Investigating the Effects of Exercise, Physical Fitness and Activity, on Cognitive Function and Academic Performance in Adolescent Schoolboys:

A Three-Pronged Approach

Joanna Wei'en Li

BSc (BioMedical Sciences)

A thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy (PhD)

School of Health Sciences, Faculty of Medicine and Health.

The University of Sydney

2021

In Memoriam

Associate Professor Helen O'Connor

Teacher, Mentor, Friend.

This thesis is dedicated to you. You were the best of all of us.

STATEMENT OF ORIGINALITY

This is to certify that to the best of my knowledge, the content of this thesis is my own work. This thesis has not been submitted for any degree or other purposes.

I certify that the intellectual content of this thesis is the product of my own work and that all the assistance received in preparing this thesis and sources have been acknowledged.

Joanna Wei'en Li

30th September 2021

AUTHOR ATTRIBUTION STATEMENT

I, Joanna Wei'en Li, certify that Chapter 3: Systematic Review was the only chapter in this thesis that was published. The published work was designed by me with data analysed by me as well. I was also the principal and corresponding author for the publication.

The respective author attributions have been included on Pg 40.

Joanna Wei'en Li

30th September 2021

As supervisor for the candidature upon which this thesis is based, I can confirm that the authorship attribution statements above are correct.

Associate Professor Rhonda Orr

Discipline of Exercise and Sports Science, Faculty of Health Sciences

The University of Sydney

30th September 2021

SUPERVISOR DECLARATION

This is to certify that the thesis entitled "Investigating the Effects of Exercise, Physical Fitness and Activity, on Cognitive Function and Academic Performance in Adolescent Schoolboys: A Three-Pronged Approach" submitted by Joanna Wei'en Li in the fulfilment of the requirements of the degree of Doctor of Philosophy is in a form ready for submission.

Associate Professor Rhonda Orr

Discipline of Exercise and Sports Science, Faculty of Health Sciences

The University of Sydney

30th September 2021

ACKNOWLEDGEMENTS

It is of great importance to note that the completion of this thesis would not be possible without the help, support, kindness and generosity of the many individuals whom I met along this arduous journey, firstly, I would like to acknowledge those within the University of Sydney. I am exceptionally grateful and incredibly indebted to my three supervisors – Associate Professor Rhonda Orr, Associate Professor Nicholas O'Dwyer, and Associate Professor Helen O'Connor (deceased). I have met many challenges along the way which detracted me from completing this thesis. However despairing the situation were, all of you never lost faith in me and gave me multiple chance to recover from all the adversities. The unwavering support and endless patience all of you rendered especially when both my mental and physical health deteriorated to a point where I was unable to pursue my candidature momentarily will remain a cherished sentiment for the rest of my life.

To my primary supervisor, Associate Professor Rhonda Orr, thank you for everything you have done for me throughout my candidature. I was not the best student to mentor but you never once gave up on me and checked in on me frequently despite your busy schedule. Your strong work ethic has always been an inspiration. Thank you for always taking the time and effort to teach me how to be a better researcher and writer. The countless sleepless nights you spent working on this thesis made its completion possible.

To my associate supervisor, Associate Professor Nicholas O'Dwyer, thank you for being such a gentleman and never turning me down when I sought your help, repeatedly and frequently especially when it comes to data analyses. You are the statistic wizard of our team and no flawed logic or reasoning gets past you. This thesis has truly benefited from your intellectual prowess. I will miss all your witty quips during our discussions. Thank you for not giving up on me as well and for stepping up to contribute even more when Helen passed.

To my associate supervisor, Associate Professor Helen O'Connor, thank you for always pushing me to be a better researcher and writing. I am incredibly honoured to have received your tutelage in academic prose and in all things pertaining to anthropometry. Your prolific writing skills and dedication to publishing manuscripts constantly inspires me to want to do better and be better. I will always remember you fondly, walking down the hallway of K Block, dressed in you grey coat, coffee in hand, always ready to tackle any challenges that comes your way.

