panel. *Br J Sports Med* 2019;53(10):640-647. doi:10.1136/bjsports-2017-098136.
35. Tomporowski PD, Davis CL, Miller PH, Naglieri JA. Exercise and children’s intelligence, cognition, and academic achievement. *Educ Psychol Rev.* 2008;20(2):111. doi:10.1007/s10648-007-9057-0.
36. Diamond A. Executive functions. *Annu Rev Psychol.* 2013;64:135-168. doi:10.1146/annurev-psych-113011-143750.
37. Haapala EA. Cardiorespiratory fitness and motor skills in relation to cognition and academic performance in children: a review. *J Hum Kinet.* 2013;36:55-68. doi:10.2478/hukin-2013-0006.
38. Best JR. Effects of physical activity on children’s executive function: contributions of experimental research on aerobic exercise. *Dev Rev.* 2010;30(4):331-351. doi:10.1016/j.dr.2010.08.001.
39. Tomporowski PD, McCullick B, Pendleton DM, Pesce C. Exercise and children's cognition: the role of exercise characteristics and a place for metacognition. *J Sport Health Sci.* 2015;4(1):47-55. doi:10.1016/j.jshs.2014.09.003.
40. Diamond A. Effects of physical exercise on executive functions: going beyond simply moving to moving with thought. *Ann Sports Med Res.* 2015;2(1):1011.
41. Pesce C. Shifting the focus from quantitative to qualitative exercise characteristics in exercise and cognition research. *J Sport Exerc Psychol.* 2012;34(6):766-786. doi:10.1123/jsep.34.6.766.

42. Donnelly JE, Greene JL, Gibson CA, et al. Physical Activity Across the Curriculum (PAAC): a randomized controlled trial to promote physical activity and diminish overweight and obesity in elementary school children. *Prev Med.* 2009;49(4):336-341. doi:10.1016/j.ypmed.2009.07.022.
43. Erwin H, Fedewa A, Beighle A, Ahn S. A quantitative review of physical activity, health, and learning outcomes associated with classroom-based physical activity interventions. *J Appl Sch Psychol.* 2012;28(1):14-36. doi:10.1080/15377903.2012.643755.
44. Norris E, Shelton N, Dunsmuir S, Duke-Williams O, Stamatakis E. Physically active lessons as physical activity and educational interventions: a systematic review of methods and results. *Prev Med.* 2015;72:116-125. doi:10.1016/j.ypmed.2014.12.027.
45. Martin R, Murtagh EM. Effect of active lessons on physical activity, academic, and health outcomes: a systematic review. *Res Q Exerc Sport.* 2017;88(2):149-168. doi:10.1080/02701367.2017.1294244.
46. Watson A, Timperio A, Brown H, Best K, Hesketh KD. Effect of classroom-based physical activity interventions on academic and physical activity outcomes: a systematic review and meta-analysis. *Int J Behav Nutr Phys Act.* 2017;14(1):114. doi:10.1186/s12966-017-0569-9.
47. van der Fels IM, te Wierike SC, Hartman E, Elferink-Gemser MT, Smith J, Visscher C. The relationship between motor skills and cognitive skills in 4–16 year old typically developing children: a systematic review. *J Sci Med Sport.* 2015;18(6):697-703. doi:10.1016/j.jsams.2014.09.007.
48. Pesce C, Croce R, Ben-Soussan TD, et al. Variability of practice as an interface between motor and cognitive development. *Int J Sport Exerc Psychol.* 2016;17(2):133-152. doi:10.1080/1612197X.2016.1223421.
49. World Health Organization. *Improving Early Childhood Development: WHO Guideline.* Geneva: World Health Organization; 2020.
50. World Health Organization. Early Child Development. World Health Organization Web site: https://www.who.int/maternal_child_adolescent/topics/child/development/en/. Published 2019. Accessed August 14th, 2019.

51. Naylor P-J, Nettlefold L, Race D, et al. Implementation of school based physical activity interventions: a systematic review. *Prev Med.* 2015;72:95-115. doi:10.1016/j.ypmed.2014.12.034.
52. Nutbeam D. Evaluating health promotion—progress, problems and solutions. *Health Promot Int.* 1998;13(1):27-44. doi:10.1093/heapro/13.1.27.
53. Shonkoff JP, Garner AS, Siegel BS, et al. The lifelong effects of early childhood adversity and toxic stress. *Pediatrics.* 2012;129(1):e232-e246. doi:10.1542/peds.2011-2663.
54. Hills AP, Mokhtar N, Byrne NM. Assessment of physical activity and energy expenditure: an overview of objective measures. *Front Nutr.* 2014;1:5. doi:10.3389/fnut.2014.00005.
55. Warren JM, Ekelund U, Besson H, Mezzani A, Geladas N, Vanhees L. Assessment of physical activity – a review of methodologies with reference to epidemiological research: a report of the exercise physiology section of the European Association of Cardiovascular Prevention and Rehabilitation. *Eur J Cardiovasc Prev Rehabil.* 2010;17(2):127-139. doi:10.1097/HJR.0b013e32832ed875.
56. Howley ET. Type of activity: resistance, aerobic and leisure versus occupational physical activity. *Med Sci Sports Exerc.* 2001;33(6):S364-S369. doi:10.1097/00005768-200106001-00005.
57. Magill RA, Anderson DI. *Motor Learning and Control: Concepts and Applications.* 10th ed. New York: McGraw-Hill 2014.
58. Logan SW, Ross SM, Chee K, Stodden DF, Robinson LE. Fundamental motor skills: a systematic review of terminology. *J Sports Sci.* 2018;36(7):781-796. doi:10.1080/02640414.2017.1340660.
59. Bruininks RH, Bruininks BD. *Bruininks-Oseretsky Test of Motor Proficiency.* 2nd ed. Circle Pines: AGS Publishing; 2005.
60. Dollman J, Okely AD, Hardy L, Timperio A, Salmon J, Hills AP. A hitchhiker's guide to assessing young people's physical activity: deciding what method to use. *J Sci Med Sport.* 2009;12(5):518-525. doi:10.1016/j.jsams.2008.09.007.
61. Corbin CB, Pangrazi RP, Franks BD. Definitions: health, fitness, and physical activity. *Pres Counc Phys Fit Sports Res Dig.* 2000.
62. Adam C, Klissouras V, Ravazzolo M, et al. *EUROFIT-European Test of Physical Fitness.* Rome: Council of Europe; 1987.

63. Welk G, Meredith MD. *Fitnessgram/Activitygram Reference Guide.* Vol 3. Dallas: The Cooper Institute; 2008.
64. Haywood KM, Getchell N. *Life Span Motor Development.* 7th ed. Champaign: Human Kinetics; 2020.
65. Henderson SE, Sugden DA, Barnett AL. *Movement Assessment Battery for Children: Examiner's manual.* 2nd ed: Pearson; 2007.
66. Ulrich D. *Test of Gross Motor Development* 2nd ed. Austin: PRO-ED; 2000.
67. Beery KE. *Beery VMI: The Beery-Buktenica Developmental Test of Visual-Motor Integration.* Minneapolis: Pearson; 2004.
68. Gallahue DL, Ozmun JC, Goodway J. *Understanding Motor Development: Infants, Children, Adolescents, Adults* 7th ed. New York: McGraw-Hill; 2012.
69. Ulrich DA. The test of gross motor development-3 (TGMD-3): administration, scoring, and international norms. *Spor Bilimleri Dergisi.* 2013;24(2):27-33.
70. New South Wales Department of Education and Training. *Get Skilled: Get Active.* Sydney: New South Wales Department of Education and Training; 2000.
71. Kohl III HW, Fulton JE, Caspersen CJ. Assessment of physical activity among children and adolescents: a review and synthesis. *Prev Med.* 2000;31(2):S54-S76. doi:10.1006/pmed.1999.0542.
72. Sirard JR, Pate RR. Physical activity assessment in children and adolescents. *Sports Med.* 2001;31(6):439-454. doi:10.2165/00007256-200131060-00004.
73. McKenzie TL, Van Der Mars H. Top 10 research questions related to assessing physical activity and its contexts using systematic observation. *Res Q Exerc Sport.* 2015;86(1):13-29. doi:10.1080/02701367.2015.991264.
74. Griffiths A, Toovey R, Morgan PE, Spittle AJ. Psychometric properties of gross motor assessment tools for children: a systematic review. *BMJ Open.* 2018;8(10):e021734. doi:10.1136/bmjopen-2018-021734.
75. Dannemiller L, Mueller M, Leitner A, Iverson E, Kaplan SL. Physical therapy management of children with Developmental Coordination Disorder: an evidence-based clinical practice guideline from the Academy of Pediatric Physical Therapy of the American Physical Therapy Association. *Pediatr Phys Ther.* 2020;32(4):278-313. doi:10.1097/PEP.0000000000000753.

76. Sallis JF, Owen N, Fisher E. Ecological Models of Health Behaviour. In: Glanz K, Rimer BK, Lewis FM, eds. *Health Behaviour and Health Education: Theory, Research and Practice* John Wiley & Sons; 2008:465-485.

77. Sallis JF, Simons-Morton BG, Stone EJ, et al. Determinants of physical activity and interventions in youth. *Med Sci Sports Exerc.* 1992;24(6):248-257.

78. Dobbins M, Husson H, DeCorby K, LaRocca RL. School‐based physical activity programs for promoting physical activity and fitness in children and adolescents aged 6 to 18. *Cochrane Database Syst Rev.* 2013;(2) doi:10.1002/14651858.CD007651.pub2.

79. Stodden DF, Goodway JD, Langendorfer SJ, et al. A developmental perspective on the role of motor skill competence in physical activity: An emergent relationship. *Quest.* 2008;60(2):290-306. doi:10.1080/00336297.2008.10483582.

80. Seefeldt V. Developmental motor patterns: Implications for elementary school physical education. In: Nadeau CH, Halliwell WR, Newell KM, Roberts GC, eds. *Psychology of Motor Behavior and Sport.* Champaign: Human Kinetics; 1980:314–323.

81. Robinson LE, Stodden DF, Barnett LM, et al. Motor competence and its effect on positive developmental trajectories of health. *Sports Med.* 2015;45(9):1273-1284. doi:10.1007/s40279-015-0351-6.

82. Poitras VJ, Gray CE, Borghese MM, et al. Systematic review of the relationships between objectively measured physical activity and health indicators in school-aged children and youth. *Appl Physiol Nutr Metab.* 2016;41(6):S197-S239. doi:10.1139/apnm-2015-0663.

83. Barnett LM, Van Beurden E, Morgan PJ, Brooks LO, Beard JR. Does childhood motor skill proficiency predict adolescent fitness? *Med Sci Sports Exerc.* 2008;40(12):2137-2144. doi:10.1249/MSS.0b013e31818160d3.

84. Commonwealth of Australia. *Make Your Move – Sit Less Be Active for Life: Australia's Physical Activity and Sedentary Behaviour Guidelines.* Canberra: Commonwealth of Australia; 2014.

85. Commonwealth of Australia. Australian 24-Hour Movement Guidelines for Children and Young People (5 to 17 years): An Integration of Physical Activity, Sedentary Behaviour, and Sleep. Department of Health Web site:

https://www1.health.gov.au/internet/main/publishing.nsf/Content/health-24-hours-phys-act-guidelines. Published 2019. Accessed May 5th, 2020.

86. Commonwealth of Australia. Australian 24-Hour Movement Guidelines for Children and Young People (5-17 years): An Integration of Physical Activity, Sedentary Behaviour and Sleep – Research Report. Department of Health Web site: https://www1.health.gov.au/internet/main/publishing.nsf/Content/ti-5-17years. Published 2019. Accessed May 5th, 2020.
87. Active Healthy Kids Australia. *Is Sport Enough? The 2014 Active Healthy Kids Australia Report Card on Physical Activity for Children and Young People.* Adelaide: Active Healthy Kids Australia; 2014.
88. Hardy LL, King L, Espinel P, Cosgrove C, A. B. *NSW Schools Physical Activity and Nutrition Survey (SPANS) 2010: Full Report.* Sydney: NSW Ministry of Health; 2010.
89. Hardy L, Reinten-Reynolds T, Espinel P, Zask A, Okely A. Prevalence and correlates of low motor skill competency in Australian children. *J Sci Med Sport.* 2012;15:S58-S59. doi:10.1016/j.jsams.2012.11.142.
90. Stassen Berger K. *The Developing Person Through the Life Span.* New York: Worth Publishers; 2008.
91. Freud S. *The Basic Writings of Sigmund Freud.* New York: Modern Library; 1938.
92. Erikson E. *Childhood and Society.* 2nd ed. New York: Norton; 1963.
93. Skinner BF. *The Behavior of Organisms. An Experimental Analysis.* New York: Appleton-Century; 1938.
94. Bandura A. *Social Foundations of Thought and Action: A Social Cognitive Theory.* Englewood Cliffs, USA: Prentice Hall; 1986.
95. Piaget J. *The Origins of Intelligence in Children.* New York: International Universities Press; 1952.
96. McLeod SA. Bruner - Learning theory in education. Simply Psychology Web site. https://www.simplypsychology.org/bruner.html Published 2019. Accessed June 27, 2020.
97. Vygotsky LS. *Mind in Society: The Development of Higher Psychological Processes.* Cambridge: Havard University Press; 1978.
98. Gottlieb A. *Individual Development and Evolution: The Genesis of Novel Behavior.* New York: Oxford University Press; 1992.

99. Center on the Developing Child Harvard University. Epigenetics and child development: how children's experiences affect their genes. https://developingchild.harvard.edu/resources/what-is-epigenetics-and-how-does-it-relate-to-child-development/. Published 2020. Accessed November 13, 2020.
100. Spencer JP, Clearfield M, Corbetta D, Ulrich B, Buchanan P, Schöner G. Moving toward a grand theory of development: In memory of Esther Thelen. *Child Dev.* 2006;77(6):1521-1538. doi:10.1111/j.1467-8624.2006.00955.x.
101. Palisano RJ, Orlin MN, and , Schreiber J, eds. *Campbell's Physical Therapy for Children*. St Louis: Elsevier; 2017.
102. Gesell A. *Infancy and Human Growth.* New York: Macmillan; 1928.
103. Malone JC. William James and BF Skinner: behaviorism, reinforcement, and interest. *Behaviorism.* 1975;3(2):140-151.
104. Thelen E. The (re)discovery of motor development: learning new things from an old field. *Dev Psychol.* 1989;25(6):946-949. doi:10.1037/0012-1649.25.6.946.
105. Harbourne RT, Dusing S. Motor development and control. In: Palisano RJ, Orlin MN, Schreiber J, eds. *Campbell's Physical Therapy for Children.* 5th ed. St Louis: Elsevier; 2017:30-77.
106. Fitts PM, Posner MI. *Human Performance.* Belmont: Brooks/Cole; 1967.
107. Gordon AM, Magill R. Motor learning: application of principles to pediatric rehabilitation. In: Palisano RJ, Orlin MN, Schreiber J, eds. *Campell's Physical Therapy for Children.* 5th ed. St Louis: Elsevier; 2017:78-98.
108. Diamond A. Close interrelation of motor development and cognitive development and of the cerebellum and prefrontal cortex. *Child Dev.* 2000;71(1):44-56. doi:10.1111/1467-8624.00117.
109. Davis CL, Tomporowski PD, McDowell JE, et al. Exercise improves executive function and achievement and alters brain activation in overweight children: a randomized, controlled trial. *Health Psychol.* 2011;30(1):91. doi:10.1037/a0021766.
110. American Psychological Association. Intelligence: definition. APA Dictionary of Psychology Web site: https://dictionary.apa.org/intelligence Published 2020. Accessed June 28, 2020.

111. American Psychological Association. Cognition: definition. APA Dictionary of Psychology Web site: https://dictionary.apa.org/cognition Published 2020. Accessed June 28, 2020.
112. Wechsler D. *Wechsler Individual Achievement Test - Australian Standardised Edition* 2nd ed. Sydney: Pearson Clinical 2007.
113. Australian Curriculum Assessment and Reporting Authority. What is literacy? Australian Curriculum Web site: https://www.australiancurriculum.edu.au/resources/national-literacy-and-numeracy-learning-progressions/national-literacy-learning-progression/what-is-literacy/. Published 2020. Accessed November 11, 2020.
114. Australian Curriculum Assessment and Reporting Authority. What is numeracy? Australian Curriculum Web site: https://www.australiancurriculum.edu.au/resources/national-literacy-and-numeracy-learning-progressions/national-numeracy-learning-progression/what-is-numeracy/?searchTerm=what+is+numeracy#dimension-content. Published 2020. Accessed November 11, 2020.
115. Best JR, Miller PH, Naglieri JA. Relations between executive function and academic achievement from ages 5 to 17 in a large, representative national sample. *Learn Individ Differ.* 2011;21(4):327-336. doi:10.1016/j.lindif.2011.01.007.
116. American Psychiatric Association. *Diagnostic and Statistical Manual of Mental Disorders (DSM-5®).* American Psychiatric Pub; 2013.
117. Piek JP, Dawson L, Smith LM, Gasson N. The role of early fine and gross motor development on later motor and cognitive ability. *Hum Mov Sci.* 2008;27(5):668-681. doi:10.1016/j.humov.2007.11.002.
118. Davis EE, Pitchford NJ, Limback E. The interrelation between cognitive and motor development in typically developing children aged 4–11 years is underpinned by visual processing and fine manual control. *Br J Psychol.* 2011;102(3):569-584.
119. Koziol LF, Budding DE, Chidekel D. From movement to thought: executive function, embodied cognition, and the cerebellum. *Cerebellum.* 2012;11(2):505-525. doi:10.1007/s12311-011-0321-y.

120. Trudeau F, Shephard RJ. Relationships of physical activity to brain health and the academic performance of schoolchildren. *Am J Lifestyle Med.* 2010;4(2):138-150. doi:10.1177/1559827609351133.
121. Chaddock L, Erickson KI, Prakash RS, et al. Basal ganglia volume is associated with aerobic fitness in preadolescent children. *Dev Neurosci.* 2010;32(3):249-256. doi:10.1159/000316648.
122. Chaddock L, Erickson KI, Prakash RS, et al. A functional MRI investigation of the association between childhood aerobic fitness and neurocognitive control. *Biol Psychol.* 2012;89(1):260-268. doi:10.1016/j.biopsycho.2011.10.017.
123. Chaddock L, Erickson KI, Prakash RS, et al. A neuroimaging investigation of the association between aerobic fitness, hippocampal volume, and memory performance in preadolescent children. *Brain Res.* 2010;1358:172-183. doi:10.1016/j.brainres.2010.08.049.
124. Krafft CE, Schaeffer DJ, Schwarz NF, et al. Improved frontoparietal white matter integrity in overweight children is associated with attendance at an after-school exercise program. *Dev Neurosci* 2014;36(1):1-9. doi:10.1159/000356219.
125. Schaeffer DJ, Krafft CE, Schwarz NF, et al. An 8‐month exercise intervention alters frontotemporal white matter integrity in overweight children. *Psychophysiology.* 2014;51(8):728-733. doi:10.1111/psyp.12227.
126. Hillman CH, Castelli DM, Buck SM. Aerobic fitness and neurocognitive function in healthy preadolescent children. *Med Sci Sports Exerc.* 2005;37(11):1967-1974. doi:10.1249/01.mss.0000176680.79702.ce.
127. Hillman CH, Pontifex MB, Castelli DM, et al. Effects of the FITKids randomized controlled trial on executive control and brain function. *Pediatrics.* 2014;134(4):e1063-e1071. doi:10.1542/peds.2013-3219.
128. Kamijo K, Pontifex MB, O'Leary KC, et al. The effects of an afterschool physical activity program on working memory in preadolescent children. *Dev Sci.* 2011;14(5):1046-1058. doi:10.1111/j.1467-7687.2011.01054.x.
129. Voelcker-Rehage C, Niemann C. Structural and functional brain changes related to different types of physical activity across the life span. *Neurosci Biobehav Rev.* 2013;37(9):2268-2295. doi:10.1016/j.neubiorev.2013.01.028.