I would like to also thank all my friends and colleagues who I have met along this journey and whose help in many ways and forms enriched my life as a student and as a person. Thank you Sarah and Alvito D'Silva as well as my godparents, Gerald and Cecilia Fang, who acted as my surrogate parents in Sydney and cared unconditionally for me while I was boarding with you. To Kelvin Pinto, thank you for your heart warming companionship and for teaching me all sorts of excel formulae and hacks that made data analyses a lot easier. To all the staff from the various schools - Tenzing Tsewang, Eka Cox, Azmy Rizman, Eugene and Leonard thank you for all the help you have rendered during data collection and the intervention protocols. Thank you for sacrificing your personal time to help me.

To all my NYSI colleagues, thank you for coming to my aid especially toward the end of the thesis were working, writing and mothering proved too much for me to handle. Special mentions to Melody Chiam who contributed immensely in the formatting and referencing of this thesis, as well as Gerald Tan (you legend) whose helped in the compilation and final stages if the thesis was pivotal to its completion. Your friendship and comradery is truly touching and very much appreciated. To Vanes, thank you for all the emotional support and for accompanying me virtually through all the late night writings.

Finally to my parents and loved ones, this thesis was definitely unachievable without your unconditional love and support. Mummy and daddy thank you for believing in me and providing me with the precious opportunity to study abroad and pursue my education further. You have both been my pillar of strength and comfort in many instances, spurring me on this incredulous journey. To my husband and son, it is your love for me and faith in me that keeps me going in the darkest of times. Lastly and most importantly, I would like to thank God for making the impossible possible. It is by your grace that I met all these amazing and generous souls along this road less travelled, leading to the fruition of this PhD journey.

TABLE OF CONTENTS

STATEMENT OF ORIGINALITY ... iii
AUTHOR ATTRIBUTION STATEMENT ... iv
SUPERVISOR DECLARATION ... v
ACKNOWLDEGMENTS ... vi
TABLE OF CONTENTS ... ix
LIST OF ABBREVIATIONS ... xii
LIST OF TABLES ... xiv
LIST OF FIGURES ... xv
ABSTRACT ... xvii
CHAPTERS OF THE THESIS PUBLISHED AS MANUSCRIPTS ... xxi

CHAPTER 1. Introduction - A review of current literature ... 1
- Literature review ... 2
- Rationale and hypotheses ... 13
- References ... 15

CHAPTER 2. Methodology ... 24
- Methodology of outcome measures ... 25
- Methodology of interventions ... 32
- Study designs ... 35
- References ... 38

CHAPTER 3. The effect of acute and chronic exercise on cognitive function and academic performance in adolescents: A systematic review ... 39
- Foreword ... 40
- Abstract ... 41
- Introduction ... 42
- Methods ... 43
- Results ... 46
- Discussion ... 54
- Conclusion ... 57
- References ... 58
- Appendices ... 61

CHAPTER 4. The effect of aerobic fitness and body composition on cognitive function and academic performance in high-achieving Singaporean male adolescents: A cross-sectional study ... 73
- Foreword ... 74

Abstract 75
Introduction 77
Methods 79
Results 84
Discussion 99
Conclusion 102
References 104
Appendices 109
CHAPTER 5. Effect of eight-week body versus brain training interventions on cognitive function and academic performance in high-achieving Singaporean male adolescents: A randomised controlled trial 113
Foreword 114
Abstract 115
Introduction 117
Methods 119
Results 125
Discussion 132
Conclusion 136
References 137
Appendices 144
CHAPTER 6. The effect of acute exercise on cognitive function and academic performance in high-fit male adolescents: An acute dose-response study 145
Foreword 146
Abstract 147
Introduction 148
Methods 150
Results 155
Discussion 160
Conclusion 163
References 164
Appendices 168
CHAPTER 7. Discussion and future directions 169
Discussion 170
Strength and limitations 175
Future directions 177
Conclusion 179
References 180
APPENDICES 187

Appendix 1: Manual of procedures: Part I - Protocol for outcome measure 187
Appendix 2: Manual of procedures: Part II - Data collection sheets 195
Appendix 3: Manual of procedures: Part III - Participant information and consent....................... 202
Appendix 4: Manual of procedures: Part IV - Body Training Program.. 226
Appendix 5: Published manuscript of systematic review 244

LIST OF ABBREVIATIONS

Abbreviations	Description
ACER	Australian Council for Educational Research
AGAT	ACER General Ability Test
AP	Academic Performance
APARQ	Adolescent Physical Activity Recall Questionnaire
APHV	Age of Peak Height Velocity
BDNF	Brain-derived Neurotrophic Factor
BMI	Body Mass Index
BRC	Brain Research Company
BRISC	Brief Risk-Resilience Index for Screening
CF	Cognitive Function
cm	Centimetre
DASS	Depression Anxiety Stress Scale
ECA	Excess Central Adiposity
h	hour
HFZ	Healthy Fitness Zone
HOC	Helen O’Connor
HR	Heart Rate
HR_{max}	Maximum Heart Rate
HR_{mean}	Average Heart Rate
IA	Insufficiently Active
JL	Joanna Li
ISAK	International Society for the Advancement of Kinanthropometry
NIZ	Needs Improvement Zone
NOD	Nicholas O’Dwyer

m	metre
MET	Metabolic Equivalent of Task
min	minutes
ml	millilitre
PA	Physical Activity
Pg	Page
RCT	Randomized Controlled Trial
RO	Rhonda Orr
RPE	Rate of Perceived Exhaustion
SA	Sufficiently Active
VO_{2peak}	Peak Oxygen Consumption (Cardiorespiratory fitness)
WHO	World Health Organisation
WtHR	Waist to Height Ratio
yrs	years

LIST OF TABLES

Chapter 2: Methodology

Table 1: Description of the cognitive domains of Thinking, Feeling and Self-regulation and their respective subdomains 30

Chapter 3: The effect of acute and chronic exercise on cognitive function and academic performance in adolescents: A systematic review

Table 1: Study design characteristics 47

Table 2: Summary of the effects of exercise on cognitive function and academic performance 49

Table A1: Methodological quality of included studies 62

Table A2: Participant characteristics 64

Table A3: Effect of exercise on the different domains of cognitive function 66

Table A4: Effect of exercise on academic performance 71

Table A5: Effect size calculations 72

Chapter 4: The effect of aerobic fitness and body composition on cognitive function and academic performance in high-achieving Singaporean male adolescents: A cross-sectional study

Table 1: Participant Characteristics 84

Table 2: Correlations (Pearson's r) between aerobic fitness and physical activity grouping variables 85

Table A1: BMI group mean values (±SE) for cognitive function and academic performance and effect sizes of group differences 109

Table A2: Physical fitness group mean values (±SE) for cognitive function and academic performance and effect sizes of significant group differences 110

Table A3: Waist to height ratio group mean values (±SE) for cognitive and academic performance and effect sizes of significant group differences 111

Table A4: Physical activity level group mean values (±SE) for cognitive and academic performance and effect sizes of significant group differences 112

Chapter 5: Effect of eight-week body versus brain training interventions on cognitive function and academic performance in high-achieving Singaporean male adolescents: A randomised controlled trial

Table 1: Participants characteristics at baseline 126

Table A1: Group mean (±SD) cognitive function (z-scores) and academic performance (%) pre- and post-intervention 144

Chapter 6: The effect of acute exercise on cognitive function and academic performance in high-fit male adolescents: An acute dose-response study

Table 1: Participant characteristics 155

Table A1: Mean (± SD) scores for cognitive function across baseline, interventions and post-testing 168

LIST OF FIGURES

Chapter 1: Introduction - A review of current literature

Figure 1: Proposed model of exercise-induced cognitive enhancement mechanism 11

Figure 2: Summary of Aim and Hypotheses – A three pronged Approach 14

Chapter 2: Methodology

Figure 1: Summary of Methods 34

Chapter 3: The effect of acute and chronic exercise on cognitive function and academic performance in adolescents: A systematic review

Figure 1: Prisma Flowchart 45

Chapter 4: The effect of aerobic fitness and body composition on cognitive function and academic performance in high-achieving Singaporean male adolescents: A cross-sectional study

Figure 1: Group mean (± standard error) z-scores for the thinking domains in the BMI group 86

Figure 2: Group mean (±SE) z-scores for the feeling domains in the BMI groups 87

Figure 3: Group mean (±SE) z-scores for the Self-regulation domains in the BMI groups... 88