130. Audit Office of New South Wales. *New South Wales Auditor-General's Report Performance Audit: Physical Activity in Government Primary Schools.* Sydney: Audit Office of New South Wales; 2012.

131. Morgan PJ, Hansen V. Classroom teachers' perceptions of the impact of barriers to teaching physical education on the quality of physical education programs. *Res Q Exerc Sport.* 2008;79(4):506-516. doi:10.1080/02701367.2008.10599517.

132. Jones JT, Furner M. *WHO Global School Health Initiative: Health-Promoting Schools : A Healthy Setting for Living, Learning and Working* Geneva: World Health Organization; 1998.

133. Gillies S, Dimitrijevich, S., & Lambert, M. *What is a Health Promoting School? A Resource to Assist Schools to Implement a Whole School Approach.* Western Australian Health Promoting Schools Association Inc.; 2011.

134. Department of Education and Training, Queensland Government. Providing occupational therapy and physiotherapy services in the Department of Education and Training: Findings from a statewide check-in 2016. https://www.together.org.au/files/2515/1494/1528/Appendix_9.Labelled.pdf Published 2016. Accessed July 12, 2020.

135. New South Wales Department of Education. Disability, learning and support: Specialist allied health scheme. https://education.nsw.gov.au/teaching-and-learning/disability-learning-and-support/programs-and-services/specialist-allied-health-service-provider-scheme-#What0. Published 2020. Accessed August 22, 2020.

136. State of Queensland (Department of Education). Speech-language therapy services. https://education.qld.gov.au/student/Documents/aa-slprc-brochure-lr.pdf. Published 2019. Accessed December 30, 2020.

137. New South Wales Department of Education. Disability, learning and support: Exercise physiology in schools. https://education.nsw.gov.au/teaching-and-learning/disability-learning-and-support/programs-and-services/specialist-allied-health-service-provider-scheme-/exercise-physiology-in-schools#What0. Published 2020. Accessed August 22, 2020.

138. Centers for Disease Control and Prevention. *Comprehensive School Physical Activity Programs: A Guide for Schools.* Atlanta: U.S. Department of Health and Human Services; 2013.

139. Hills AP, Dengel DR, Lubans DR. Supporting public health priorities: recommendations for physical education and physical activity promotion in schools. *Prog Cardiovasc Dis.* 2015;57(4):368-374. doi:10.1016/j.pcad.2014.09.010.

140. Durlak JA, DuPre EP. Implementation matters: a review of research on the influence of implementation on program outcomes and the factors affecting implementation. *Am J Community Psychol.* 2008;41(3-4):327-350. doi:10.1007/s10464-008-9165-0.

141. Bronfenbrenner U. Toward an experimental ecology of human development. *Am Psychol.* 1977;32(7):513. doi:10.1037/0003-066X.32.7.513.

142. McLeroy KR, Bibeau D, Steckler A, Glanz K. An ecological perspective on health promotion programs. *Health Educ Q.* 1988;15(4):351-377. doi:10.1177/109019818801500401.

143. Spence JC, Lee RE. Toward a comprehensive model of physical activity. *Psychol Sport Exerc.* 2003;4(1):7-24. doi:10.1016/S1469-0292(02)00014-6.

144. Centers for Disease Control and Prevention. Health Equity Resource Toolkit for State Practitioners Addressing Obesity Disparities. https://www.cdc.gov/obesity/downloads/cdchealthequityobesitytoolkit508.pdf. Published 2016. Accessed June 1, 2016.

145. Cassar S, Salmon J, Timperio A, et al. Adoption, implementation and sustainability of school-based physical activity and sedentary behaviour interventions in real-world settings: a systematic review. *Int J Behav Nutr Phys Act.* 2019;16(1):120. doi:10.1186/s12966-019-0876-4.

146. Webster CA, Russ L, Vazou S, Goh T, Erwin H. Integrating movement in academic classrooms: understanding, applying and advancing the knowledge base. *Obes Rev.* 2015;16(8):691-701. doi:10.1111/obr.12285.

147. Kibbe DL, Hackett J, Hurley M, et al. Ten years of TAKE 10!®: integrating physical activity with academic concepts in elementary school classrooms. *Prev Med.* 2011;52:S43-S50. doi:10.1016/j.ypmed.2011.01.025.

148. Active Healthy Kids Australia. *Physical Literacy: Do Our Kids Have All the Tools? The 2016 Active Healthy Kids Australia Report Card on Physical Activity for Children and Young People.* Adelaide: Active Healthy Kids Australia; 2016.

149. Tomporowski PD, Lambourne K, Okumura MS. Physical activity interventions and children's mental function: an introduction and overview. *Prev Med.* 2011;52:S3-S9. doi:10.1016/j.ypmed.2011.01.028.

150. Cacciotti K, Milne N, Orr R. Physical activity and childhood academic achievement: A critical review. *Health Behav Policy Rev.* 2015;2(1):35-45. doi:10.14485/HBPR.2.1.4.

151. Hillman CH, Kamijo K, Scudder M. A review of chronic and acute physical activity participation on neuroelectric measures of brain health and cognition during childhood. *Prev Med.* 2011;52:S21-S28. doi:10.1016/j.ypmed.2011.01.024.

152. Ahamed Y, Macdonald H, Reed K, Naylor P-J, Liu-Ambrose T, Mckay H. School-based physical activity does not compromise children's academic performance. *Med Sci Sports Exerc.* 2007;39(2):371-376. doi:10.1249/01.mss.0000241654.45500.8e

153. Kavale K, Mattson PD. “One jumped off the balance beam”: meta-analysis of perceptual-motor training. *J Learn Disabil.* 1983;16(3):165-173. doi:10.1177/002221948301600307.

154. Hyatt KJ, Stephenson J, Carter M. A review of three controversial educational practices: perceptual motor programs, sensory integration, and tinted lenses. *Educ Treat Children.* 2009;32(2):313-342.

155. Cameron CE, Cottone EA, Murrah WM, Grissmer DW. How are motor skills linked to children's school performance and academic achievement? *Child Dev Perspect.* 2016;10(2):93-98. doi:10.1111/cdep.12168.

156. Grissmer D, Grimm KJ, Aiyer SM, Murrah WM, Steele JS. Fine motor skills and early comprehension of the world: two new school readiness indicators. *Dev Psychol.* 2010;46(5):1008-1017. doi:10.1037/a0020104.

157. Moher D, Liberati A, Tetzlaff J, Altman DG, Group P. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med.* 2009;6(7):e1000097. doi:10.1371/journal.pmed.1000097.

158. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Public Health Rev.* 1998;52(6):377-384. doi:10.1136/jech.52.6.377.

159. Eng J, Teasell R, Miller W, et al. Spinal cord injury rehabilitation evidence: method of the SCIRE systematic review. *Top Spinal Cord Inj Rehabil.* 2007;13(1):1-10. doi:10.1310/sci1301-1.
160. Kennelly J. Methodological approach to assessing the evidence. *Reducing Racial/ethnic Disparities in Reproductive and Perinatal Outcomes.* Boston: Springer; 2011:7-19.
161. Lyons K, Radburn C, Orr R, Pope R. A profile of injuries sustained by law enforcement officers: a critical review. *Int J Environ Health Res.* 2017;14(2):142. doi:10.3390/ijerph14020142.
162. Terry R, Hing W, Orr R, Milne N. Do coursework summative assessments predict clinical performance? a systematic review. *BMC Med Educ.* 2017;17(1):40. doi:10.1186/s12909-017-0878-3.
163. Viera AJ, Garrett JM. Understanding interobserver agreement: the kappa statistic. *Fam Med.* 2005;37(5):360-363.
164. Evans J. *Straightforward Statistics for the Behavioral Sciences.* Thomson Brooks/Cole Publishing Co; 1996.
165. Sallis JF, Prochaska JJ, Taylor WC. A review of correlates of physical activity of children and adolescents. *Med Sci Sports Exerc.* 2000;32(5):963-975.
166. Cliff DP, Hesketh KD, Vella SA, et al. Objectively measured sedentary behaviour and health and development in children and adolescents: systematic review and meta‐analysis. *Obes Rev.* 2016;17(4):330-344. doi:10.1111/obr.12371.
167. Bellocchi S, Muneaux M, Huau A, Lévêque Y, Jover M, Ducrot S. Exploring the link between visual perception, visual–motor integration, and reading in normal developing and impaired children using DTVP‐2. *Dyslexia.* 2017;23(3):296-315. doi:10.1002/dys.1561.
168. Potter D, Mashburn A, Grissmer D. The family, neuroscience, and academic skills: an interdisciplinary account of social class gaps in children’s test scores. *Soc Sci Res.* 2013;42(2):446-464. doi:10.1016/j.ssresearch.2012.09.009.
169. Chagas DV, Leporace G, Batista LA. Relationships between motor coordination and academic achievement in middle school children. *Int J Exerc Sci.* 2016;9(5):616-624.

170. Jaakkola T, Hillman C, Kalaja S, Liukkonen J. The associations among fundamental movement skills, self-reported physical activity and academic performance during junior high school in Finland. *J Sports Sci.* 2015;33(16):1719-1729. doi:10.1080/02640414.2015.1004640.
171. Morales J, Gonzalez L-M, Guerra M, Virgili C, Unnithan V. Physical activity, perceptual-motor performance, and academic learning in 9- to-16-years-old school children. *Int J Sport Psychol.* 2011;42(4):401-415.
172. Rigoli D, Piek JP, Kane R, Oosterlaan J. Motor coordination, working memory, and academic achievement in a normative adolescent sample: testing a mediation model. *Arch Clin Neuropsychol.* 2012;27(7):766-780. doi:10.1093/arclin/acs061.
173. Van Niekerk L, Du Toit D, Pienaar AE. The relationship between motor proficiency and academic performance of adolescent learners in Potchefstroom, South Africa: the PAHL study. *Afr J Phys Health Educ Recreat Dance.* 2015;21(4:2):1321-1336.
174. Esteban-Cornejo I, Tejero-Gonzalez CM, Martinez-Gomez D, et al. Independent and combined influence of the components of physical fitness on academic performance in youth. *J Pediatr.* 2014;165(2):306-312.e302. doi:10.1016/j.jpeds.2014.04.044.
175. Xiang M, Gu X, Jackson A, Zhang T, Wang X, Guo Q. Understanding adolescents' mental health and academic achievement: Does physical fitness matter? *Sch Psychol Int.* 2017;38(6):647-663. doi:10.1177/0143034317717582.
176. Dinehart L, Manfra L. Associations between low-income children's fine motor skills in preschool and academic performance in second grade. *Early Educ Dev.* 2013;24(2):138-161. doi:10.1080/10409289.2011.636729.
177. Duran CA, Byers A, Cameron CE, Grissmer D. Unique and compensatory associations of executive functioning and visuomotor integration with mathematics performance in early elementary school. *Early Child Res Q.* 2018;42:21-30. doi:10.1016/j.ecresq.2017.08.005.
178. Erasmus M, Janse van Rensburg O, Pienaar AE, Ellis S. The effect of a perceptual–motor intervention programme on learning readiness of grade R learners from South African deprived environments. *Early Child Dev Care.* 2016;186(4):596-611. doi:10.1080/03004430.2015.1048245.

179. Gandhi M, Teivaanmaki T, Maleta K, Duan X, Ashorn P, Cheung YB. Child development at 5 years of age predicted mathematics ability and schooling outcomes in Malawian adolescents. *Acta Paediatr.* 2013;102(1):58-65. doi:10.1111/apa.12021.

180. Manfra L, Squires C, Dinehart LH, Bleiker C, Hartman SC, Winsler A. Preschool writing and premathematics predict grade 3 achievement for low-income, ethnically diverse children. *J Educ Res.* 2017;110(5):528-537. doi:10.1080/00220671.2016.1145095.

181. Pitchford NJ, Papini C, Outhwaite LA, Gulliford A. Fine motor skills predict maths ability better than they predict reading ability in the early primary school years. *Front Psychol.* 2016:1-17. doi:10.3389/fpsyg.2016.00783.

182. Pienaar AE, Barhorst R, Twisk JWR. Relationships between academic performance, SES school type and perceptual-motor skills in first grade South African learners: NW-CHILD study. *Child Care Health Dev.* 2014;40(3):370-378. doi:10.1111/cch.12059.

183. Cameron CE, Brock LL, Murrah WM, et al. Fine motor skills and executive function both contribute to kindergarten achievement. *Child Dev.* 2012;83(4):1229-1244. doi:10.1111/j.1467-8624.2012.01768.x.

184. Kim H, Duran CA, Cameron CE, Grissmer D. Developmental relations among motor and cognitive processes and mathematics skills. *Child Dev.* 2018;89(2):476-494. doi:10.1111/cdev.12752.

185. Kurdek LA, Sinclair RJ. Predicting reading and mathematics achievement in fourth-grade children from kindergarten readiness scores. *J Educ Psychol.* 2001;93(3):451-455. doi:10.1037/0022-0663.93.3.451.

186. Lachance JA, Mazzocco MMM. A longitudinal analysis of sex differences in math and spatial skills in primary school age children. *Learn Individ Differ.* 2006;16(3):195-216. doi:10.1016/j.lindif.2005.12.001.

187. Son S-H, Meisels SJ. The relationship of young children's motor skills to later reading and math achievement. *Merrill Palmer Q.* 2006;52(4):755-778. doi:10.1353/mpq.2006.0033.

188. Becker DR, Miao A, Duncan R, McClelland MM. Behavioral self-regulation and executive function both predict visuomotor skills and early academic achievement. *Early Child Res Q.* 2014;29(4):411-424. doi:10.1016/j.ecresq.2014.04.014.

189. Cadoret G, Bigras N, Duval S, Lemay L, Tremblay T, Lemire J. The mediating role of cognitive ability on the relationship between motor proficiency and early academic achievement in children. *Hum Mov Sci.* 2018;57:149-157. doi:10.1016/j.humov.2017.12.002.
190. Mayes SD, Calhoun SL, Bixler EO, Zimmerman DN. IQ and neuropsychological predictors of academic achievement. *Learn Individ Differ.* 2009;19(2):238-241. doi:10.1016/j.lindif.2008.09.001.
191. Sortor JM, Kulp MT. Are the results of the Beery-Buktenica Developmental Test of Visual-Motor Integration and its subtests related to achievement test scores? *Optom Vis Sci.* 2003;80(11):758-763.
192. Verdine BN, Irwin CM, Michnick Golinkoff R, Hirsh-Pasek K. Contributions of executive function and spatial skills to preschool mathematics achievement. *J Exp Child Psychol.* 2014;126:37-51. doi:10.1016/j.jecp.2014.02.012.
193. Luo Z, Jose PE, Huntsinger CS, Pigott TD. Fine motor skills and mathematics achievement in East Asian American and European American kindergartners and first graders. *Br J Dev Psychol.* 2007;25(4):595-614. doi:10.1348/026151007X185329.
194. Roebers CM, Röthlisberger M, Neuenschwander R, Cimeli P, Michel E, Jäger K. The relation between cognitive and motor performance and their relevance for children’s transition to school: A latent variable approach. *Hum Mov Sci.* 2014;33:284-297. doi:10.1016/j.humov.2013.08.011.
195. Pagani LS, Fitzpatrick C, Archambault I, Janosz M. School readiness and later achievement: A French Canadian replication and extension. *Dev Psychol.* 2010;46(5):984-994. doi:10.1037/a0018881.
196. Geertsen SS, Thomas R, Larsen MN, et al. Motor skills and exercise capacity are associated with objective measures of cognitive functions and academic performance in preadolescent children. *PLoS One.* 2016;11(8):1-16. doi:10.1371/journal.pone.0161960.
197. Pagani LS, Messier S. Links between motor skills and indicators of school readiness at kindergarten entry in urban disadvantaged children. *J Educ Develop Psychol.* 2012;2(1):95. doi:10.5539/jedp.v2n1p95
198. Dunn M, Loxton H, Naidoo A. Correlations of scores on the developmental test of visual-motor integration and copying test in a South African multi-ethnic

preschool sample *Percept Mot Skills.* 2006;103(3):951-958. doi:10.2466/PMS.1033.951-958.

199. Suggate S, Stoeger H, Fischer U. Finger-based numerical skills link fine motor skills to numerical development in preschoolers. *Percept Mot Skills.* 2017;124(6):1085-1106. doi:10.1177/0031512517727405.

200. Haapala EA, Poikkeus A-M, Tompuri T, et al. Associations of motor and cardiovascular performance with academic skills in children. *Med Sci Sports Exerc.* 2014;46(5):1016-1024. doi:10.1249/MSS.0000000000000186.

201. Aadland KN, Ommundsen Y, Aadland E, et al. Executive functions do not mediate prospective relations between indices of physical activity and academic performance: The Active Smarter Kids (ASK) study. *Front Psychol.* 2017;8:1088. doi:10.3389/fpsyg.2017.01088.

202. Lonnemann J, Linkersdörfer J, Heselhaus V, Hasselhorn M, Lindberg S. Relations between balancing and arithmetic skills in children: evidence of cerebellar involvement? *J Neurolinguistics.* 2011;24(5):592-601. doi:10.1016/j.jneuroling.2011.02.005.

203. Murrihy C, Bailey M, Roodenburg J. Psychomotor ability and short-term memory, and reading and mathematics achievement in children. *Arch Clin Neuropsychol.* 2017;32(5):618-630. doi:10.1093/arclin/acx033.

204. van der Niet AG, Hartman E, Smith J, Visscher C. Modeling relationships between physical fitness, executive functioning, and academic achievement in primary school children. *Psychol Sport Exerc.* 2014;15(4):319-325. doi:10.1016/j.psychsport.2014.02.010.

205. Magistro D, Bardaglio G, Rabaglietti E. Gross motor skills and academic achievement in typically developing children: The mediating effect of ADHD related behaviours. *Cogn Brain Behav.* 2015;19(2):149.

206. Aadland KN, Moe VF, Aadland E, Anderssen SA, Resaland GK, Ommundsen Y. Relationships between physical activity, sedentary time, aerobic fitness, motor skills and executive function and academic performance in children. *Ment Health Phys Act.* 2017;12:10-18. doi:10.1016/j.mhpa.2017.01.001.

207. Wang Y, Yin L, McBride C. Unique predictors of early reading and writing: a one-year longitudinal study of Chinese kindergarteners. *Early Child Res Q.* 2015;32:51-59. doi:10.1016/j.ecresq.2015.02.004.