Figure 4: Mean (±SE) BMI group scores for the AGAT domains 88

Figure 5: Mean (±SE) z-scores across the thinking domains for the WtHR groups 89

Figure 6: Mean (±SE) z-scores across the Feeling domains in the WtHR groups 90

Figure 7: Mean (±SE) z-scores across the Self-regulation domains in the WtHR groups 91

Figure 8: Mean (±SE) AGAT scores in the WtHR groups 91

Figure 9: Mean (±SE) z-scores for Thinking domains in the fitness groups 92

Figure 10: Mean (±SE) z-scores for Feeling domains in the fitness groups 93

Figure 11: Mean (±SE) z-scores for Self-regulation domains in the fitness groups 94

Figure 12: Mean (±SE) AGAT scores for the fitness groups.. 95

Figure 13: Mean (±SE) z-scores for Thinking domains in the physical activity groups... 96

Figure 14: Mean (±SE) z-scores for Feeling domains in the physical activity groups 97

Figure 15: Mean (±SE) z-scores for Self-regulation domains in the fitness groups 97

Figure 16: Mean (±SE) AGAT scores in the physical activity groups 98

Chapter 5: Effect of eight-week body versus brain training interventions on cognitive function and academic performance in high-achieving Singaporean male adolescents: A randomised controlled trial

Figure 1: Group mean (± SE) aerobic fitness before and after the interventions............. 127

Figure 2: Group mean (± SE) BMI before and after the interventions 127

Figure 3: Group mean (± SE) thinking scores before and after the interventions 128

Figure 4: Group mean (± SE) feeling scores before and after the interventions............. 129

Figure 5: Group mean (± SE) self-regulation scores before and after the interventions.. 130
Figure 6: Group mean (± SE) AGAT scores before and after the interventions 131

Chapter 6: The effect of acute exercise on cognitive function and academic performance in high-fit male adolescents: An acute dose-response study

Figure 1: Experimental protocol ……………………………………………………….151
Figure 2: AGAT scores (mean ± standard error [SE]) pre- and post-testing 156
Figure 3: Thinking subdomain z-scores (mean ± SE) for baseline, the three training interventions and final testing:... 157
Figure 4: Self-regulation subdomain z-scores (mean ± SE) for baseline, the three training interventions and final testing 158
Figure 5: Feeling subdomain z-scores (mean ± SE) for baseline, the three training interventions and final testing 160

ABSTRACT

Adolescence, identified as the period in human growth which occurs during ages 13 to 18 years, is a time marked by considerable hormonal, behavioural and physical changes. The prefrontal cortex in adolescence have been found to remain plastic and continues to develop into early adulthood. This makes adolescence an opportune phase to examine the impact of environmental factors on this brain region. Exercise has been postulated to be able to illicit cognitive improvement across the lifespan. Although there have been general consensus amongst researchers supporting a positive association between physical activity and cognition, literature in the adolescent population have been found to be lacking in both quality and quantity. As cognitive function has been demonstrated to be a predictor of academic performance in students, studies investigating the exercise-cognition relationship in children and youth often include academic performance as a secondary outcome measure.

The purpose of this thesis was to contribute to the limited literature in adolescence and provide insights into the relationship between exercise, cognition and academic performance. In order to fully investigate this relationship, a total of three experiments were designed: (I) cross-sectional study; (II) randomised controlled trial; and (III) acute dose-response study with the intention of adding high quality evidence to the existing body of literature. Prior to the implementation of these studies, a systematic review was conducted to analyse the strength and limitation of current literature. All study participants were males as the possible confounding effect of the menstrual cycle on cognition in female adolescents was taken into consideration. Participants were recruited across three high schools in Singapore and Australia.

The first study completed in this thesis is a systematic review reported in Chapter 3. This robust review found 11 experimental studies pertaining to the relationship between exercise intervention protocols (chronic and acute) and cognitive function (CF) and academic performance (AP) in adolescents (13 to 18 years). A key focus of the review was to include studies that conducted an exercise intervention and investigated its impact on either CF and/or AP instead of studies that only measured physical activity levels (such as through questionnaires or pedometers).The main findings of the systematic review was

that the evidence for the effect of either chronic or aerobic exercise on CF and AP in adolescents is equivocal and limited in quantity and quality. It was concluded that limited and low-quality literature in this field hinders understanding of the relation between acute and chronic exercise and CF and AP. The use of non-validated cognitive and academic assessments as well as the poor reporting of exercise intensity and dose, contributed to the variability of exercise impact on CF and AP. Future studies would benefit from the collaboration between neuroscientists with expertise in cognition and its assessment and exercise scientists with expertise in the prescription and measurement of exercise.

The second study (Chapter 4) completed in this thesis is a cross-sectional study that sought to investigate the effect of physical fitness and activity, as well as body composition on CF and AP in adolescence. A total of 250 participants from two Singaporean high-schools were recruited. Incidentally, both schools were ranked first and second in academic standing in Singapore. A key finding from this study was that contrary to literature, fitter boys with healthy body composition were found to have poorer CF and AP outcomes as compared to their less fit and overweight/obese counterparts. Additionally, a concerning and unexpected finding from this study was that all participants regardless of fitness and body composition status had negative depression, anxiety, stress and negativity bias scores (indicative of one's sensitivity to stress). Most importantly, despite a majority of the participants having normal body composition and healthy fitness, and just over half being sufficiently active, it highlighted a concerning possibility that these Singaporean schoolboys may have prioritised academic performance over overall mental well-being.

A randomised-controlled trial (n =143) was the third study (Chapter 5) completed in this thesis with the main aim being examination of the differential impacts that Body training and Brain training might potentially have on CF and AP. Contrary to the hypothesis that both exercise and cognitive training would illicit cognitive enhancement in adolescents after eight weeks of intervention, the study results found that neither Body nor Brain training had an impact on CF or AP. However, the aerobic exercise protocol in the Body training group was found to be effective in increasing cardiorespiratory fitness in adolescent males of mean age (15.7 ± 0.4 years). Lastly, although obese and overweight boys had significantly poorer depression, anxiety and stress outcomes compared to normal-weight boys, they showed no difference in academic performance or thinking scores. This finding also adds to the current literature supporting the notion that body composition is a predictor of depression in youth.

The last study in this thesis was an acute dose-response study where the participants comprised 38 Australian male high school students. The aim of this study was to investigate the effect of different single-bout exercise types on CF. AP was hypothesised to not improve after each intervention (aerobic, resistance and stretching) as the effects of acute exercise was thought to be transient in nature. Similar to the randomised-controlled trial, no effect on CF and AP was found after 30 minutes of acute exercise. The study results may be limited by the small sample size and non-homogenous fitness status of participants (97% of participants were classified in the "healthy fitness zone"). Future studies with a larger sample size and examining various degree of exercise intensity is warranted to establish a more conclusive association between acute exercise and cognition in the adolescent population.

In summary, findings from the three studies of this thesis (Chapter 4 – 6) did not support the hypothesis that exercise improves CF and AP in adolescent schoolboys. Contrary to the general literature, this thesis found that fitter boys had poorer cognitive (thinking scores) and academic performance than their less fit counterparts. Additionally, this thesis also demonstrated a positive association between unhealthy body composition and the cognitive domains of Feeling and Self-regulation in adolescent males. Although both chronic (Chapter 5) and acute (Chapter 6) intervention protocols did not illicit any significant changes in CF or AP, the detailed reporting of these study designs and methods gives valuable insights on the exercise dose and protocol for future studies to take reference from. Additionally, the eight weeks exercise intervention protocol was found to have significantly improved the cardiorespiratory fitness of study participants.

In conclusion, the literature on the effects of exercise on cognition in youth and young adults presents inconsistent findings. In contrast, there is consistent evidence for positive effects of exercise in elderly adults with varying degrees of age-related cognitive decline, as well as in population with clinically diagnosed brain and cognitive deficits. These divergent findings suggest that it may be more difficult to modify brain function in a healthy population. Future studies in healthy population should focus on the differential effect of exercise intensity, fitness status and age may have on CF and AP when examining the relationship between exercise and cognition.

CHAPTERS OF THE THESIS PUBLISHED AS MANUSCRIPTS

CHAPTER 3

Li, J. W., O'Connor, H., O'Dwyer, N., & Orr, R. (2017). The effect of acute and chronic exercise on cognitive function and academic performance in adolescents: A systematic review. *Journal of science and medicine in sport*, 20(9), 841–848.