208. McPhillips M, Jordan-Black J-A. The effect of social disadvantage on motor development in young children: a comparative study. *J Child Psychol Psychiatry.* 2007;48(12):1214-1222. doi:10.1111/j.1469-7610.2007.01814.x.
209. Cameron CE, Hatfield BE, Brock LL, et al. Visuomotor integration and inhibitory control compensate for each other in school readiness. *Dev Psychol.* 2015;51(11):1529-1543. doi:10.1037/a0039740.
210. Doyen A-L, Lambert E, Dumas F, Carlier M. Manual performance as predictor of literacy acquisition: a study from kindergarten to grade 1. *Cogn Dev.* 2017;43:80-90. doi:10.1016/j.cogdev.2017.02.011.
211. Schatschneider C, Fletcher JM, Francis DJ, Carlson CD, Foorman BR. Kindergarten prediction of reading skills: a longitudinal comparative analysis. *J Educ Psychol.* 2004;96(2):265-282. doi:10.1037/0022-0663.96.2.265.
212. Sigmundsson H, Englund K, Haga M. Associations of physical fitness and motor competence with reading skills in 9-and 12-year-old children: a longitudinal study. *SAGE Open.* 2017;7(2):2158244017712769. doi:10.1177/2158244017712769.
213. Santi KL, Francis DJ, Currie D, Wang Q. Visual-motor integration skills: accuracy of predicting reading. *Optom Vis Sci.* 2015;92(2):217-226. doi:10.1097/opx.0000000000000473.
214. Suggate S, Pufke E, Stoeger H. Do fine motor skills contribute to early reading development? *J Res Read.* 2018;41(1):1-19. doi:10.1111/1467-9817.12081.
215. Papadimitriou AM, Vlachos FM. Which specific skills developing during preschool years predict the reading performance in the first and second grade of primary school? *Early Child Dev Care.* 2014;184(11):1706-1722. doi:10.1080/03004430.2013.875542.
216. Memis A, Sivri DA. The analysis of reading skills and visual perception levels of first grade Turkish students. *J Educ Train Stud.* 2016;4(8):161-166. doi:10.11114/jets.v4i8.1663.
217. Chang M, Gu X. The role of executive function in linking fundamental motor skills and reading proficiency in socioeconomically disadvantaged kindergarteners. *Learn Individ Differ.* 2018;61:250-255. doi:10.1016/j.lindif.2018.01.002.
218. Beck MM, Lind RR, Geertsen SS, Ritz C, Lundbye-Jensen J, Wienecke J. Motor-enriched learning activities can improve mathematical performance in

preadolescent children. *Front Hum Neurosci.* 2016;10:1-14. doi:10.3389/fnhum.2016.00645.

219. Callcott D, Hammond L, Hill S. The synergistic effect of teaching a combined explicit movement and phonological awareness program to preschool aged students. *Early Child Educ J.* 2015;43(3):201-211. doi:10.1007/s10643-014-0652-7.

220. Ericsson I. Motor skills, attention and academic achievements. an intervention study in school years 1-3. *Br Educ Res J.* 2008;34(3):301-313. doi:10.1080/01411920701609299.

221. Adkins DL, Boychuk J, Remple MS, Kleim JA. Motor training induces experience-specific patterns of plasticity across motor cortex and spinal cord. *J Appl Physiol.* 2006;101(6):1776-1782. doi:10.1152/japplphysiol.00515.2006.

222. Gouws C. Influence of an 8-week kinderkinetic movement programme on the scholastic performance of children aged 6-8 years. *Afr J Phys Health Educ Recreat Dance.* 2015;21(4:2):1355-1362.

223. Ericsson I, Karlsson MK. Motor skills and school performance in children with daily physical education in school - a 9-year intervention study. *Scand J Med Sci Sports.* 2014;24(2):273-278. doi:10.1111/j.1600-0838.2012.01458.x.

224. Ardoy DN, Fernandez-Rodriguez JM, Jimenez-Pavon D, Castillo R, Ruiz JR, Ortega FB. A physical education trial improves adolescents' cognitive performance and academic achievement: the EDUFIT study. *Scand J Med Sci Sports.* 2014;24(1):e52-61. doi:10.1111/sms.12093.

225. Fredericks CR, Kokot SJ, Krog S. Using a developmental movement programme to enhance academic skills in grade 1 learners *South African Journal for Research in Sport, Physical Education & Recreation* 2006;28(1):29-42.

226. Uhrich TA, Swalm RL. A pilot study of a possible effect from a motor task on reading performance. *Percept Mot Skills.* 2007;104(3):1035-1041. doi:10.2466/pms.104.3.1035-1041.

227. Macdonald K, Milne N, Orr R, Pope R. Relationships between motor proficiency and academic performance in mathematics and reading in school-aged children and adolescents: A systematic review. *Int J Environ Res Public Health.* 2018;15(8):1603. doi:10.3390/ijerph15081603

228. Pearson Clinical. What is a user level? https://www.pearsonclinical.com.au/products/view/588 Published 2019. Accessed August 31, 2019.
229. Australian Curriculum Assessment and Reporting Authority. Glossary: Index of community socio-educational advantage (ICSEA). My School Web site: https://www.myschool.edu.au/glossary/#i Published 2019. Accessed August 14, 2019.
230. *IBM SPSS Statistics Version 26.* [computer program]. Chicago: IBM Corporation; 2019.
231. Cohen J. *Statistical Power Analysis for the Behavioural Sciences.* 2nd ed. Hillsdale: Lawrence Erlbaum Associates; 1988.
232. Faul F, Erdfelder E, Lang A-G, Buchner A. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods* 2007;39:175-191. doi:10.3758/BF03193146.
233. Allen P, Bennett K. *SPSS Statistics-A Practical Guide.* Sydney: Cengage Learning Australia Pty Ltd; 2012.
234. Field A. *Discovering Statistics using IBM SPSS Statistics.* 4th ed. Los Angeles: Sage; 2013.
235. Carlson AG, Rowe E, Curby TW. Disentangling fine motor skills' relations to academic achievement: the relative contributions of visual-spatial integration and visual-motor coordination. *J Genet Psychol.* 2013;174(5):514-533. doi:10.1080/00221325.2012.717122.
236. McClelland MM, Cameron CE. Developing together: the role of executive function and motor skills in children's early academic lives. *Early Child Res Q.* 2019;46:142-151. doi:10.1016/j.ecresq.2018.03.014.
237. Okely AD, Salmon J, Vella S, et al. *A systematic review to update the Australian physical activity guidelines for children and young people.* Canberra: Commonwealth of Australia; 2012.
238. Biddle SJ, Ciaccioni S, Thomas G, Vergeer I. Physical activity and mental health in children and adolescents: an updated review of reviews and an analysis of causality. *Psychol Sport Exerc.* 2019;42:146-155. doi:10.1016/j.psychsport.2018.08.011.
239. Russ LB, Webster CA, Beets MW, et al. Development of the system for observing student movement in academic routines and transitions

(SOSMART). *Health Educ Behav.* 2017;44(2):304-315. doi:10.1177/1090198116657778.

240. McIver KL, Brown WH, Pfeiffer KA, Dowda M, Pate RR. Development and testing of the observational system for recording physical activity in children: elementary school. *Res Q Exerc Sport.* 2016;87(1):101-109. doi:10.1080/02701367.2015.1125994.

241. Survey Monkey. Margin of error calculator. https://www.surveymonkey.com/mp/margin-of-error-calculator/ Published 2020. Accessed January 10, 2020.

242. McKenzie TL, Sallis JF, Nader PR. SOFIT: System for observing fitness instruction time. *J Teach Phys Educ.* 1992;11(2):195-205. doi:10.1123/jtpe.11.2.195.

243. McKenzie TL, Marshall SJ, Sallis JF, Conway TL. Leisure-time physical activity in school environments: an observational study using SOPLAY. *Prev Med.* 2000;30(1):70-77. doi:10.1006/pmed.1999.0591.

244. Brown WH, Pfeiffer KA, McIver KL, Dowda M, Almeida JM, Pate RR. Assessing preschool children's physical activity: the observational system for recording physical activity in children-preschool version. *Res Q Exerc Sport.* 2006;77(2):167-176. doi:10.1080/02701367.2006.10599351.

245. Tapp J, Wehby J, Ellis D. A multiple option observation system for experimental studies: MOOSES. *Behav Res Methods Instrum Comput.* 1995;27(1):25-31. doi:10.3758/BF03203616.

246. Australian Curriculum Assessment and Reporting Authority. Learning F-2. Australian Curriculum Web site: https://www.australiancurriculum.edu.au/f-10-curriculum/learning-f-2/ Published 2019. Accessed April 15, 2019.

247. Riley N, Lubans DR, Morgan PJ, Young M. Outcomes and process evaluation of a programme integrating physical activity into the primary school mathematics curriculum: the EASY minds pilot randomised controlled trial. *J Sci Med Sport.* 2015;18(6):656-661. doi:10.1016/j.jsams.2014.09.005.

248. Australian Curriculum Assessment and Reporting Authority. Health and Physical Education. Australian Curriculum Web site: https://www.australiancurriculum.edu.au/f-10-curriculum/health-and-physical-education/. Published 2021. Accessed March 7, 2021.

249. Stylianou M, Walker JL. An assessment of Australian school physical activity and nutrition policies. *Aust N Z J Public Health.* 2018;42(1):16-21. doi:10.1111/1753-6405.12751.
250. Lonsdale C, Rosenkranz RR, Peralta LR, Bennie A, Fahey P, Lubans DR. A systematic review and meta-analysis of interventions designed to increase moderate-to-vigorous physical activity in school physical education lessons. *Prev Med.* 2013;56(2):152-161.
251. Howie EK, Schatz J, Pate RR. Acute effects of classroom exercise breaks on executive function and math performance: a dose–response study. *Res Q Exerc Sport.* 2015;86(3):217-224. doi:10.1080/02701367.2015.1039892.
252. Whitt-Glover MC, Ham SA, Yancey AK. Instant Recess®: a practical tool for increasing physical activity during the school day. *Prog Community Health Partnersh.* 2011;5(3):289-297. doi:10.1353/cpr.2011.0031.
253. Guthold G, Stevens, G.A., Riley, L.M., Bull, F.C. Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1·6 million participants. *Lancet Child Adolesc Health.* 2019; doi:10.1016/S2352-4642(19)30323-2.
254. Schranz N, Glennon V, Evans J, et al. Results from Australia’s 2018 report card on physical activity for children and youth. *J Phys Act Health.* 2018;15(Supplement 2):S315-S317. doi:10.1123/jpah.2018-0418.
255. Bauman A, Nutbeam D. *Evaluation in a Nutshell: A Practical Guide to the Evaluation of Health Promotion Programs.* Sydney: Mcgraw-Hill; 2013.
256. Carlson JA, Engelberg JK, Cain KL, et al. Contextual factors related to implementation of classroom physical activity breaks. *Transl Behav Med.* 2017;7(3):581-592. doi:10.1007/s13142-017-0509-x.
257. Webster CA, Zarrett N, Cook BS, Egan C, Nesbitt D, Weaver RG. Movement integration in elementary classrooms: teacher perceptions and implications for program planning. *Eval Program Plann.* 2017;61:134-143. doi:10.1016/j.evalprogplan.2016.12.011.
258. Michael RD, Webster CA, Egan CA, et al. Facilitators and barriers to movement Integration in elementary classrooms: a systematic review. *Res Q Exerc Sport.* 2019;90(2):151-162. doi:10.1080/02701367.2019.1571675.
259. Usher W, Anderton A. Giving the teacher a voice: perceptions regarding the barriers and enablers associated with the implementation of Smart Moves

(compulsory physical activity) within primary state schools. *Cogent Education.* 2014;1(1):980383. doi:10.1080/2331186X.2014.980383.

260. Mazzoli E, Koorts H, Salmon J, et al. Feasibility of breaking up sitting time in mainstream and special schools with a cognitively challenging motor task. *J Sport Health Sci.* 2019;8(2):137-148. doi:10.1016/j.jshs.2019.01.002.
261. Watson A, Timperio A, Brown H, Hesketh KD. Process evaluation of a classroom active break (ACTI-BREAK) program for improving academic-related and physical activity outcomes for students in years 3 and 4. *BMC Public Health.* 2019;19(1):633. doi:10.1186/s12889-019-6982-z.
262. Macdonald D, Abbott R, Lisahunter, Hay P, McCuaig L. Physical activity–academic achievement: student and teacher perspectives on the ‘new’nexus. *Phys Educ Sport Pedagogy.* 2014;19(4):436-449. doi:10.1080/17408989.2013.769510.
263. *Qualtrics software* [computer program]. Provo, Utah.: Qualtrics; 2013.
264. Sallis JF, McKenzie TL, Conway TL, et al. Environmental interventions for eating and physical activity: a randomized controlled trial in middle schools. *Am J Prev Med.* 2003;24(3):209-217. doi:10.1016/S0749-3797(02)00646-3.
265. Elo S, Kyngäs H. The qualitative content analysis process. *J Adv Nurs.* 2008;62(1):107-115. doi:10.1111/j.1365-2648.2007.04569.x.
266. Fink A. *How to Conduct Surveys: A Step-by-Step Guide.* 3rd ed. Thousand Oaks: Sage Publications; 2006.
267. Lynn P, Beerten R, Laiho J, Martin J. *Recommended Standard Final Outcome Categories and Standard Definitions of Response Rate for Social Surveys.* Working Papers of the Institute for Social and Economic Research, paper 2001-2023; 2001.
268. The American Association for Public Opinion Research. *Standard Definitions: Final Dispositions of Case Codes and Outcome Rates for Surveys.* 9th ed: The American Association for Public Opinion Research; 2016.
269. *NVivo qualitative data analysis software* [computer program]. Version 12: QSR International Pty Ltd; 2018.
270. Langille J-LD, Rodgers WM. Exploring the influence of a social ecological model on school-based physical activity. *Health Educ Behav.* 2010;37(6):879-894. doi:10.1177/1090198110367877.

271. Creswell J, Clark VP. *Designing and Conducting Mixed Methods Research.* Thousand Oaks: Sage Publications; 2011.

272. Macdonald K, Milne N, Pope R, Orr R. Factors influencing the provision of classroom-based physical activity to students in the early years of primary school: a survey of educators. *Early Child Educ J.* 2020:1-13.

273. Erwin H, Fedewa A, Ahn S. Student academic performance outcomes of a classroom physical activity ıntervention: a pilot study. *International Electronic Journal of Elementary Education.* 2017;4(3):473-487.

274. Fedewa AL, Ahn S, Erwin H, Davis MC. A randomized controlled design investigating the effects of classroom-based physical activity on children's fluid intelligence and achievement. *Sch Psychol Int.* 2015;36(2):135-153. doi:10.1177/0143034314565424.

275. Have M, Nielsen JH, Ernst MT, et al. Classroom-based physical activity improves children's math achievement: a randomized controlled trial. *PLoS One.* 2018;13(12):e0208787. doi:10.1371/journal.pone.0208787.

276. Hallingberg B, Turley R, Segrott J, et al. Exploratory studies to decide whether and how to proceed with full-scale evaluations of public health interventions: a systematic review of guidance. *Pilot Feasibility Stud.* 2018;4(1):104. doi:10.1186/s40814-018-0290-8.

277. Department of Education. *Fundamental Motor Skills: A Manual for Classroom Teachers.* Melbourne: Department of Education; 1996.

278. Mullender-Wijnsma MJ, Hartman E, de Greeff JW, Doolaard S, Bosker RJ, Visscher C. Physically active math and language lessons improve academic achievement: a cluster randomized controlled trial. *Pediatrics.* 2016;137(3):e20152743. doi:10.1542/peds.2015-2743.

279. Hollar D, Messiah SE, Lopez-Mitnik G, Hollar TL, Almon M, Agatston AS. Effect of a two-year obesity prevention intervention on percentile changes in body mass index and academic performance in low-income elementary school children. *Am J Public Health.* 2010;100(4):646-653.

280. Mullender‐Wijnsma MJ, Hartman E, de Greeff JW, Bosker RJ, Doolaard S, Visscher C. Improving academic performance of school‐age children by physical activity in the classroom: 1‐year program evaluation. *J Sch Health.* 2015;85(6):365-371. doi:10.1111/josh.12259.

281. Resaland GK, Aadland E, Moe VF, et al. Effects of physical activity on school children's academic performance: the Active Smarter Kids (ASK) cluster-randomized controlled trial. *Prev Med.* 2016;91:322-328. doi:10.1016/j.ypmed.2016.09.005.

282. Donnelly JE, Hillman CH, Greene JL, et al. Physical activity and academic achievement across the curriculum: results from a 3-year cluster-randomized trial. *Prev Med.* 2017;99:140-145. doi:10.1016/j.ypmed.2017.02.006.

283. Reed JA, Einstein G, Hahn E, Hooker SP, Gross VP, Kravitz J. Examining the impact of integrating physical activity on fluid intelligence and academic performance in an elementary school setting: a preliminary investigation. *J Phys Act Health.* 2010;7(3):343-351. doi:10.1123/jpah.7.3.343.

284. International Organisation of Physical Therapists in Paediatrics. Statement on paediatric essential and recommended content areas in entry level professional physical therapy education. https://71d3eecd-d358-4043-b57d-0a1cb1a9bd95.filesusr.com/ugd/2a564c_d5afe7fa9ef44a47a8823cfd2893d911.pdf. Published 2011. Accessed September 8, 2019.

285. McMaster University. Partnering for Change. CanChild Web site: https://www.canchild.ca/en/research-in-practice/current-studies/partnering-for-change. Published 2020. Accessed December 30, 2020.

286. Missiuna CA, Pollock NA, Levac DE, et al. Partnering for change: an innovative school-based occupational therapy service delivery model for children with developmental coordination disorder. *Can J Occup Ther.* 2012;79(1):41-50. doi:10.2182/cjot.2012.79.1.6.

287. Occupational Therapy Australia. *Occupational Therapy Guide to Good Practice: Working with Children.* Fitzroy: Occupational Therapy Australia; 2016.

288. The Australian Council for Health Physical Education and Recreation (ACHPER). The importance of the health and physical education learning area in schools: ACHPER national position statement https://www.achper.org.au/advocacy/national-position-statements/importance-of-hpe-in-schools. Published 2014. Accessed December 30, 2020.

289. Exercise & Sports Science Australia (ESSA). Accredited exercise physiologist scope of practice.

https://www.essa.org.au/Public/Professional_Standards/ESSA_Scope_of_Practice_documents.aspx. Published 2018. Accessed December 20, 2020.

290. Australian Physiotherapy Association. Health and Wellbeing of Children and Young People: Position Statement. . https://australian.physio/sites/default/files/RESOURCES/2018_HealthWellbeing_ChildrenandYoungPeople.pdf. Published 2013. Accessed August 25, 2020.

291. World Physiotherapy. Policy statement: Non-communicable diseases. World Physiotherapy Web site: https://world.physio/policy/ps-ncd. Published 2019. Accessed June 21, 2020.

292. American Physical Therapy Association. Physical Therapists' Role in Prevention, Wellness, Fitness, Health Promotion, and Management of Disease and Disability (Position). https://www.apta.org/apta-and-you/leadership-and-governance/policies/pt-role-advocacy. Published 2019. Accessed June 28, 2020.

293. Academy of Pediatric Physical Therapy. The Role and Scope of Pediatric Physical Therapy in Fitness, Wellness, Health Promotion, and Prevention. https://pediatricapta.org/includes/fact-sheets/pdfs/12%20Role%20and%20Scope%20in%20Fitness%20Health%20Promo.pdf?v=1.1 Published 2012. Accessed June 28, 2020.

294. American Occupational Therapy Association. Occupational therapy's role with health promotion. https://www.aota.org/~/media/Corporate/Files/AboutOT/Professionals/WhatIsOT/HW/Facts/FactSheet_HealthPromotion.pdf. Published 2015. Accessed December 30, 2020.

295. Von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE): explanation and elaboration. *Ann Intern Med.* 2007;147(8):573-577. doi:10.7326/0003-4819-147-8-200710160-00010.

296. Koorts H, Eakin E, Estabrooks P, Timperio A, Salmon J, Bauman A. Implementation and scale up of population physical activity interventions for clinical and community settings: the PRACTIS guide. *Int J Behav Nutr Phys Act.* 2018;15(1):51. doi:10.1186/s12966-018-0678-0.

297. Australian Association for Research in Education. National Application Form https://www.aare.edu.au/research-and-advocacy/research-ethics/national-application-form/. Published 2018. Accessed May 10, 2018.
298. Bowen DJ, Kreuter M, Spring B, et al. How we design feasibility studies. *Am J Prev Med.* 2009;36(5):452-457. doi:10.1016/j.amepre.2009.02.002.

Appendices

Appendix A: Supplementary Table S1 from published manuscript (Chapter 3)

Table S1: Key data extracted from observational studies examining the relationship between motor proficiency and academic performance in mathematics and reading in school-aged children and adolescents

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
Aadland et al. (b) (2017) Norway	Longitudinal (7-months follow-up) (sample from Active Smarter Kids cluster-randomized controlled trial)	n=1129 children; 48% girls; Age: M=10.2 ± 0.3 years Schools: n=57	Motor skills composite: Catching with one hand; Throwing at a wall target (both from Movement ABC-2); Shuttle run 10 x 5m (from EUROFIT)	Standardized Norwegian National tests (Numeracy)	Standardized Norwegian National tests (Reading)	ActiGraph accelerometer (physical activity and sedentary time) Andersen test (aerobic fitness) Stroop Color and Word Test (executive function (EF) – inhibition) Verbal Fluency Test (EF - cognitive flexibility) The Trail Making Test (EF - cognitive flexibility) Wechsler Intelligence Scale for Children (4th Edition) – Digit Span Test (EF –working memory) Demographic information (age, body fat, pubertal status, birth weight, SES)	At baseline, significant very weak positive associations between numeracy and aiming (r=0.13, p≤0.05) and catching (r=0.19, p≤0.05); significant association between numeracy and time taken to complete shuttle run (r=-0.28, p≤0.05). At follow up, significant very weak-to-weak positive associations between numeracy and aiming (r=0.18, p≤0.05) and catching (r=0.20, p≤0.05); significant association between numeracy and time taken to complete shuttle run (r=-0.31, p≤0.05) At baseline, significant very weak positive associations between reading and catching (r=0.10, p≤0.05); significant inverse association between reading and time taken to complete shuttle run (r=-0.19, p≤0.05). At follow up, significant very weak positive associations between reading and aiming (r=0.13, p≤0.05) and catching (r=0.13, p≤0.05); significant association between reading and shuttle run (r=-0.20, p≤0.05) A modest mediation effect of executive function was found for the relation between the shuttle run and academic performance in numeracy	85%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
Bellocchi et al. (2017) France	Longitudinal (16-months follow-up)	n=36 children; Age: (T0) M=64.2±3.9 months; (T1) M=82.2±3.9 months SES: Sample was not educationally disadvantaged	Developmental Test of Visual Perception (2nd Edition): Visual motor integration (VMI)		New Language Examination Battery (phoneme identification task; rhyme task; phonological awareness) (assessed at T0) Alouette Test-R (reading fluency and accuracy) (assessed at T1)	Developmental Test of Visual Perception (2nd Edition) (general visual perception quotient; motor reduced visual perception) (assessed at T0)	Significant moderate positive associations between VMI (T0) and reading accuracy (T1) (r=0.456, p<0.01) VMI score (β=0.33, p<0.05) was a significant predictor of reading accuracy No significant associations between VMI and reading fluency, rhyme and phoneme identification	50%
Cameron et al. (2012) USA	Longitudinal (~ 9-months follow-up)	n=213 children; 53% girls; Motor test age (T0): M=4.96±0.42 years; range 3.5-5.75 Achievement test age (T1): M=5.44±0.33 years; range 4.64-6.21 years) SES: Middle SES background Ethnicity: 57% Caucasian, 34% Multiracial, 4% Asian, 3% African American, 1% Hispanic, 1% Arabic	Early Screening Inventory-Revised Fine motor composite (FMC) (replicating a gate with cube blocks; drawing a person; design copy, overall score) Gross motor composite (GMC) (balance, walk line, hopping, skipping) (assessed in pre-kindergarten (TO))	Woodcock Johnson III Test of Achievement (Applied problems subtest) (assessed in fall (T1) and spring (T2) of kindergarten)	Woodcock Johnson III Test of Achievement (Letter-word identification; Passage comprehension; Sound awareness) (assessed in fall (T1) and spring (T2) of kindergarten)	Parent Questionnaire (maternal education) Head-Toes-Knees-Shoulders test (executive function) Woodcock Johnson III Test of Achievement (Picture vocabulary)	Significant weak positive associations found for Fine Motor Composite (FMC) (T0) and reading composite (r=0.35-0.37, p<0.01); letter-word identification (r=0.35-0.37, p<0.01); passage comprehension (r=0.25-0.32, p<0.01); sound awareness (r=0.27-0.29, p<0.01); and applied problems (r= 0.17-0.25, p<0.01) at T1 and T2 Significant very weak-to-weak positive associations found for block task (T0) and all reading outcomes (r=0.15-0.24, p<0.01; applied problems (r=0.11-0.17, p<0.01) at T1 and T2 Significant very weak-to-weak positive associations found for design copy task (T0) and all reading outcomes (r=0.22-0.38, p<0.01); applied problems (r=0.16-0.24, p<0.01) at T1 and T2 Significant very weak-to-weak positive associations found for draw-a-person	70%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
							task (T0) and all reading outcomes (r=0.13-0.20, p<0.01) at T1 and T2 Significant very weak positive associations found for GMC (T0) and reading composite (r=0.17-0.20, p<0.05); passage comprehension (r=0.16, p<0.05); and applied problems (r=0.18-0.19, p<0.05) at T1 and T2 Non-significant associations for GMC (T0) and letter-word identification (T1), sound awareness (T2); and for draw-a-person (T0) and applied problems (T1 and T2) Findings suggest that executive function and fine motor skills make independent contributions to children's entry-level achievement as well as improvement from fall to spring of kindergarten.	
Cameron et al. (2015) USA	Longitudinal (~5-months follow-up) (sample from a randomized controlled trial)	n=467 children; 50.5% girls; Age (T1): Mean = 4.20 ±0.49 years; range 2.72-4.99 SES: Predominantly low income Ethnicity: African American (43%),	Beery-Buktenica Developmental Test of Visual-Motor Integration (Short Form) – Visual Motor Integration (assessed at T1)		Test of Preschool Early Literacy: Print knowledge; Phonological awareness subtests (assessed at T1 and T2)	Pencil tap test (EF-Inhibitory control) Wechsler Preschool and Primary Scale of Intelligence-Revised: Backward digit span test (EF-verbal working memory) Peabody Picture Vocabulary Test-III (receptive vocabulary)	Significant weak-to-moderate positive associations found for Visual motor integration (VMI) (T1) and phonological awareness (T1 and T2) (r=0.31-0.37, p<0.01); and print knowledge (T1 and T2) (r=0.43-0.44, p<0.01)	70%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
		Hispanic (32%); White/ Caucasian (14%), Asian (3%), Multiracial/other (5%), No data (3%) 81% children had English as first language				Woodcock Johnson III Psycho-educational Battery: Picture vocabulary subtest (expressive language) Preschool learning behaviors scale		
Chang et al. (2018) USA	Longitudinal (~6-months follow-up)	n=145 children, 49% girls; Age: M=66.23±2.53 months Schools: n=3 SES: 93% received free lunch (i.e. socially disadvantaged) Ethnicity: 50.3% Latino/Hispanic, 26.4% Caucasian, 21.4% African American, 1.4% Multiracial	PE Metrics (fundamental movement skills index: object control - dribbling, underhand throwing, locomotor - hopping, sliding) (assessed at T0)		Early Literacy Inventory (global reading proficiency) (assessed at T1)	Behavior Rating Inventory of Executive Function - Preschool (inhibit, shift, emotional control, working memory, plan/organize) Demographic information (age, gender, race and language background)	Significant weak positive associations between reading proficiency (T1) and fundamental movement skills (FMS) index (r=0.24, p<0.01), object control (r=0.18, p<0.05) and locomotor (r=0.23, p<0.01) at T0 FMS assessed at the beginning of kindergarten, especially locomotor skills, accounted for a small but unique amount of variance in reading at the end of kindergarten regardless of age, gender, race and language background Relationship between FMS and reading proficiency was fully mediated by global executive function	70%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
Dinehart and Manfra (2013) USA	Longitudinal (~3-years follow-up) (sample from Miami-Dade School Readiness Project)	n=3 234 children; 53% girls; Age (T0): Mean=62.5±3.6 months at T1; re-assessed in Grade 2 (T1) SES: Low SES sample Ethnicity: Hispanic (57%), African American (35%), White/Other (8%)	Learning Accomplishment Profile Diagnostic: Fine motor manipulation (manual dexterity) Fine motor writing (grapho-motor abilities / copying) (assessed at end of pre-kindergarten - T0)	Stanford Achievement Test (SAT10) and GPA (mathematics) (assessed at T1)	Stanford Achievement Test (SAT10) and GPA (reading) (assessed at T1)	Learning Accomplishment Profile Diagnostic (Expressive language ability; language comprehension; cognitive counting; cognitive matching; early counting) Demographics (ethnicity, SES, language spoken at home, days absent from school)	Significant weak positive associations found for fine motor manipulation (FMM) (T0) and SAT10 math (T1) (r=0.22); Unique effect of FMM (T0) (B=1.75, p<0.001) on SAT10 math (T1) with a small effect size (Cohen's d=0.09) Significant weak positive associations found for fine motor manipulation (FMM) (T0 and GPA math (T1) (r=0.21); Unique effect of FMM (T0) (B=0.03, p<0.001) on GPA math (T1) with a modest effect size (Cohen's d=0.14) Significant very weak positive associations found for FMM (T0) and SAT 10 reading (T1) (r=0.15), and GPA reading (T1) (r=0.15) Significant weak positive associations found for fine motor writing (FMW) (T0) and SAT10 math (T1) (r=0.33); Unique effect of FMW (T0) (B=1.20, p<0.001) on SAT10 math (T1) with a small effect size (Cohen's d=0.11) Significant weak positive associations found for fine motor writing (FMW) (T0) and GPA math (T1) (r=0.31, no p-value); Unique effect of FMW (T0) (B=0.03, p<0.001) on GPA maths (T1) with a modest effect size (Cohen's d=0.21) Significant weak positive associations found for FMW (T0) and SAT10 reading (T1) (r=0.30); Unique effect of FMW (T0) (B=0.75, p<0.001) on SAT10 reading (T1) with a modest effect size (Cohen's d=0.11)	80%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
							Significant weak positive associations found for FMW (T0) and GPA reading (T1) (r=0.28); Unique effect of FMW (T0) (B=0.03, p<0.001) on GPA reading (T1) with a modest effect size (Cohen's d=0.11)	
Doyen et al. (2017) France	Longitudinal (~7-months follow-up)	n=86 kindergarten children; 51% girls; Age (T0): Mean = 6.0 years, range: 5 years, 5 months-6 years, 5 months Schools: n=3; Classes: n=6 At follow-up: n=73 Year 1 children; 49% girls	Peg-moving task (manual performance – sum of the mean time taken to move 10 pegs over three trials) (assessed at T0)		Phonological awareness (rhyme matching, syllable segmentation, phoneme recognition) (assessed at T0) Grade 1 assessments: Reading comprehension; word reading; pseudoword reading (assessed at T1)		Manual performance (T0) was significantly and inversely associated with phonological awareness (T0) (r=-0.23, p<0.05); reading comprehension (T1) (r=-0.24, p<0.05); word reading (T1) (r=-0.27, p<0.05); pseudoword reading (T1) (r=-0.24, p<0.05) (i.e. a slower the time on the peg-moving task, the weaker the literacy scores)	65%
Duran et al. (2018) USA	Longitudinal (~6.5-months follow-up) (sample from experimental study)	n=162 children (total); 50% girls n=89 kindergarten children; 48% girls; Age (T0): M=5.5 years ± 4.0 months; n=73 Year 1 children; 52% girls; Age (T0): M=6.6 years ±4.5 months	Developmental Neuro-psychological Assessment: Design copy subtest (visual motor integration) (assessed at T0)	Woodcock Johnson III - Test of Achievement (Applied problems subtest) KeyMath3-3 composite (geometry; measurement; numeration)		Developmental Neuro-psychological Assessment (Attention/EF domain) Demographics (age, gender, ethnicity, SES, group)	Significant moderate-strong positive associations between visual motor integration (VMI) (T0) and combined mathematics composite (T0 and T1) (r=0.57-0.62, p<0.05).; Significant moderate-strong positive associations between VMI (T0) and KeyMath composite and individual measures (T0 and T1) (r=0.40-0.61) Significant moderate positive associations between VMI (T0) and applied problems (T0 and T1) (r=0.50-0.56)	70%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
		SES: 95% qualified for free or reduced-price lunch – low SES Ethnicity: 92% African American		Test of Early Mathematics Ability (TEMA) (assessed at T0 and T1)			Significant moderate positive associations between VMI (T0) and TEMA (T0 and T1) (r=0.53-0.57) EF and VMI were robust and unique predictors of improvement in mathematics performance in a sample of low-SES students in kindergarten / grade 1	
Gandhi et al. (2012) Malawi	Prospective cohort study (~12-years follow-up) (sample from the Lungwena Child Survival Study)	n=415 children (51% original sample of 813); 50.6% female; Age (T0): 5 years; Age (T1): 12 years SES level: 37.1% low, 41% middle, 21.9% high	Developmental Assessment: (gross and fine motor items) (assessed at T0)	12-year old assessments (% of correctly answered maths questions) (assessed at T1)		Developmental Assessment (language and social items) Demographics (age and height; birth weight; gender; gestational duration, father's occupation / literacy, mother's literacy; wealth index; highest school grade complete; number of times a school grade was repeated)	Fine motor score (T0) was independently associated with mathematics score (T1) (regression coefficient=0.412, p=0.032) (observed data); (regression coefficient=0.445, p=0.011) (imputed data) Non-significant associations found for gross motor score (T0) and mathematics (T1) (regression coefficient=0.206, p=0.176) (observed data); (regression coefficient=0.184, p=0.216) (imputed data)	80%
Grissmer et al (2010) USA	Longitudinal (~5-years follow-up) Sample from three data sets:	n=7 830 children (ECLS-K study) n=5 462 children (NLSY study);	ECLS-K study: Early Screening Inventory: Gross motor (skipping, hopping, walking backwards, stand on one foot) and Fine	ECLS-K: Achievement tests (mathematical thinking) Peabody Individual	ECLS-K: Achievement tests (language and literacy) Peabody Individual	Socioemotional (attention, externalizing I&II, Internalizing, social skills) ECLS-K: Achievement tests	Significant positive association found for fine motor and reading achievement (β=0.07, p<0.00001); and maths achievement (β=0.14, p<0.00001) in ECLS-K study	40%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
	Early Childhood Longitudinal Study – Kindergarten Cohort (ECLS-K) National Longitudinal Survey of Youth (NLSY) British Birth Cohort Study (BCS)	Age: 22-47 months n=1 778 (BCS study); Age: 5 years	motor skills (building blocks, copying figures, draw-a-person) BCS study: Fine motor skills (design copy, human figure drawing, profile drawing)	Achievement Test (maths) BCS: Achievement tests (maths)	Achievement Test (reading) BCS: Achievement tests (reading)	(general knowledge; self-control) BCS: Achievement tests (school readiness measures - intellectual and behavioral development) NLSY: Motor and social development instrument assessing children from ages 22-47 months	Significant positive association found for reading achievement and design copy (β=0.26, $p<0.001$); human figure drawing (β=0.09, $p<0.01$) in BCS study Significant positive association found for maths achievement and design copy (β=0.36, $p<0.001$); human figure drawing (β=0.09, $p<0.01$) in BCS study Gross motor measure was not a significant predictor for mathematics achievement and reading achievement	
Haapala et al. (2014) Finland	Longitudinal (~3-years follow-up) (sample from Physical Activity and Nutrition in Children Study and First Steps study)	n=174 children; 43% girls; Age (T0): M=7.7±0.4 years; range 6-8 years At follow up (Grade 3): n=167; 43% girls	5 x 5m Shuttle run test (speed and agility); flamingo balance test; box and block test (manual dexterity); overall motor performance (assessed in Grade 1-T0)	Basic Arithmetic Test (arithmetic skills) (assessed in Grade 1 (T0), Grade 2 (T1) and Grade 3 (T2))	Nationally normed reading battery (reading fluency and comprehension) (assessed in Grade 1 (T0), Grade 2 (T1) and Grade 3 (T2))	Physical measures: Max cycle ergometer (cardiovascular performance); body composition; pubertal status; PA Questionnaire, Parental education Risk of reading disability	Overall, poorer motor performance was associated with worse academic skills in children, especially among boys. Overall motor performance (T0) was associated with reading fluency in grades 1-3 (β=0.28-0.35); reading comprehension in grades 1-3 (β=0.19-0.22); and arithmetic skills in grades 1-3 (β=0.39-0.41) For boys: Longer shuttle run time (T0) was associated with poorer reading fluency in grades 1-3 (β=-0.29 to -0.39, $p<0.01$); reading comprehension in grades 1-2 (β=-0.25 to -0.29, $p<0.05$); and arithmetic skills in grades 1-3 (β=-0.33 to -0.40, $p<0.003$);	85%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
							Poorer balance (T0) was related to poorer reading comprehension in grade 1 (β=-0.20, p=<0.042) Smaller number of cubes moved in box and block test was related to poorer reading fluency in grades 1-2 (β=0.23 to -0.28, p<0.05); reading comprehension in grade 3 (β=0.23, p=0.037); and arithmetic skills in grades 1-2 (β=0.21-0.23, p<0.043) For girls: Longer shuttle run time was associated with poorer reading fluency in grade 3 (β=-0.27, p=0.027); and arithmetic skills in grade 2 (β=-0.25, p=0.0040) Smaller number of cubes moved in box and block test was related to poorer reading fluency in grades 2 (β=0.26, p=0.030)	
Jaakola et al. (2015) Finland	Longitudinal (~2-years follow-up)	n=325 high school students; 50% girls; Age (T0): M=13.08±0.25 years Schools: n=3; classes: n=10	Fundamental movement skill (FMS) tests (leaping, 10 x 5m shuttle run, dribbling, FMS sum score) (assessed in Grade 7 and 8)	Academic performance (marks in mathematics for Grades 7-9)	Academic performance (marks in Finnish language for Grades 7-9)	Self-reported PA	Significant very weak-to-moderate associations between Leaping test (grades 7 and 8) and marks in maths (grades 7-9) for girls (r=0.18-0.41, p<0.05); and weak associations between leaping test (grade 8) and marks in maths (grades 7 and 9) for boys (r=0.24-0.30) Significant very weak positive associations between dribbling task (grade 7) and marks in Finnish language (grade 7) for girls (r=0.17, p<0.05); and marks in maths (grade 9) for boys (r=0.18, p<0.05)	80%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
							Significant very weak positive associations between shuttle run (grade 7) and marks in Finnish language (grade 7) for boys (r=0.17, p<0.05); and marks in maths (grade 9) for boys (r=0.16, p<0.05) Significant very weak positive associations between shuttle run (grade 8) and marks in maths (grade 8 and 9) for boys (r=0.18-0.19, p<0.05); and marks in maths (grade 9) for girls (r=0.20, p<0.05); and Finnish language (grade 7) for boys (r=0.17, p<0.05) Significant very weak positive associations between FMS sum score (grade 7) and maths (grade 7 and 9) for boys (r=0.16-0.18, p<0.05); maths (grade 8 and 9) for girls (r=0.16-0.19, p<0.05) Significant very weak-to-weak positive associations between FMS sum score (grade 8) and maths (grades 7-9) for boys (r=0.18-0.25, p<0.01); maths (grades 8 and 9) for girls (r=0.23-0.25, p<0.05)	
Kim et al. (2017) USA	Longitudinal (2-years follow-up) (sample from three experimental studies)	n=135 Kindergarten students; 50% girls; Age: Mean=5.6±0.3 7 years; range 5.0-6.8 years n=119 Grade 1 students; 46% girls;	Neuro-psychological assessment battery: Visual motor integration (design copy); Visual motor precision (fine motor coordination)	Key Math-3 Diagnostic Assessment (numeration; geometry; measurement) (assessed at beginning of Kindergarten (T0), end of		Demographics (study site; lunch subsidy status; treatment group status) Neuro-psychological assessment battery (visual attention - attention/ EF)	Visual motor integration (VMI) and maths were positively and reciprocally related. Fine motor coordination (FMC) at beginning of kindergarten indirectly contributed to mathematics at the end of year 1 through its effect on VMI at the end of kindergarten Partial correlations (controlling for age):	80%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
		Age: M=6.7±0.43 years; range 6.0-7.9 years SES: 71% eligible for a lunch subsidy Ethnicity: 71% African American, 26% Caucasian, 3% other (Hispanic or Multiracial)	(assessed at beginning of Kindergarten (T0), end of Kindergarten (T1) and end of Grade 1 (T2))	Kindergarten (T1) and end of Grade 1 (T2))			Significant moderate positive associations for kindergarten students between VMI (T0-T2) and maths (T0-T2) (r=0.417-0.575, p<0.01) Significant weak positive associations for kindergarten students between FMC (T0-T2) and maths (T0-T2) (r=0.250-0.383, p<0.01) Significant moderate-to-strong positive associations for year 1 students between VMI (T0-T2) and maths (T0-T2) (r=0.529-0.669, p<0.01), Significant weak positive associations between FMC (T0-T2) and math (T0) (r=0.208-0.237, p<0.05) Non-significant associations for kindergarten students between FMC (T0, T2) and maths (T2); and for year 1 students between FMC (T1) and maths (T0-T2) For both cohorts, FMC did not directly predict mathematic skills	