CHAPTER 1

Introduction - A review of current literature

LITERATURE REVIEW

Exercise and Cognition

The health benefits of participating in regular physical activity and maintaining physical fitness are widely established.[1,2] It has been clearly demonstrated that physical activity decreases the risk of developing a range of diseases including cardiovascular disease, stroke, some cancers, obesity and type II diabetes.[3-5] In addition to the effects on physical health, there has been substantial interest in research supporting a beneficial impact of physical activity and/or improved fitness on cognitive function across the lifespan.[6,7] Throughout literature, the term "exercise" has been used interchangeably with "physical activity[8]" and they both share common elements such as bodily movements produced by skeletal muscles that expands energy[9]. Exercise can be defined as 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[9]. As such exercise can be thought of as a subset of physical activity. The notion that exercise can be a non-invasive and non-pharmacological benefit to cognition[10] has contributed to the proliferation of research in this field across multiple cohorts and age groups, including older adults with Alzheimer's disease,[11,12] school-aged children with obesity[13] or depression,[14] and patients recovering from traumatic brain injury.[15,16] In healthy school-aged children and adolescents, systematic reviews[17-21] and meta analyses[22,23] have demonstrated evidence that exercise may play an important role in enhancing cognitive function. However, the variability in the research outcome seems to be limited by factors such as difficulty in recruitment of schools and school-going participants resulting in the experimental population not being representative of the general population, inadequate sample size, non-standardised and non-validated measure of cognitive performance and null reporting of effect sizes and their respective confidence intervals.[20,21]

Exercise and academic performance

Cognitive abilities such as executive function, memory, attention and self-regulation have been thought to be predictive of academic performance.[24] Hence, alongside the research of how exercise may impact cognition is the way exercise may also impact academic performance in school-aged children and adolescents. Similarly, there has been evidence indicative of the beneficial effect of exercise on academic performance but with variability in the research outcomes.[25,26] [27,28]Apart from cognitive function, academic performance is affected by many factors including but not limited to student attitude, attendance and interest, quality of learning, as well as socio-economic status and self-motivation.[29] Although evidence supporting the beneficial effects of acute and chronic exercise on academic performance in adolescents is limited,[30,31] studies investigating the effect of physical activity on academic performance in adolescents have demonstrated a positive association between increased physical activity levels and better academic outcomes.[23,32]

Adolescence and neuroplasticity: An Opportune Phase

Adolescence is the transitory phase between childhood and adulthood (usually between 10 to 19 years of age), where an individual experiences a multitude of changes involving the physical, physiological, cognitive and psychological state[33]. Puberty is the term often used in literature to describe the physiological and physical changes one undergoes during this phase.[34] Puberty is complete, only when individuals' reproductive capacities are reached and their sexual organs have matured, resulting in the ability to conceive.[34] During this period of adolescence hallmarked by accelerated somatic growth, individuals experience the aforementioned changes often at varying rates and speed.[34] The sex hormones estrogen and testosterone not only drives growth velocity and upregulates other hormones during puberty, but have also found to impact the brain.[34] High densities of estrogen and testosterone receptors can be found in the Amgydala, Hippocampus and Nucleus Accumbens[35]. A recent study in both rodents and humans concluded that estrogen receptors found in the Hippocampus and Prefrontal Cortex facilitates higher cognitive function.[36]

Through the use of magnetic resonance imaging (MRI), research in the past three decades into the adolescent brain has seen significant progress, with studies shedding light on the morphological and functional changes that occur during adolescence.[37-39] In particular MRI studies have found that myelinogenesis and neurogenesis continues in the adolescent brain, with its neuronal network remaining structurally and functionally vulnerable to the significant increase in estrogen, testosterone and progesterone during puberty.[37,40] Apart from the changes observed in the limbic system which impacts self-control and decision-making, a surge in myelination in the frontal lobe of the brain also indicates a possible pubertal impact on cognition in adolescents.[37,40]