Kurdek and Sinclair (2001) USA	Longitudinal (~4-5-years follow-up)	n=281 children; 53% girls. Baseline data collected in Kindergarten (T0) At follow-up in Grade 4 (T1): Age: M=11.22±0.35 years; range 10.48-12.05 years	Kindergarten Diagnostic Instrument: Visual motor integration (VMI); Gross motor skills (jumping, skipping, hopping) (assessed at T0)	Ohio proficiency-based assessments in mathematics (assessed at T1)	Ohio proficiency-based assessments in reading (assessed at T1)	Kindergarten Diagnostic Instrument: Verbal skills (auditory memory; concept mastery; form perception; general information; number skills; verbal association; verbal opposite; vocabulary) Visual motor skills (body awareness,	Significant weak positive association between visual motor integration (T0) and maths (T1) (r=0.21, p<0.01). Significant weak positive associations between gross motor skills (T0) and reading (T1) (r=0.17, p<0.01) and maths (T1) (r=0.17, p<0.01) Non-significant associations between VMI (T0) and reading (T1)	75%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
		Middle-class SES 93% White				visual discrimination, visual memory)		
Lachance et al. (2006) USA	Longitudinal (~3-years follow-up)	At baseline (Kindergarten): n=249 children; 52% girls; Age (T0): M=5.83±0.35 years (boys); M=5.72±0.33 years (girls) At follow up (Grade 3): n=214 children; 51% girls; Age: M=8.73±0.30 years (boys); M=8.61±0.32 years (girls) Ethnicity: 89% Caucasian (boys), 83% Caucasian (girls)	Beery-Buktenica Develop-mental Test of Visual-Motor Integration (4th Ed) (assessed in Kindergarten (T0), Grade 1 (T1), Grade 2 (T2) and Grade 3 (T3))	Test of Early Mathematical Ability-2nd Edition (TEMA-2) Keymath revised (numeration, geometry; addition; subtraction; measurement; time and money) Woodcock Johnson-revised (math calculation) Counting trials Maths facts	Woodcock Johnson - Revised (Letter word identification; Word attack) Reading fluency Rapid automatized reading (single word retrieval fluency)	Wechsler Abbreviated Scale of Intelligence (overall cognitive ability) Developmental Test of Visual Perception (2nd edition) - motor reduced subtests (perceptual skills)	Positive associations between visual motor integration (VMI) (T0-T3) and TEMA-2 (T0-T3) (r=0.29-0.49, p=0.05) Positive associations between VMI (T0-T3) and Letter word identification (T0-T3) (r=0.28-0.53, p=0.05) Positive associations between VMI (T0-T3) and word attack (T0-T3) (r=0.21-0.38, p=0.05)	65%
Luo et al. (2007) USA	Longitudinal (~18-months follow-up) (sample from Early Childhood	n=9 816 European American (EUA) Kindergarten children; 49% girls; Age: (T)): M=68.61 months (EUA)	Early Screening Inventory-Revised (ESI-R) – Fine motor skills (replicating a gate with cube blocks, drawing a person, copying 5 simple	Child Assessment Battery (mathematics achievement) (assessed in Kindergarten and Grade 1)		Demographics (SES, parental education level; parental educational expectations for child)	Fine motor skills were positively related to mathematics at kindergarten entry, with the strength of the relationship similar between EAA and EUA children. Fine motor skills were predictive of mathematics performance over time	80%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
	Longitudinal Study – Kindergarten Class (ECLS-K))	n=244 East Asian American (EAA) Children; 51% girls; Age: M=67.07 months (EAA) Ethnicity: White / non-Hispanic (EUA); Asian (EAA)	figures; composite score) (assessed at beginning of Kindergarten)					
Magistro et al. (2015) Italy	Longitudinal (~8-months follow-up)	n=63 children; 48% girls; Age: M=8.4±0.4 years Schools: n=3 Ethnicity: 83% Italian, 9% Romanian, 8% Albanian	Test of Gross Motor Development (2nd Edition) (gross motor skills) (assessed at beginning of school year – T0)	End of school year teacher questionnaire – (scholastic achievement in mathematics) (assessed at end of school year – T1)		Family structure End of school year self-report questionnaire (Attention Deficit Hyperactivity Disorder behavior, scholastic achievements – overall, PE)	Significant moderate positive associations between gross motor skills and maths achievement (r=0.41, p<0.01)	40%
Manfra et al. (2017) USA	Longitudinal (~3-4 years follow-up) (sample from the Miami School Readiness Project)	n=1442; 52.3% girls; Age (T0): 4 years SES: 88.2% registered for free lunch program (low income) Ethnicity: 63.2% Hispanic/Latin	Learning Accomplishment Profile Diagnostic (LAP-D): Fine motor subtest (fine motor manipulation; fine motor copying)	FCAT (student achievement - maths domains) Stanford Achievement Test (10th Ed) (SAT-10) Grade 3 classroom performance (GPA)	FCAT (student achievement - reading domains) Stanford Achievement Test (10th Ed) (SAT-10) Grade 3 classroom performance (GPA)	Demographic information (age, gender, immigration, race/ethnicity, number of days absent, Grade 3 free/reduced lunch status, parental income) LAP-D - cognitive (matching / counting subtest); Language	Significant associations between fine motor manipulation (FMM) and SAT-10 reading (r=0.18, p<0.001), reading GPA (r=0.18, p<0.001), SAT-10 maths (r=0.24, p<0.001), maths GPA (r=0.24, p<0.001) Significant associations between fine motor copying (FMC) and SAT-10 reading (r=0.33, p<0.001), reading GPA (r=0.26, p<0.001), SAT-10 maths (r=0.35, p<0.001), maths GPA (r=0.27, p<0.001),	65%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
		o, 32.3% Black, 3.3% White, 1.2% Other T1: Preschool T2: Year 3	(assessed in Pre-Kindergarten T0)	* Grades (0=F, 4=A) (assessed in Grade 3 – T1)	* Grades (0=F, 4=A) (assessed in Grade 3 – T1)	(comprehension, naming)	While controlling for demographic factors, days absent and school, FMC was a significant predictor of Grade 3 SAT-10 reading (β=0.74, p<0.001) and Grade 3 SAT-10 mathematics (β=0.72, p<0.001) FMM was a significant predictor of Grade SAT-10 mathematics (β=0.48, p<0.001)	
Pagani et al. (a) (2010) Canada	Longitudinal (2-year follow-up) (sample from the Quebec Longitudinal Study of Child Development)	N=1 145 children; 47% girls; Age: 65 months	Teacher-rated motor assessment: Gross motor skills (well-coordinated; climbs stairs; overall physical development) Fine motor skills (proficiency at holding a pen; ability to manipulate object) (assessed in Kindergarten – T0)	Number Knowledge Test (NKT) - (maths) (assessed in Kindergarten – T0) Teacher-reported academic achievement (maths) (assessed in Grade 2 – T1)	Teacher-reported achievement (reading) (assessed in Grade 2 – T1)	Family characteristics (maternal education, SES, income) Peabody Picture Vocabulary Test (vocabulary knowledge) Social Behavior Questionnaire (children's behavioral adjustment) Teacher-rated scale on classroom engagement	Significant very weak-to-weak positive association found between NKT (T0) and fine motor (T0) (r=0.30, p<0.0001); and gross motor (T0) (r=0.19, p<0.0001) Significant very weak-to-weak positive association found between teacher-rated maths marks (T1) and fine motor (T0) (r=0.34, p<0.0001); and gross motor (T0) (r=0.20, p<0.0001) Significant very weak-to-weak positive association found between teacher-rated reading marks (T1) and fine motor (T0) (r=0.35, p<0.0001); and gross motor (T0) (r=0.23, p<0.0001) Fine motor skills in kindergarten were predictive of grade 2 achievement, reading (β=0.11, p<0.01) and maths (β=0.17, p<0.001)	90%
Papadimitiriou et al. (2014) Greece	Longitudinal (2-years follow-up)	Kindergarten (T0): n=300 children; 49% girls; Age: M=5.6±0.36 years; range 5.1-6.7 years	Motor skills test (bead threading task; shape copying task; postural stability task – inclination from upright) (assessed at T0)		Phonological Awareness test (syllable segmentation; recognition of common initial phoneme; deletion of syllable and	Rapid naming test Receptive vocabulary task (oral language skills) Expressive vocabulary task (oral language skills)	Significant weak positive associations between fine motor skills (shape copying) (T0) and phonological awareness (T0) (r=0.337, p<0.01), grade 1 reading performance (T1) (r=0.245, p<0.01), grade 2 reading performance (T2) (r=0.232, p<0.01)	45%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
		Grade 1 (T1): n=288 children; 51% girls; Age: M= 6.7±0.37 years; range 6.1-7.7 years Grade 2 (T2) n=287 children (49% girls); Age: M=7.6±0.37 years; range 7.1-8.2 years			deletion of phoneme) (assessed at T0) Standardized Greek reading tests: word reading accuracy / fluency; pseudoword reading accuracy / fluency; reading comprehension) (assessed at T1 and T2)	Digit span task (phonological short term memory) Pseudo-words repetition task (phonological short term memory) Sound-order test (auditory discrimination)	Significant associations between the inclination from upright on a postural stability task and phonological awareness (r=-0.251, p<0.01), grade 1 reading performance (r=-0.144, p<0.05), grade 2 reading performance (r=-0.0117. p<0.05) (i.e. the larger the inclination from upright on the postural stability task, the lower the scores on reading tasks) Non-significant findings between fine motor skills (bead threading) and phonological awareness; reading performance in grades 1 and 2 Shape copying skills in kindergarten predictive of reading accuracy in grade 2 (β=0.19, p<0.01)	
Roebers et al. (2014) Switzerland	Longitudinal (2-years follow-up)	Pre-Kindergarten (T0): n=169 children; 45.6% girls); Age: M=69.4±4.28 months Grade 1 (T2): n=116 children; Age: M=7 years, 9 months Ethnicity: >97 % sample white	Movement Assessment Battery for Children – 2nd Edition (manual dexterity scale) (assessed at T0 and T1)	Heidelberger Rechentest – Standardized mathematics test (assessed at T2)	Wurburger Leise Lese Probe – Standardized reading test Salzburger Lese-Screening – Standardized reading test (assessed at T2)	Cognitive Flexibility Task (Executive function (EF)) Fruit-Stroop Task (EF) Backwards Color Recall task (EF) Culture-Fair Intelligence Test (intelligence) Test of Non-Verbal Intelligence (intelligence)	Significant weak positive associations between reading achievement (T2) and threading beads (T0) (r=0.36, p<0.001); posting coins (T0) (r=0.27, p<0.001); threading lace (T1) (r=0.34, p<0.001); placing pegs (r=0.35, p<0.001); drawing trail (T0 and T1) (r=0.28-0.35, p<0.001) Significant weak positive associations between maths achievement (T2) and threading beads (T0) (r=0.28, p<0.001), posting coins (T0) (r=0.24, p<0.01), threading lace (T1) (r=0.37, p<0.001), placing pegs (T1) (r=0.35, p<0.001); drawing trail (T0 and T1) (r=0.18-0.23, p<0.05)	85%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
Schatschneider et al. (2004) USA	Longitudinal (3-years follow-up) (sample from larger longitudinal study)	n=540 children (total) n=384 children in Kindergarten (T0) to grade 1 (T1) cohort; 50% girls; Ethnicity: 54.4% Caucasian, 16.8% African American, 15,2% Hispanic, 12.4% Asian, 1.3% Other n=189 children in Kindergarten (T0), Grade 1 (T1) and Grade 2 (T2) cohort; 48% girls; Ethnicity: 54% Caucasian, 14.3% African American, 16.4% Hispanic, 14.3% Asian, 1% other	Beery Test of Visual Motor Integration (visual-motor integration)		Phonological awareness Alphabetic knowledge (letter names, letter sounds) (assessed at T0) Woodcock-Johnson Psycho-Educational Battery – Revised: (Letter word identification, passage comprehension) Test of Word Reading Efficiency (word reading efficiency) (assessed at T1 and T2)	Clinical Evaluation of Language Functions - Revised (expressive syntax; syntactic comprehension) Rapid Automatized Naming Peabody Picture Vocabulary Test - Revised (oral vocabulary) Recognition-discrimination test (visual perceptual task)	Very weak-to-weak correlations found between visual motor integration (VMI) and reading variables (letter sounds/names, phonological awareness, passage comprehension, word identification, word reading efficiency) from October Kindergarten to end of Grade 1/ 2 (r=0.27-0.37) as well as April Kindergarten to end of Grade 1 / 2 (r=0.13-0.34) VMI consistently less related to early reading achievement than phonological awareness, rapid automatized naming letter and knowledge of letter names and sounds When controlling for phonological awareness, VMI not a significant predictor for reading outcomes in Grade 1 & 2	65%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
Sigmundsson et al. (2017) Norway	Longitudinal (~2 ½ years follow-up)	(T0): n=67; 46% girls Age: M=9.7±0.3 years; range: 9.3-10.2 years (T1): n=58; 48% girls Age: M=12.1±0.2 years	TPF - physical fitness (jumping, throwing, climbing, running) Movement ABC (manual dexterity, ball skills, balance) (assessed at T0 and T1)		Word Chain Test (reading achievement) (assessed at T0 and T2)		Significant moderate positive association found between reading and physical fitness in 9-year old girls (r=0.404, p<0.05) All other associations between overall motor competence (MABC) and physical fitness (TPF) and reading in children who are 9 and 12 years of age were not significant	55%
Son and Meisels (2006) USA	Longitudinal (~18-months follow-up) (sample from the Early Childhood Longitudinal Study-Kindergarten)	Kindergarten (T0) n=12 583 children; 49.6% girls; Age: M=65±4.07 months; range 49 to 83 months Grade 1 (T1) SES: 20% income below poverty line Ethnicity: 15.5% African American, 17.5% Hispanic	Early Screening Inventory-Revised: Visual motor skills (building a gate, draw-a-person, copying figures) Gross motor skills (balancing, hopping, skipping, walking backwards) (assessed at T0)	National Center for Education Statistics (mathematics assessments) (assessed at T0 and T1)	National Center for Education Statistics (reading assessments) (assessed at T0 and T1)	Demographics (age; gender; ethnicity; home language; SES)	Significant weak-to-moderate positive associations between visual motor skills (T0) and reading (T0 and T1) (r=0.35-0.40, p<0.001); and maths achievement (T0 and T1) (r=0.44-0.48, p<0.001) Significant weak positive associations between gross motor skills (T0) and reading (T0 and T1) (r=0.15-0.19, p<0.001); and maths (T0 and T1) (r=0.20-0.22, p<0.001)	90%
Verdine et al. (2014) USA	Longitudinal	Pre-Kindergarten (T0): n=44 children; 50% girls; Age: M=45.5±2.37 months; range 38-48 months;	Beery Test of Visual-Motor Integration – (visual-motor integration) (assessed at T1)	Wechsler Individual Achievement Test (3rd Edition) (math problem solving subtest) (assessed at T1)		Demographics (SES, gender) Peabody Picture Vocabulary Test (vocabulary)	Significant strong positive association between visual motor integration (VMI) and maths (r=0.673, p<0.01) Significant partial correlations (controlling for SES, gender and vocabulary) between VMI and maths (r=0.43, p=0.005)	80%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
		Age (T1): M=57.1±2.54 months; range 52-62 months SES: 45% low SES				Flexible Item Selection Task (cognitive flexibility) The Tap Test (inhibitory control) Test of Spatial Assembly (early geometric and spatial reasoning)	VMI was a significant predictor of maths (β=0.346, p=0.05)	
Wang et al. (2015) China	Longitudinal (1-year follow-up)	Kindergarten (T0) n=85 children; 53% girls; Age: M= 5 years 2 months; range 4 years 9 months-6 years 2 months (T1): n=73 Year children SES: Middle income families	Visual-motor skill (Copying Korean and Hebrew words) (assessed at T0)		Chinese word recognition task (word reading) (assessed at T0 and T1) Phonological Awareness (assessed at T0)	Mother's highest level of education Visual-orthographic copying skill – unfamiliar Chinese Rapid Automatized Naming for numbers Raven's Standard Progressive Matrices (non-verbal IQ) Chinese word writing Semantic radical awareness Stanford-Binet Intelligence Scale - vocabulary subtest (expressive vocabulary) Morphological awareness	After controlling for age and IQ, no significant associations between Chinese reading and copying skills (r=0.15-0.23, ns)	75%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
Aadland et al. (a) (2017) Norway	Cross-sectional (61.7% sample from Active Smarter Kids cluster-randomized controlled trial)	n=697 children; 51% girls; Age: M=10.2±0.3 years Schools: n=57	Motor skills composite: Catching with one hand; Throwing at a wall target (both from Movement ABC-2); Shuttle run 10 x 5m (from EUROFIT)	Standardized Norwegian National tests (Numeracy)	Standardized Norwegian National tests (Reading)	ActiGraph accelerometer (physical activity and sedentary time) Andersen test (aerobic fitness) Stroop Color and Word Test (executive function (EF) – inhibition) Verbal Fluency Test (EF - cognitive flexibility) The Trail making test (EF- cognitive flexibility) Wechsler Intelligence Scale for Children (4th Edition) - Digit Span Test (EF–working memory) Demographic information (age, body fat, pubertal status, birth weight, SES)	Significant positive associations between motor skills composite and numeracy for boys (standardized regression coefficient β=0.17, p<0.05); and girls (β=0.22, p<0.05) Significant positive associations between motor skills composite and reading for girls (β=0.14, p<0.05) Non-significant associations between motor skills composite and reading for boys	70%
Becker et al. (2014) USA	Cross-sectional	n=127 pre-kindergarten and kindergarten children; 46% girls; Age M=68.55±7.75	Beery Visual-Motor Integration (6th Edition) Visual-motor skills (VMS)	Woodcock Johnson Psycho-Educational Battery-III Tests of Achievement) (applied	Woodcock Johnson Psycho-Educational Battery-III Tests of Achievement (letter-word	Maternal education, enrolment in Head Start, English language Woodcock Johnson Psycho-Educational Battery-III Tests of	Significant strong positive association between VMS and letter-word identification (r=0.62, p<0.05); and mathematics (r=0.59, p<0.05) Children's VMS scores were positively associated with children's emergent literacy scores (β=0.18, p=0.015),	60%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
		months; range 53-80 months n=49 prekindergarte n children; 45% girls; Age: M= 59.88 months n=78 kindergarten children; 47% girls; Age: M=74 months SES: Middle and low income households Ethnicity: 67% white, 2% African American, 15% Latino/ Hispanic, 5% Asian/Pacific Islander, 11% other		problems subtest)	identification subtest)	Achievement – (picture vocabulary subtest - expressive and receptive vocabulary) Head-Toes-Knees-Shoulders task (behavioral self-regulation) Day-Night Stroop task (inhibitory control) Woodcock-Johnson Auditory Working Memory (working memory)	(adjusting for English language learner status, gender, age and maternal education) Children's VMS scores were significantly related to maths (β=0.13, p=0.045), (adjusting for English language learner status, gender, age and maternal education)	
Cadoret et al. (2018) Canada	Cross-sectional (sample from longitudinal research project - Young Children and their	n=152 children; 55% girls; Age: 7 years	Bruininks Oseretsky Test of Motor Proficiency (2nd Edition) (Short Form) (Total motor proficiency standard score)	Wechsler Individual Achievement Test (2nd Edition) (mathematics composite)	Wechsler Individual Achievement Test (2nd Edition) (reading composite)	Wechsler Intelligence Scale for Children (4th Edition) (cognitive ability)	Significant weak positive association between Total motor proficiency and reading composite (r=0.28, p<0.01) Significant weak positive association between Total motor proficiency and mathematics composite (r=0.21, p<0.05)	60%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
	Environment s)						The relation between motor proficiency and academic performance is mediated by cognitive ability (specifically working memory and perceptual reasoning processes)	
Chagas et al. (2016) Brazil	Cross-sectional	n=122 students; 57.4% girls; Age: range 12-14 years M=13.8±0.7 years (girls); M=13.8±0.6 years (boys)	Korper-koordination Test fur Kinder (Gross motor coordination – walking backwards, one-leg hop, two-leg jump, moving sideways)	Portuguese Mathematics standardized regional test (academic achievement in maths)	Portuguese Language standardized regional test (academic achievement in reading)	Body mass (kg) Physical Activity Questionnaire for Older Children (PA levels)	No significant associations found for gross motor coordination and reading/ mathematics	50%
Dunn et al. (2006) South Africa	Cross-sectional	n=238 children; 47% girls Age: M=5.8±0.3years; range 4 years 9 months-7 years, 0 months SES: 86 participants from Upper, 58 middle, 25 lower Ethnicity: 28% White, 30% Black, 42% coloured	Beery Developmental Test of Visual-Motor Integration (3rd Edition): Visual motor integration Copying test (visual motor integration)	Teacher's ratings on academic abilities (arithmetic skills - 7 point Likert scale)	Teacher's ratings on academic abilities (reading skills - 7 point Likert scale)	Teacher's ratings on academic abilities (school readiness, fine motor skills, concentration, writing)	Significant moderate positive associations found for visual motor integration (VMI) and arithmetic (r=0.44, p<0.01); reading (r=0.42, p<0.01) Significant moderate-to-strong positive associations between Copying test and arithmetic (r=0.58, p<0.01); and reading (r=0.60, p<0.01)	40%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
Esteban-Cornejo et al. (2014) Spain	Cross-sectional (sample from the UP & DOWN longitudinal study)	n=2038 children and adolescents; 48.5% girls; Age: Mean 10.20±3.31 years; range 6-18 years	Assessing Levels of Physical Activity (ALPHA) fitness test battery - Motor ability (4 x 10m shuttle run test of speed of movement, agility and coordination)	Individual grades (mathematics)		Individual grades (language) and combined Grade Point Average ALPHA fitness test battery (muscular strength, cardiorespiratory capacity) Demographics (SES, pubertal status, BMI, waist circumference)	Significant positive associations found for motor ability and mathematics (standardised regression coefficient β=0.254, p<0.001) (controlling for gender, age, city, pubertal status and maternal education) Motor ability was independently and significantly associated with mathematics (β=0.185, p<0.001) (controlling for gender, age, city, pubertal status and maternal education, cardiorespiratory capacity, muscular strength)	60%
Geerstsen et al. (2016) Denmark	Cross-sectional	n=423 children; 49.4% girls; Age: Mean= 9.29±0.35 years; range 8-10 years Schools: n=7; Classes: n=20	Visuomotor accuracy-tracking task (fine motor skills) Coordination wall task (gross motor skills)	Danish Standardized test of academic performance (mathematics)	Danish Standardized test of academic performance (reading comprehension)	Anthropometric measures (body mass, BMI, tanner stage) YoYo intermittent recovery level 1 children's test (exercise capacity) Cambridge Neuro-psychological Test Automated Battery (reaction time, sustained attention ability, spatial working memory, paired associated learning, free-recall word memory)	Fine motor skill was associated with better academic performance in mathematics (estimated slope coefficient 0.20±0.03, p<0.001) and reading comprehension (estimated slope coefficient of 0.26±0.05, p<0.001) Better performance in gross motor skills (i.e. shorter time to complete the wall) was associated with better scores in mathematics (estimated slope coefficient -0.22±0.03, p<0.001) and reading comprehension (estimated slope coefficient -0.32±0.05, p<0.001)	55%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
Lonneman et al. (2011) Germany	Cross-sectional	n=53 children; 40% girls; Age: M=9.0 years; range 8 to 10 years	Static balance tasks (standing on right or left leg, eyes open / closed)	DEMAT 2+ German scholastic achievement test for mathematics Arithmetic tasks (addition with/without carrying, subtraction with/without borrowing, multiplication)		D2 Test of Attention (attentional capabilities) Raven's Standard Progressive Matrices Plus (reasoning capabilities)	Balancing with eyes open was related to DEMAT 2+ score (r=0.25, p<0.05), multiplication (r=0.25-0.31, p<0.05) and addition/subtraction tasks without carrying/borrowing (r=0.23-0.24, p<0.05) Balancing with eyes closed was related to multiplication (r=0.36-0.37, p<0.05) and subtraction with borrowing (r=0.26-0.34, p<0.05) Significant partial correlations between balance tasks with eyes closed and multiplication (r=0.30-0.34, p<0.05); subtraction with borrowing (r=0.26-0.27, p<0.05) but not for less complex addition/subtraction tasks (controlling for age, attentional and reasoning capabilities)	55%
Mayes et al. (2009) USA	Cross-sectional (sample from a general population epidemiologic study of sleep disorders in children)	n=214 children; 53% girls; Age: M=8.6±1.5 years; range 6-12 years Ethnicity: 78% White, 17% Black, 5% Asian	Beery Developmental Test of Visual-Motor Integration (4th Edition): Visual-motor integration (VMI) Grooved Pegboard Test (fine motor ability)	Wide Range Achievement Test (3rd Edition) (arithmetic subtest)	Wide Range Achievement Test (3rd Edition) (reading subtest)	Gordan Diagnostic System (attention) Wechsler Intelligence Scale for Children-III Digit span (working memory, attention); Symbol search (processing speed); Coding (grapho-motor speed) California Verbal Learning Test (memory) Wisconsin Card Sorting Test-64 (set shifting and mental flexibility)	IQ, VMI and Coding significant predictors of maths VMI and fine motor skills not predictors of reading achievement scores	60%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
						Stroop Color and Word Test (response inhibition) Animal Naming Test (verbal fluency) Pediatric Behavior Scale (ADHD Subscale) Wechsler Abbreviated Scale of Intelligence (IQ)		
McPhillips and Jordan-Black (2007) Ireland	Cross-sectional	n=239 Year 1 children; 39% girls; Age: M=57.4±3.6 months n=276 Year 4 children; 50% girls; Age: M=101.4±4.5 months	Movement ABC (M-ABC) (manual dexterity, ball skills, balance skills)		Wechsler Objective Reading Dimensions (basic reading subtest) (assessed only in Year 4 children)	Shilder Test (persistence of asymmetrical tonic neck reflex) British Picture Vocabulary Scale (receptive language) Brown Attention Deficit Disorder Scale SES	Simple regression analyses found that motor skills may be weakly predictive of attainment of reading without confounds Multiple regression analyses found that motor skills are not predictive of reading in context of other predictors	75%
Memis et al. (2016) Turkey	Cross-sectional	n=168 children in Grade 1; 50% girls	Developmental Visual Perception Test (2^{nd} Edition) – Visual motor integration		Informal Reading Inventory (reading levels, reading comprehension, reading errors)	Developmental Visual Perception Test (2^{nd} Edition) (general visual perception, motor-reduced visual perception)	Significant moderate positive associations between visual motor integration (VMI) and reading speed (r=0.454, p<0.01), reading comprehension (r=0.469, p<0.01) Significant association between VMI and reading errors (r=-0.418, p<0.01)	20%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
Morales et al. (2011) Spain	Cross-sectional	n=487 children and adolescents; 51% girls n=243 children 9-12 years) n=244 children 13-16 years Schools: n=6 SES: Low to Medium	Tower of cubes test (fine motor skills – time taken to build a tower out of cubes) Target Throwing test (gross motor skills – time taken to throw ball at target and catch three times)	Battery of Differential and General Skills (maths skills test)		Clinical history questionnaire Extra-curricular physical activity (modified from International Physical Activity Questionnaire) Battery of Differential and General Skills (oral skills test)	For cohort aged 9-12 years: Maths performance was significantly and inversely associated with the time taken to build a tower out of cubes (r=-0.727, p<0.05). Maths performance was significantly and inversely associated with the time taken to throw and catch a ball three times (r=-0.439, p<0.05) For cohort aged 13-16 years: Maths performance was significantly and inversely associated with the time taken to build a tower out of cubes r=-0. (643, p<0.05). Maths performance was significantly and inversely associated with the time taken to throw and catch a ball three times (r=-0.163, p<0.05) (i.e. the slower the time taken to complete fine and gross motor tasks, the lower the score on the maths skills test)	50%
Murrihy et al. (2017) Australia	Cross-sectional	n=133 children; 54.1% girls; Age: M=9.7 years, range 8-12.5 years	McCarron Assessment of Neuromuscular Development: Psychomotor ability (finger-nose-finger, jumping, heel toe walking, standing on one foot)	Australian Woodcock Johnson III Tests of Achievement Battery: Mathematics achievement (calculation, applied problems)	Australian Woodcock Johnson III Tests of Achievement Battery: Reading achievement (letter-word identification, passage comprehension)	Automated Working Memory Assessment (short-term memory) Australian Woodcock Johnson III tests of Cognitive Abilities (general intellectual ability, working memory, crystallized intelligence, fluid intelligence)	Significant weak positive associations between letter word identification and finger-nose test (r=0.33, p<0.001); and heel-toe walking (r=0.32, p<0.001) Significant weak positive associations between finger-nose test and calculation (r=0.26, p<0.05) Psychomotor ability (finger nose, walking, jumping, balance) did not have a positive direct effect on reading achievement or maths achievement. However, the size of standardized indirect effect of psychomotor ability on reading (β=0.25, p<0.05) and	55%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
							maths β=0.22, p<0.05) was found to be statistically significant, supporting the prediction that psychomotor ability leads to higher reading achievement through the mechanism of short-term memory	
Pagani and Messier (2012) Canada	Cross-sectional (sample from Montreal Longitudinal Preschool Study)	N=522 Kindergarten children	Teacher-rated motor assessment: Gross motor skills (well-coordinated; climbs stairs; overall physical development) Fine motor skills (proficiency at holding a pen; ability to manipulate object) Perceptual motor skills (copying, writing)	Number Knowledge Test (maths) Teacher-reported academic achievement (maths)	Teacher-reported academic achievement (reading)	Peabody Picture Vocabulary Test (verbal competence) Social Behavior Questionnaire (behavioral adjustment) Control variables (family/child characteristics)	Significant weak positive association between early maths skills and teacher-rated fine motor skills (r=0.29, p<0.001), perceptual motor abilities (r=0.31, p<0.001) and gross motor ability (r=0.20, p<0.001) After controlling for other confounding factors, significant associations were found between maths skills and fine motor (β=0.16, p<0.01) and perceptual motor (β=0.14, p<0.01)	60%
Pienaar et al. (2013) South Africa	Cross-sectional (sample from North West-CHILD longitudinal study)	n=812 Year 1 children; 48.5% girls; Age: M=6.78±0.49 years SES: n=19.1% quintile 1 (poorest); n=21.2%	Bruininks Oseretsky Test of Motor Proficiency (2nd Edition) - Short Form Beery-Buktenica Developmental Test of Visual-Motor Integration (4th	Mastery of Basic Learning Areas Questionnaire (mathematics ability rated on 4-point Likert scale)	Mastery of Basic Learning Areas Questionnaire (reading ability rated on a 4-point Likert scale)	Demographics (BMI, age, gender, SES, ethnicity)	Results for visual motor integration (VMI) are highly significant for mastery of mathematics and reading VMI motor coordination standard score not significantly related to the mathematics score but was related to reading Relationship with mathematics and reading stronger for VMI than for BOT-	85%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
		quintile 5 (highest) Ethnicity: 70% Black, 27% White, 2% Coloured, 1% Indian	Edition) (visual-motor integration (VMI) total score, visual perception subtest (VMI-VP), motor co-ordination subtest (VMI-MC)				2 (short form), and to a lesser degree VMI-motor coordination	
Pitchford et al. (2016) England	Cross-sectional	n=62 Year 1 children; 53% girls; Age: 5 years, 5 months to 6 years, 8 months Low SES areas	Bruininks Oseretsky Test of Motor Proficiency (2nd Edition) – (Long Form) (fine motor precision, fine motor integration subtests)	Wechsler Individual Achievement Test (2nd Edition) (mathematical reasoning subtest)	Wechsler Individual Achievement Test (2nd Edition) (word reading subtest)	SES	Significant weak-to-moderate positive associations between fine motor integration and word reading (r=0.377, p=0.003) and mathematical reasoning (r=0.569, p<0.001) Significant moderate positive association between fine motor precision and mathematical reasoning (r=0.597, p<0.001) Non-significant findings between fine motor precision and word reading Fine motor integration was found to be a significant predictor of early maths ability, but not a significant predictor of early reading ability, even when cognitive abilities were taken into account	50%
Potter et al. (2013) USA	Cross-sectional (sample from Early Childhood Longitudinal Study – Kindergarten Cohort)	N=19 173 kindergarten children; 49% girls; Age: M=5.62±0.36 years	Early Screening Inventory-Revised: Fine motor skills: (replicating a gate with cube blocks; drawing a person; copying 5 simple figures)	Early Childhood Longitudinal Study – Kindergarten Cohort (Mathematics assessments)	Early Childhood Longitudinal Study – Kindergarten Cohort (Reading assessments)	General knowledge assessment Demographics (SES, parental educational expectation, gender, age, ethnicity, family structure, non-English speaking background)	Fine motor skills were positively associated with children's reading skills, which remained significant even after controlling for other development factors Fine motor skills had a moderately strong and positive independent association with performance on the math assessment, which remained	90%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
						Developmental factors (socio-emotional wellbeing, attentiveness, post-natal factors)	significant after controlling for other development factors	
Rigoli et al. (2012) Australia	Cross-sectional	n=93 adolescents; 41% girls; Age: Mean=14.2±1.1 years, SD=1.1; range 12-16 years Varying SES	Movement Assessment Battery for Children (2nd Edition) (manual dexterity, aiming and catching, balance)	Wechsler Individual Achievement Test (2nd Edition) Australian (numerical operations)	Wechsler Individual Achievement Test (2nd Edition) Australian (word reading)	Wechsler Intelligence Scale for Children-IV (cognitive ability) N-back task (visuospatial working memory) Parent-rated strengths and weaknesses of ADHD symptoms and normal behavior scale	Significant weak positive associations between aiming & catching and word reading (r=0.280, p<0.01) and numerical operations (r=0.229, p<0.05) Aiming & catching did not have a direct impact on academic achievement, it impacted via working memory Non-significant findings for both manual dexterity and balance with word reading/numerical operations	70%
Santi et al. (2014) USA	Cross-sectional (sample from a larger longitudinal study)	n=778 children in Grades 1 and 2; 52% girls Grade 1: n=617 Grade 2: n=550 SES: 8% low, 40% working, 46% middle-upper Ethnicity: 50% white, 18% African American, 16% Hispanic,	Beery-Buktenica Developmental Test of Visual-Motor Integration (3rd Edition): Visual motor integration		Woodcock-Johnson Psycho-Educational Battery – Revised (passage comprehension) Formal Reading Inventory (reading comprehension) Comprehensive Test of Phonological Processing (phonological awareness)	Wechsler Intelligence Scale for Children – Revised (performance / verbal IQ) Peabody Picture Vocabulary Test – Revised (vocabulary recognition) Woodcock-Johnson Psycho-Educational Battery – Revised: (reading vocabulary) Rapid Automatized Naming Test (rapid naming)	Visual motor integration (VMI) skills are related to reading in both grades 1 and 2 Significant very weak-to-weak positive correlations between VMI and passage comprehension (r=0.33, p<0.0015); formal reading inventory (r=0.19, p<0.0015), phonological awareness (r=0.37, p<0.0015), letter-word identification (r=0.35, p<0.0015), word attack (r=0.33, p<0.0015) and word reading efficiency (r=0.30, p<0.0015) in Grade 1 Significant very weak-to-weak correlations between VMI and passage comprehension (r=0.21, p<0.0015); phonological awareness (r=0.32, p<0.0015), letter-word	65%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
		15% Asian 1% Other			Woodcock-Johnson Psycho-Educational Battery – Revised: (letter word identification, word attack) Word Reading Efficiency (fluency)		identification (r=0.30, p<0.0015), word attack (r=0.31, p<0.0015) and word reading efficiency (r=0.25, p<0.0015) in Grade 2 Non-significant findings between VMI and formal reading inventory in Grade 2 (r=0.08, p=0.059) When other known predictors of reading are included (e.g. phonological awareness, decoding, fluency and vocabulary), contribution of VMI to reading over and above the other predictors is negligible	
Sortor and Kulp (2003) USA	Cross-sectional	n=155 children in Grades 2 to 4; Age: M=8.4±1.0 years; range 7 to 10 years n=42 Grade 2 n=55 Grade 3 n=58 Grade 4 Primarily white, middle-class, suburban elementary school	Beery Visual Motor Integration Test (4th Edition): Visual motor integration (VMI); VMI Supplemental Developmental Test of Motor Coordination	Stanford Achievement Test Series (9th Ed) (total math percentile)	Stanford Achievement Test Series (9th Ed) (reading percentile scores)	Otis-Lennon School Ability Test (verbal ability score / cognitive ability) VMI Supplemental Developmental Test of Visual Perception (visual analysis/spatial skills-motor-reduced)	Significant relation between math achievement and performance on tests of VMI, visual perception and motor coordination Partial correlations (controlling for age and verbal ability) showed there were significant associations between VMI standard score and maths (r=0.274, p=0.001) and reading (r=0.163, p=0.05) Controlling for age and verbal ability, there were significant associations between VMI-motor coordination and maths (r=0.218, p=0.008) and reading (r=0.184, p=0.027) Multiple regression analyses found VMI and motor coordination were not predictive of reading and maths achievement	50%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
Suggate et al. (2017) Germany	Cross-sectional	n=81 children; 50.6% girls; Age: M=4 years 9 months, SD=11.14 months, range 39-76 months	Fine motor skills (pegboard task, bead threading, block turning)	Overall numerical skills (combination of non-finger based and finger-based numerical skills) Non finger-based numerical skills (i.e. counting and arithmetic without using fingers) Finger-based numerical skills (i.e. children prompted to use fingers count)		Parental questionnaire (children's country of birth, languages spoken at home, educational achievement at secondary and tertiary levels) Peabody Picture Vocabulary Test-IV (German) (receptive vocabulary)	Significant strong positive associations between fine motor skills and overall numerical skills (r=0.73), finger-based numerical skills (r=0.69) and non-finger based numerical skills (r=0.70) Linear regression analyses showed that fine motor skills (independent of age and receptive vocabulary) contributed significantly to overall numerical skills (β=0.34, p<0.05), finger-based numerical skills (β=0.40, p<0.05), non-finger-based numerical skills (β=0.24, p<0.05) Controlling for age, the link between FMS and non-finger-based numerical skills was mediated by finger numerical skills	45%
Suggate et al. (2018) Germany	Cross-sectional	n=144 children; 55.6% girls; Age: Mean=6 years, 1 month, SD=3.28 months	Movement ABC (German version) (posting coins, threading beads, tracing through a maze) Grapho-motor skills: Greek-letter copying task		Bielefelder Screening Test for the Identification of Early Reading difficulties (phonemic awareness) Dynamic Indicators of Basic Early Literacy Skills (letter naming task) Reading skill (estimated with non-word decoding, word reading and	Parental questionnaire (ethnicity, language spoken at home, country of birth, educational achievement) Writing: Name writing Wechsler Preschool and Primary Scale of Intelligence (concept ecognition, general knowledge, picture concepts, expressive/ receptive vocabulary subtests)	Significant very weak-to-weak positive associations between phonemic awareness and coin posting (dominant hand) (r=0.19, p<0.05), coin posting (non-dominant hand) (r=0.17, p<0.05), maze tracing (r=0.18, p<0.05) and fine motor total (r=0.23, p<0.05) Significant very weak positive associations between word reading and fine motor total (r=0.18, p<0.05) Significant weak positive associations between grapho-motor skills and phonemic awareness (r=0.26, p<0.05), letter naming (r=0.25, p<0.05) and word reading (r=0.27, p<0.05)	60%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
					reading of high-frequency words)	Kaseler concentration test (attention)		
van der Niet et al. (2014) Netherlands	Cross-sectional	n=263 children; 45% girls; Age: M=9.5±1.2 years; range 7-12 years SES: 12% low or middle low SES	EUROFIT (Physical fitness) Standing broad jump (explosive leg strength) Sit-ups (trunk strength) 10 x 5m shuttle run (running speed and agility)	Dutch standardized test scores on maths	Dutch standardized test scores on reading	Anthropometrics (height, weight, BMI) 20m shuttle run (cardiorespiratory endurance) Tower of London test (problem solving skills) Trailmaking test (cognitive flexibility) Dutch standardised test scores on spelling	Significant association between maths and time taken to complete shuttle run (r=-0.22, p<0.01) Significant very weak-to-weak positive associations between maths and trunk strength (r=0.15, p<0.05) and leg strength (r=0.32, p<0.01) Significant very weak positive associations between reading and leg strength (r=0.18, p<0.01) Non-significant associations between reading and speed and agility and trunk strength	65%
Van Niekerk et al. (2015) South Africa	Cross-sectional (sample from Physical Activity and Health Longitudinal study)	n=236 adolescents; 58% girls; Age: 13-14 years	Bruininks Oseretsky Test of Motor Proficiency (2nd Edition) (Short Form)	End of year report (average maths marks)			Significant very weak-to-weak positive correlations for total group between maths and draw a line (r=0.16, p<0.05) and fold paper (r=0.13. p<0.05); hop on one leg (r=0.18, p<0.05); sit ups (r=0.29, p<0.05); total motor proficiency (r=0.23, p<0.05) Non-significant findings for total group between maths and fine motor integration, manual dexterity, upper limb coordination, body coordination, balance and strength (push ups)	35%

Authors (Year), Country	Study Design	Study Participants Sample size (n); (% girls); Age (Mean ± SD); SES; Ethnicity	Outcome Measures			Covariates	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)			
Xiang et al. (2017) China	Cross-sectional	n=144 adolescents; 33% girls; Age: M=14.55±0.62 years; range 13-17 years	Skill related physical fitness: 50m dash (running speed) Standing long jump (power)	Chinese standardized test (Mathematics)	Chinese standardized test (language literacy)	FITNESSGRAM; Health-related physical fitness (CRF, muscular fitness, body composition) Center for Epidemiological Studies Depression Scale (Depression)	Significant weak positive association between skill-related physical fitness and mathematics ($r=0.17$, $p<0.05$)	45%

Appendix B: Supplementary Table S2 from published manuscript (Chapter 3)

Table S2: Key data extracted from experimental studies examining the impact of motor proficiency-related interventions on academic performance in mathematics and reading in school-aged children and adolescents.

Authors (Year), Country	Study Design	Study Participants Sample size; (% girls); Age (Mean ± SD; range); schools (n); classes (n); SES; Ethnicity	Outcome Measures			Covariates	Intervention (dose, frequency, duration, groups)	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)				
Beck et al. (2016) Denmark	Experimental Cluster randomized intervention 6-week intervention with 8-week follow up	Total: n=165; 47% girls; Age: M=7.5±0.02 years n=3 Danish public schools; n=9 year 1 school classes Control group (CON): n=57 participants; 50.9% girls; Age: M=7.5 ± 0.02 years Fine motor math group (FMM): n=53; 43.4% girls; Age: M=7.5±0.03 years Gross motor math group (GMM): n=55; 45.5% girls; Age: M=7.5±0.02 years	Coordination Wall (gross motor skills; movements performed require crossing of the vertical midline) Perdue Pegboard Test (fine motor skills; manual dexterity, bimanual fine motor coordination) Assessments occurred before (T0), immediately after (T1) and 8 weeks after the intervention (T2)	Mathematical test (standardized, diagnostic test in Denmark) Assessments occurred before (T0), immediately after (T1) and 8 weeks after the intervention (T2)		Cognitive Tests Modified Eriksen Flanker Test (executive function) Cambridge Neuro-psychological Test Automated Battery - Spatial span test (visuo-spatial short term memory) Free-recall wordlist memory test (phonological short term memory) Andersen Test (CV fitness) Physical load during intervention (heart rate (HR) monitoring; accelerometers - time spent in low, moderate-	60-minute mathematics lessons, 3 x week, 6 continuous weeks. Delivered by classroom teacher. CON: Received non-motor enriched conventional mathematical teaching FMM group: Mathematical teaching enriched with fine motor activity GMM group: Mathematical teaching enriched with gross motor activity To standardize within and between intervention groups, research staff delivered	Applying gross motor enriched math lessons resulted in a greater improvement in mathematical performance compared to fine motor enriched math and conventional math lessons All groups improved their mathematical performance T0 to T1. Changes in mean mathematical performance significantly greater in GMM compared to FMM (1.87 ± 0.71 correct answers, p=0.02). No significant differences in mathematical performance observed at T2 Subgroup analyses revealed normal math performers benefitted from GMM compared to both CON and FMM (not observed in low math performers) Changes in gross motor performance accounted for ~ 25% of the effects of the intervention on mathematical performance	71%

Authors (Year), Country	Study Design	Study Participants Sample size; (% girls); Age (Mean ± SD; range); schools (n); classes (n); SES; Ethnicity	Outcome Measures			Covariates	Intervention (dose, frequency, duration, groups)	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)				
						vigorous HR zones)	three workshops of three hours to classroom teachers. Teachers received teaching manuals. Regular communication between research staff and classroom teachers	Changes in fine motor performance accounted for ~ 10.7% of the effects of the intervention on mathematical performance	
Callcott et al. (2015) Australia	Quasi - experimental – controlled pre-post design Intervention delivered over one school year	Initially n=400 (100 per group); Age: between 4-5 years n=8 primary schools Middle to high Index of Community Socio-educational Advantage Literacy + Movement Group (Lit +Movt): n=85 Literacy Group (Lit only): n=67 Movement Group (Movt only): n=67 Control (Con): n=79	Movement Assessment Battery for Children-2nd Edition (MABC-2) (manual dexterity, aiming and catching, balance)		Test of Phonological Awareness (PA)	Developmental Spelling Test Wide range Achievement Test - Revised: (spelling subtest)	Intervention delivered by classroom teacher Lit + Movt Group: Let's Decode (phonological awareness and systematic decoding instruction - 15 min each day) + Moving on with Literacy (30 action songs with movement challenge and language - 15 min per day), 5 days per week, school terms 1 to 4 Lit Group: Let's Decode – 15 min per day, 5 days per week, school terms 1 to 4	Lit + Movt group's average post-test performance on phonological awareness test was better than each of the other groups (Lit only, Movt only, Con) Significant main effect of the intervention after controlling for pre-test differences (p=0.001). Lit + Movt group performed significantly better than their peers in both the Movt only (p=0.003) and Con (p=0.001) Students in the Lit + Movt group performed better at post-test on the MABC-2 test and made the largest average gains than the other groups. Significant difference found between the Lit + Movt group and Con group.	50%

Authors (Year), Country	Study Design	Study Participants Sample size; (% girls); Age (Mean ± SD; range); schools (n); classes (n); SES; Ethnicity	Outcome Measures			Covariates	Intervention (dose, frequency, duration, groups)	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)				
							Movt Group: Moving on with Literacy – 15 min per day, 5 days per week, school terms 1 to 4 Control Group: classroom teachers conducted their regular pre-primary program, which included PE and English Research staff delivered professional development sessions to classroom teachers to teach Let's Decode and Moving on with Literacy programs. Research staff visited each classroom teacher and observed them teaching programs and visited once per term.		

Authors (Year), Country	Study Design	Study Participants Sample size; (% girls); Age (Mean ± SD; range); schools (n); classes (n); SES; Ethnicity	Outcome Measures			Covariates	Intervention (dose, frequency, duration, groups)	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)				
Erasmus et al. (2016) South Africa	Quasi-experimental – controlled pre-post design 10-week intervention	n=48; Age: 5-6 years n=2 schools, n=2 classes Experimental group (Exp): n=21; 52% girls; Quintile 1 school (low SES) Control group (Con): n=27; 59% girls; Quintile 2 school (low SES)	La Roux's Group Test for School Readiness: Fine motor ability (completion of a maze and writing patterns); Gross motor coordination: (Single leg stance (SLS)-eyes open/closed) hop, walking heel-to-toe on straight line) (Pre / post-test)	La Roux's Group Test for School Readiness: Number concept subtest (counting concrete objects, amounts and relationships) (Pre / post- test)		La Roux's Group Test for School Readiness (5 subtests) Visual perception; spatial orientation; language experience; drawing human figure; auditory perception	Intervention program delivered by research staff for 40 minutes each lesson, 3 x a week for 10 weeks Intervention program included gross motor (20 min), fine motor (10 min) and perceptual exercises (visual and auditory discrimination, spatial orientation, midline crossing – 10 min)	Experimental group improved significantly in the sub-items for number concept (p<0.012, Cohen's d effect size d=1.13), gross motor coordination (p<0.01, Cohen's d effect size d=2.16). Improvements in the number concept subtest were not significantly better than the control group following the intervention (when controlling for differences in pre-test scores) Experimental group scored significantly better in the post-test (moderate and large effects) than the control group in visual perception, language experiences, gross motor coordination (p=0.0088, Cohen's d effect size d=2.08) and total score (p=0.0089, Cohen's d effect size d=0.80)	54%

Authors (Year), Country	Study Design	Study Participants Sample size; (% girls); Age (Mean ± SD; range); schools (n); classes (n); SES; Ethnicity	Outcome Measures			Covariates	Intervention (dose, frequency, duration, groups)	Main Findings	Critical Appraisal Percentage (%)
			Motor proficiency	Academic performance (mathematics)	Academic performance (reading)				
Ericsson (2008) Sweden	Quasi-experimental, non-randomized, controlled design 3-year intervention	n=251; age: 7-9 years School: n=1 Two intervention groups (n=152); one control group (n=99)	MUGI Observation Checklist (16 gross motor tasks: skip jumping, hopping, SLS, throwing, dribbling, catching; measuring 2 variables of motor skills (balance/ bilateral coordination)	Lus Test (national test in mathematics)	Lus test (reading development, word test reading test)	Conner's questionnaire (attention and impulse control) Questionnaire to parents (father/mother education, income, attitudes to PA, amount of PA in spare time (children and parents)	Intervention group: 60-minute lesson of Physical Education (PE), 5 lessons per week ± one extra 45-minute lesson of motor training per week. Lessons under the supervision of the school's PE teacher (3 lessons per week) or local sports clubs (2 lessons per week) Control group: Usual 60-minute PE lesson, 2 lessons per week	After 2 years, pupils in intervention group had better results than pupils in control group in national tests for Swedish with overall large differences in results between groups (Cramer's index 0.29) Pupils in intervention group had better results in national mathematics tests than control with overall small differences in results between groups (Cramer's index 0.21) There were significant differences in academic performance between pupils with good motor skills and pupils with deficits in motor skills in both the intervention and control groups Pupils in intervention group had better motor skills than pupils in the control group (after 1 year difference between groups was large - Cramer's index 0.24; after three years, differences were very large Cramer's index 0.37)	25%

Appendix C: Participant questionnaire (Chapter 6)

Participant Questionnaire

Welcome! Thank you for your interest in completing this questionnaire.

ELIGIBILITY

To participate in this questionnaire, please confirm that you meet the following criteria:

- Hold an accredited teaching qualification; and
- Are eligible to work in Australian public, independent or catholic primary schools; and
- Teach the Foundation – Year 2 Australian Curriculum to students

OR

- Have responsibility as a school principal, deputy principal or assistant principal to supervise/oversee the delivery of the Foundation – Year 2 Australian Curriculum at your school

CONSENT

Please note, the completion of this questionnaire will be taken as an expression of your consent to participate in this research. All responses will be anonymous. After reading through the Participant Information Sheet, do you consent to take part in this research questionnaire?

- ◯ Yes
- ◯ No

SECTION 1: DEMOGRAPHIC INFORMATION

In which Australian state/territory do you currently work?

- ◯ Queensland
- ◯ New South Wales
- ◯ Victoria
- ◯ Tasmania
- ◯ South Australia
- ◯ Western Australia
- ◯ Australian Capital Territory
- ◯ Northern Territory

Which of the following best describes the geographical location of your primary school?

- ○ Major city
- ○ Large regional area
- ○ Small regional area
- ○ Remote area
- ○ Very remote area

What type of primary school do you currently work at?

- ☐ Public
- ☐ Catholic
- ☐ Independent
- ☐ Other (please specify)

____

How many years of teaching experience do you have?

____

Does your school currently have a Comprehensive School Physical Activity Policy?

(Please note: A Comprehensive School Physical Activity Policy for a school involves the development, implementation and evaluation of (i) a quality Physical Education (PE) program; (ii) availability of physical activity opportunities before and after school; (iii) availability of physical activity opportunities during the school day; (iv) staff involvement in programs; and (v) family and community engagement)

◯ Yes

◯ No

◯ Unsure

What role are you currently undertaking at your primary school?

- ☐ Classroom teacher
- ☐ School principal
- ☐ Deputy principal
- ☐ Assistant principal

What year level/s are you currently working with or responsible for?

- ☐ Prep / Kindergarten
- ☐ Year 1
- ☐ Year 2

Page Break

SECTION 2: CLASSROOM-BASED PHYSICAL ACTIVITY

According to Australia's Physical Activity and Sedentary Behaviour Guidelines (5-12 years), physical activity is *'any activity that gets children moving, makes their breathing become quicker and their hearts beat faster'*

Classroom-based physical activity can be defined as *'physical activity carried out during regular class time and can occur either inside or outside the classroom (e.g. hallway, playground), and is distinct from school recess/lunch break times.'*

Classroom-based physical activity may include:

i) **Physically active lessons:** Incorporating physical activity into academic lessons (e.g. having students jump on a number line during a maths lesson)

ii) **Physical activity breaks:** Physical activity carried out between academic lessons/transition periods with an academic focus (e.g. students complete a short dance video that involves counting by tens) or without an academic focus (e.g. students copying movements demonstrated by classroom teacher)

Have you ever completed any professional development and/or training regarding the different methods of classroom-based physical activity?

○ Yes

○ No

○ Unsure

If YES, what was the source of training for any professional development and/or training you may have completed?

- ☐ Undergraduate degree
- ☐ Postgraduate program
- ☐ Professional development session / workshop (at school)
- ☐ Professional development session / workshop (external to school)
- ☐ Other (please specify)

____

If YES, approximately how many hours of training have you completed on this topic?

____

Do you currently provide classroom-based physical activity to students in Prep/Kindergarten to Year 2?

- ○ Yes
- ○ No

On average, how many times per week do you provide classroom-based physical activity to students in Prep/Kindergarten?

◯ Unsure / Not applicable

◯ No classroom-based physical activity is currently provided

◯ 1-2

◯ 3-5

◯ >5

On average, how many times per week do you provide classroom-based physical activity to students in Year 1?

◯ Unsure / Not applicable

◯ No classroom-based physical activity is currently provided

◯ 1-2

◯ 3-5

◯ >5

On average, how many times per week do you provide classroom-based physical activity to students in Year 2?

- ◯ Unsure / Not applicable
- ◯ No classroom-based physical activity is currently provided
- ◯ 1-2
- ◯ 3-5
- ◯ >5

What method/s of classroom-based physical activity do you currently provide students in Prep/Kindergarten to Year 2 as part of the regular school day?

- ☐ Physically active lessons (i.e. physical activity integrated into key learning areas)
- ☐ Physical activity breaks between academic lessons/transition periods with an academic focus
- ☐ Physical activity breaks between academic lessons/transition periods without an academic focus
- ☐ Other (please specify) ____________________

PHYSICALLY ACTIVE LESSONS

Into which key learning areas of the Foundation - Year 2 curriculum do you currently incorporate physically active lessons (i.e. physical activity integrated into academic lessons)?

- [ ] None
- [ ] English
- [ ] Maths
- [ ] Science
- [ ] Humanities and Social Science
- [ ] The Arts
- [ ] Technologies
- [ ] Health and Physical Education
- [ ] Languages

On average, how much time is allocated to each physically active lesson?

- ☐ Unsure
- ☐ No physically active lessons are currently provided
- ☐ < 10 minutes
- ☐ 11-20 minutes
- ☐ 21-30 minutes
- ☐ 31-40 minutes
- ☐ 41-50 minutes
- ☐ 51-60 minutes

What type of physical activity is included in physically active lessons?

- ☐ Unsure
- ☐ No physically active lessons are currently provided
- ☐ Gross motor skills (e.g. jump, hop, skip, throw/catch, kick, balance)
- ☐ Cardio-respiratory fitness activities (e.g. running, dancing)
- ☐ Strengthening activities (e.g. climbing, swinging on monkey bars)
- ☐ Flexibility activities (e.g. yoga, stretching)
- ☐ Other (please specify)

____

In which location are physically active lessons provided to students?

- ☐ Unsure
- ☐ Inside the classroom
- ☐ In the hallway
- ☐ In the playground
- ☐ Other area (please specify) ____________________

PHYSICAL ACTIVITY BREAKS

On average, how much time is allocated to each physical activity break?

- ☐ Unsure
- ☐ No physical activity breaks are currently provided
- ☐ < 1 minute
- ☐ 1-5 minutes
- ☐ 6-10 minutes
- ☐ 11-15 minutes
- ☐ 16-20 minutes
- ☐ 21-25 minutes
- ☐ 26-30 minutes

What type of physical activity is included in physical activity breaks?

- ☐ Unsure
- ☐ No physical activity breaks are currently provided
- ☐ Gross motor skills (e.g. jump, hop, skip, throw/catch, kick, balance)
- ☐ Cardio-respiratory fitness activities (e.g. running, dancing)
- ☐ Strengthening activities (e.g. climbing, swinging on monkey bars)
- ☐ Flexibility activities (e.g. yoga, stretching)
- ☐ Other (please specify)

____

In which location are physical activity breaks provided to students?

- ☐ Unsure
- ☐ Inside the classroom
- ☐ In the hallway
- ☐ In the playground
- ☐ Other area (please specify)

____

If you were to provide classroom-based physical activity to students in Prep/Kindergarten to Year 2 as part of the regular school day in the future, what methods would you be likely to choose?

- ☐ None
- ☐ Physically active lessons (i.e. physical activity integrated into key learning areas)
- ☐ Physical activity breaks between academic lessons/transition periods <u>with</u> an academic focus
- ☐ Physical activity breaks between academic lessons/transition periods <u>without</u> an academic focus
- ☐ Other (please specify) ____

Into which key learning areas of the Foundation - Year 2 curriculum would you be most willing to incorporate physical activity?

- [ ] None
- [ ] English
- [ ] Maths
- [ ] Science
- [ ] Humanities and Social Sciences
- [ ] The Arts
- [ ] Technologies
- [ ] Health and Physical Education
- [ ] Language

Page Break

SECTION 3: FACILITATORS AND BARRIERS TO CLASSROOM-BASED PHYSICAL ACTIVITY

This section of the questionnaire asks about the various factors which may influence the ability / willingness of school staff to provide different methods of classroom-based physical activity to students in Prep/Kindergarten to Year 2.

Listed below are the *personal / professional factors* that may influence the ability / willingness of primary school staff to provide different methods of classroom-based physical activity to students in Prep/Kindergarten to Year 2.
For Principals: Please indicate from a *school administration perspective* whether you perceive the following factors to be facilitators or barriers to providing classroom-based physical activity at your school.
For Classroom Teachers: Please indicate from a *classroom teacher perspective* whether you perceive the following factors to be facilitators or barriers to providing classroom-based physical activity at your school.

	Strong Barrier	Barrier	Neither	Facilitator	Strong Facilitator
Your perception of the need to provide classroom-based physical activity at your school	☐	☐	☐	☐	☐
Your perception of the benefits of providing classroom-based physical activity at your school	☐	☐	☐	☐	☐
Your perceived competence (self-efficacy) to plan and deliver classroom-based physical activity at your school	☐	☐	☐	☐	☐

Listed below are *student factors* that may influence the ability / willingness of primary school staff to provide different methods of classroom-based physical activity programs to students in Prep/Kindergarten to Year 2.

For Principals: Please indicate from a *school administration perspective* whether you perceive the following factors to be facilitators or barriers to providing classroom-based physical activity at your school.

For Classroom Teachers: Please indicate from a *classroom teacher perspective* whether you perceive the following factors to be facilitators or barriers to providing classroom-based physical activity at your school.

	Strong Barrier	Barrier	Neither	Facilitator	Strong Facilitator
Disruptive student behaviour during or following classroom-based physical activity	☐	☐	☐	☐	☐
Improvement in student engagement during or following classroom-based physical activity	☐	☐	☐	☐	☐
Ability for students with additional support/learning needs to participate in classroom-based physical activity	☐	☐	☐	☐	☐

Listed below are the *peer factors* that may influence the ability / willingness of primary school staff to provide different methods of classroom-based physical activity programs to students in Prep/Kindergarten to Year 2.

For Principals: Please indicate from a *school administration perspective* whether you perceive the following factors to be facilitators or barriers to providing classroom-based physical activity at your school.

For Classroom Teachers: Please indicate from a *classroom teacher perspective* whether you perceive the following factors to be facilitators or barriers to providing classroom-based physical activity at your school.

	Strong Barrier	Barrier	Neither	Facilitator	Strong Facilitator
Attitudes and beliefs from peers towards classroom-based physical activity at your school	☐	☐	☐	☐	☐
Ability for staff to participate in peer observation of classroom-based physical activity	☐	☐	☐	☐	☐
Ability for staff to share ideas and resources for classroom-based physical activity with colleagues	☐	☐	☐	☐	☐

Listed below are *school administration factors* that may influence the ability / willingness of primary school staff to provide different methods of classroom-based physical activity programs to students in Prep/Kindergarten to Year 2.

For Principals: Please indicate from a *school administration perspective* whether you perceive the following factors to be facilitators or barriers to providing classroom-based physical activity at your school.

For Classroom Teachers: Please indicate from a *classroom teacher perspective* whether you perceive the following factors to be facilitators or barriers to providing classroom-based physical activity at your school.

	Strong Barrier	Barrier	Neither	Facilitator	Strong Facilitator
Having sufficient time to schedule classroom-based physical activity into the regular school routine	☐	☐	☐	☐	☐
Having a supportive school climate (including support from administration)	☐	☐	☐	☐	☐
Compatibility of classroom-based physical activity with school values	☐	☐	☐	☐	☐

Listed below are the *school environment factors* that may influence the ability / willingness of primary school staff to provide different methods of classroom-based physical activity programs to students in Prep/Kindergarten to Year 2.

For Principals: Please indicate from a *school administration perspective* whether you perceive the following factors to be facilitators or barriers to providing classroom-based physical activity at your school.

For Classroom Teachers: Please indicate from a *classroom teacher perspective* whether you perceive the following factors to be facilitators or barriers to providing classroom-based physical activity at your school.

	Strong Barrier	Barrier	Neither	Facilitator	Strong Facilitator
The amount of space available inside the classroom	☐	☐	☐	☐	☐
The amount of space available outside in the playground	☐	☐	☐	☐	☐

Listed below are the *training / support factors* that may influence the ability / willingness of primary school staff to provide different methods of classroom-based physical activity programs to students in Prep/Kindergarten to Year 2.

For Principals: Please indicate from a *school administration perspective* whether you perceive the following factors to be facilitators or barriers to providing classroom-based physical activity at your school.

For Classroom Teachers: Please indicate from a *classroom teacher perspective* whether you perceive the following factors to be facilitators or barriers to providing classroom-based physical activity at your school.

	Strong Barrier	Barrier	Neither	Facilitator	Strong Facilitator
The provision of professional development / training to staff to ensure they have the necessary knowledge and skills to provide physical activity opportunities in the classroom	☐	☐	☐	☐	☐
Availability of quality resources, including examples of developmentally appropriate methods of classroom-based physical activity	☐	☐	☐	☐	☐

Listed below are the ***policy factors*** that may influence the ability / willingness of primary school staff to provide different methods of classroom-based physical activity programs to students in Prep/Kindergarten to Year 2.

For Principals: Please indicate from a *school administration perspective* whether you perceive the following factors to be facilitators or barriers to providing classroom-based physical activity at your school.

For Classroom Teachers: Please indicate from a *classroom teacher perspective* whether you perceive the following factors to be facilitators or barriers to providing classroom-based physical activity at your school.

	Strong Barrier	Barrier	Neither	Facilitator	Strong Facilitator
Reading an evidence-based research article from an esteemed educational journal that describes how physical activity may enhance children's learning	☐	☐	☐	☐	☐
Awareness and knowledge of *Australia's Physical Activity and Sedentary Behaviour Guidelines* that recommend children aged 5-12 years should accumulate at least 60 minutes of moderate to vigorous intensity physical activity every day	☐	☐	☐	☐	☐
Awareness and knowledge of Australia's National Physical Activity Policy recommending that primary schools provide students with 120 to 150 minutes of PE and organised physical activity each week	☐	☐	☐	☐	☐

SECTION 4: SUGGESTIONS FOR OVERCOMING PERCEIVED BARRIERS TO CLASSROOM-BASED PHYSICAL ACTIVITY

Please list <u>three</u> major barriers you think would influence the ability / willingness of staff at your school to provide classroom-based physical activity to students in Prep/Kindergarten to Year 2

Please provide any suggestions for overcoming these major barriers

Appendix D: Supplementary Table S9: Development of the 12-week classroom based gross motor program (Chapter 7)

Parameter	12-week Program	Rationale
Stakeholders	Stakeholders included in the development of the 12-week program: • PhD candidate/registered physiotherapist (the Clinical Coordinator of the Tweed Healthy Schools program) • Doctoral research supervisors • Primary school principal • Two Year 1 classroom teachers • Physiotherapy and exercise science university students Parental consent and student assent was also sought.	The main objective of the Tweed Healthy schools project (THSP) was to improve the health and learning outcomes of school students through the provision of a university student-led health service within the school setting. As part of this project, university health science students were supervised and supported to implement individual, whole-of-class and schoolwide initiatives for school students and staff. One of the whole-of-class initiatives that was implemented as part of the THSP was the delivery of a 12-week classroom-based gross motor program to Year 1 students. This meant that the classroom teachers were able to benefit from having a registered physiotherapist design and deliver the program with assistance from physiotherapy and exercise science students, which helped demonstrate to them the feasibility of implementing such as program. The study reported in Chapter 7 was conceptualised to evaluate the 12-week program. Thus, the timeframe in which the study was conducted was constrained by the funding period of the project (i.e., funding ceased at the end of December 2014).
Design	Exploratory pilot study	The present study was conceptualised because of the opportunity presented by the Tweed Healthy Schools Project (THSP) for accompanying evaluation research. This study involved evaluating specific outcomes among children in the two Year 1 classes that participated in the THSP and in another Year 1 class at a separate but demographically similar school, which had not implemented the THSP and thus constituted a comparison class. On this basis, the present study was exploratory in nature, in which outcomes associated with exposure or non-exposure to THSP activities were evaluated in the form of a pilot study.

Parameter	12-week Program	Rationale
Sample size	55	All students enrolled in the three mainstream Year 1 classes (n = 64) were invited and eligible to participate in the study. Two of the three Year 1 classes (Classes R and M) were from one school and the other Year 1 class was from another school which was demographically similar and undertaking the same Year 1 Australian Curriculum (Class N). Prior to being invited to participate in the study, all children were enrolled in their pre-existing Year 1 school classes. These pre-existing classes had been allocated under normal school procedures (Class N) or the THSP (Classes R and M).
Intervention population	Year 1 school children	Evidence suggests that motor proficiency is positively associated with both health-related[9,11,12] and academic outcomes,[37] thus the early years of primary school may represent an ideal time to target children's motor skill development through the implementation of school-based motor skill programs.
Implementers	Researchers (registered physiotherapist, physiotherapy and exercise science students) in collaboration with classroom teachers	A meta-analysis by Fedewa and Ahn[29] reported that children appeared to benefit from physical activity (PA) interventions regardless of who was directing the intervention. However, no previous studies have reported findings from classroom-based gross motor skill programs that have been designed and delivered by a physiotherapist, with assistance from physiotherapy and exercise science university students. Physiotherapists are allied health professionals trained to design, implement and evaluate age-appropriate programs to facilitate motor development, motor control and motor planning and therefore are suitably qualified to design and deliver gross motor programs.[284] As physiotherapy and exercise science students were undertaking their clinical placement as part of the THSP, they were available to assist the registered physiotherapist to deliver the 12-week program. The scope and sequence of the Year 1 mathematics and English curriculum for the third and fourth school terms were provided by the classroom teachers for the two Year 1 classes involved to inform planning of physically active lessons. Planned gross motor activities were then integrated into academic lessons based on their alignment with the weekly academic focus.
Type of physical activity	The classroom-based program delivered in this study comprised a	The type of PA chosen as the focus of this program was motor skills.

Parameter	12-week Program	Rationale
	combination of gross motor activities with an academic focus (i.e., physically active reading or mathematics lessons) and without an academic focus (i.e., gross motor circuit) Cognitively engaging motor skill program (i.e., tasks that requires motor and problem-solving skills/mental engagement) .	Ideally, children should demonstrate mastery of object control and locomotor skills by Grade 6;[17] however, current trends suggest that Australian boys and girls are only achieving low levels of FMS competency by this year level. It has been suggested that focussing on improving children's motor proficiency during the early years of primary school may result in more permanent changes in their capability, consistent with the principles of motor learning.[81,83] Prior to this study being conducted in 2014, a narrative review of the literature was conducted. Evidence was found to support relationships between children's motor proficiency, health-related physical fitness and participation in PA,[9,11,12] as well as positive relationships between PA, cognition and academic performance in children and adolescents.[28,29,38] There is emerging evidence to suggest that school-based motor skill interventions may be beneficial for improving children's motor proficiency.[13,15] This includes populations of typically developing children as well as children who have, or are at risk of, motor skill delays or deficits (e.g., children with neurodevelopmental conditions). No systematic reviews were identified that examined relationships between motor proficiency and specific academic outcomes in school-aged children and adolescents, even though both motor proficiency and the components of health-related physical fitness are considered core aspects of children's physical development. Furthermore, it was evident that very few studies had evaluated the impact of PA interventions on children's motor proficiency outcomes.[220] Considerable variability was evident in the types of PA interventions examined in studies; however, studies predominantly investigated the impact of aerobic types of PA interventions on children's cognition and academic performance with fewer studies examining the impact of motor skill interventions.[29] In relation to classroom-based PA interventions, most experimental studies evaluated their impact on children's PA on academic outcomes, but seldom their impact on children's motor proficiency outcomes.[43,147] Experimental studies also primarily investigated the impact of aerobic types of classroom-based PA

Parameter	12-week Program	Rationale
		interventions on children's PA and academic outcomes. Therefore, further exploration is warranted regarding the impact of classroom-based motor skill interventions on children's academic outcomes (specifically numeracy and literacy) and motor proficiency.
Theoretical background	Motor development and motor learning Principles of variability of practice (complexity, novelty, diversity, effort and successfulness)	Hypotheses regarding the mechanisms that may underpin the PA-cognition relationship continue to be tested and stem from research conducted by multiple disciplines including exercise and cognition, developmental neuroscience, motor development, motor learning and motor control. For example, biological and psychosocial mechanisms as well as mechanisms relating to the context in which children learn have been proposed.[38] Increased activation of the pre-frontal cortex and cerebellum during the skill acquisition phase of learning a motor task highlights the cognitive demand inherent in complex motor skill acquisition.[108] Modifying the practice environment during motor learning by applying principles of variability of practice to the tasks may optimise motor and cognitive processes.[48] The gross motor circuits and physically active lessons included activities that promoted gross motor skill development.[70,277] The focus during each session was on quality of movement, with feedback provided to Year 1 students regarding their technique as appropriate. Each week, gross motor activities were also varied and progressed as student abilities allowed, to engage and continuously challenge students during sessions and to be consistent with the principles of variability of practice.
Intensity	Not specified	The intensity of PA undertaken by students during sessions was not recorded, as the focus during gross motor circuits and physically active lessons was on quality of movement, along with variation and progression of activities. Additionally, the aim during physically active lessons was to match gross motor activities with the focus of learning for the week.
Duration	12 weeks	The optimal duration of an effective classroom-based PA program was unknown when this study was conceptualised. A Cochrane review by Dobbins et al[78] investigated the effectiveness of school-based PA interventions in promoting children's PA and physical fitness. PA interventions had to be implemented for a

Parameter	12-week Program	Rationale
		minimum of 12 weeks. Evidence was found to suggest that PA interventions of longer duration may be needed to effect change. The program also took place over school terms 3 and 4, following data collection at the beginning of Term 3.
Frequency	• Gross motor circuit (4 x 15 min/week) • Physically active reading lessons (4 x 10 min/week) • Physically active mathematics lessons (3 x 15 min/week)	The frequency and duration of the gross motor circuit and physically active lessons were negotiated in consultation with the classroom teachers. As both classes participated in the gross motor circuit, the most convenient time to schedule this was before academic lessons commenced. This occurred four days per week as students had a spelling test on Friday mornings. There is evidence to suggest that acute bouts of exercise can lead to improved on-task behaviour.[33,46] Physically active reading lessons were incorporated into reading group rotations, thus dictating the 10-minute duration. This occurred four days per week as students had a spelling test on Friday mornings. In collaboration with the teacher, physically active mathematics lessons were implemented into the final 15 minutes of the designated mathematics class. This occurred three days per week on the days when mathematics lessons were scheduled.
Outcome measures	**Academic performance (reading and mathematics)** • Wechsler Individual Achievement Test – 2nd Edition **Motor proficiency** • Bruininks-Oseretsky Test of Motor Proficiency – 2nd Edition	• The WIAT-II is considered a reliable and valid standardised academic achievement test.[112] • The BOT-2 is considered a gold-standard valid and reliable motor assessment tool for use in children and adolescents.[59]
Participant moderators	Age, sex, ethnicity, Index of Community Socio-Educational Advantage, relevant medical history	
Groups	1. Class N (Control): Regular Year 1 English	This study involved evaluating specific outcomes among children in the two Year 1 classes that participated in the THSP and in another Year 1 class at a separate

Parameter	12-week Program	Rationale
	mathematics and PE program (Delivered by classroom teacher) 2. Class R (Intervention group): Regular Year 1 English mathematics and PE program (Delivered by classroom teacher) AND gross motor circuit (4 x 15 min/week), physically active reading lessons (4 x 10 min/week) (delivered by a physiotherapist) 3. Class M (Intervention group): Regular Year 1 English mathematics and PE program (Delivered by classroom teacher) AND gross motor circuit (4 x 15 min/week), physically active mathematics lessons (3 x 15 min/week) (delivered by a physiotherapist)	but demographically similar school, which had not implemented the THSP and thus constituted a comparison class.

Appendix E: Certificate of conference presentation (Chapter 3)

World Confederation for Physical Therapy

CONGRESS 2019

Geneva

10-13 May

CERTIFICATE OF PRESENTATION

This is to certify that

Kirsty Macdonald

presented

Platform: Classic (PL) number PL-2139

RELATIONSHIPS BETWEEN MOTOR PROFICIENCY AND ACADEMIC PERFORMANCE IN MATHEMATICS AND READING IN SCHOOL-AGED CHILDREN AND ADOLESCENTS: A SYSTEMATIC REVIEW

at the World Confederation for Physical Therapy Congress 2019 on
Sunday, 12 May 2019

WCPT President

World Confederation for Physical Therapy

Chair, Congress Programme Committee

World Confederation for Physical Therapy

Appendix F: Certificate of conference presentation (Chapter 7)

World Confederation for Physical Therapy

CONGRESS 2019

Geneva

10-13 May

CERTIFICATE OF PRESENTATION

This is to certify that

Kirsty Macdonald

presented

Platform: Classic (PL) number PL-2116

IMPACT OF A 12-WEEK CLASSROOM-BASED GROSS MOTOR PROGRAM ON MOTOR PROFICIENCY, MATHEMATICS AND READING PERFORMANCE OF YEAR 1 SCHOOL CHILDREN

at the World Confederation for Physical Therapy Congress 2019 on

Saturday, 11 May 2019

WCPT President	Chair, Congress Programme Committee
World Confederation for Physical Therapy	World Confederation for Physical Therapy