Neuroplasticity can be referred to as the significant neural circuitry (brain wiring") changes that occurs when an individual acquires a new skill, and as a result of the process of the skill acquisition, synthesis, elaboration and stabilization of neural networks are observed. [37-39] Neuronal proliferation, rewiring, dendritic pruning, and environmental exposure are important components of brain plasticity during adolescence with the Prefrontal Cortex found to be in a process of continuous reconstruction, consolidation, and maturation.[37] Although most literature would concur that adolescence is a phase lasting through the teenage years of 11 to 19 years of age, it is widely believed that the adolescent brain continue to experience "rewiring" into early adulthood till approximately the age of 25[41]. As such, brain maturation and as a result cognition, may have the longest runway in terms of change elicited by puberty. The vulnerability and susceptibility of the adolescent brain to environmental factors as well as its neuroplasticity thus make adolescence an opportune phase for investigating potential influences to cognitive function.

Physical Activity in Adolescents

Because of its plasticity, the adolescent period provides a protracted window of opportunity for individuals to develop talents and acquire new skills. However, because of its sensitivity, the adolescent brain is also highly susceptible and impacted by negative influences such as, trauma, chronic stress, drug abuse, and sedentary lifestyles.[42,43] The World Health Organisation (WHO) defines physical activity as any bodily movement produced by skeletal muscles that requires energy expenditure[44]. Physical activity refers to all movement including during leisure time, as well as during transport and commutation to and from places[44]. In children and adolescents (5 to 17 years), it is recommended that they should do at least 60 minutes per day of moderate-to-vigorous intensity, mostly aerobic, physical activity, across the week[44]. Sedentary behaviour can be defined as expanding slightly more energy above one's resting metabolic rate but not enough to be quantified as light-intensity physical activity (1.0-1.5 metabolic equivalents (METs[45])). Common sedentary behaviours include activities which predominantly involves sitting, such as television viewing, computer use and desk-based work[46]. Sedentary lifestyle and behaviours in children and adolescents have been associated with overweight and obesity and has become an increasing concern in many developed countries[47-50] and have started to be evident in some developing countries as well.[51,52] It has been suggested that the increased used and availability of technology particularly watching television, playing video games and using computers are critical sedentary factors contributing to the prevalence of obesity in children and adolescents.[46] In a recent systematic review, Pate et al found that children sedentary behaviour increased as they aged, with adolescents between the ages of 12 to 19 spending an average of 7.5 to 8h per day being sedentary.[46] Additionally, the World Health Organization (WHO)[53] found that more than 80% of school-aged adolescents (1.6 million 11-17 year olds across 146 countries) failed to meet the current recommendations of at least one hour of moderate-to-vigorous physical activity per day. It is important to note that a child or adolescent may meet the recommended physical activity guideline per day but still spend a large proportion of the day in sedentary behaviours each day[46]. In addition to the global trend of the increased in sedentary behaviour in children and adolescents, a study by Tomkinson et al found a temporal trend of a decline in cardiorespiratory fitness of children and adolescents age (9 to 17 years) from 1981 to 2014, with cardiorespiratory fitness decreasing 7.3% (3.3ml/kg/min) over the span of 33 years in high and upper-middle income countries[54].

Body composition and cognitive function and academic performance

Although physical activity and exercise have been shown to be beneficial in all life stages,[6,23,55,56] early intervention, especially during the schooling years of children and adolescents, are crucial in improving and maintaining the cognitive health and function of an individual throughout their lifespan.[17,57] However, in addition to declining physical activity levels globally, there has also been a worldwide trend of increasing body mass index (BMI) in children and adolescents,[58] presenting with risk factors for later-life cardiovascular disease[59]. This is a major health concern. Furthermore, studies have found that overweight and/or obese students have differing prefrontal cortex structures[60] and reduced white matter integrity[61] as well as poorer cognitive[62-66] and academic[67-69] outcomes, compared with their normal-weight counterparts. Thus, in addition to physical activity and exercise, body composition is an important consideration in regard to cognition and academic performance in adolescents.

The dynamic state of the adolescent body coupled with the complexity of the rate of growth and development makes adolescents a difficult population to study often with limited research done. As such, an in depth investigation in the adolescent population regarding the beneficial effects of exercise on cognition will be beneficial in informing schools, parents, teachers and administrators about recommended findings concerning the role of physical activity and exercise in the holistic development of an adolescent.

Effect of chronic and acute exercise on cognition

Exercise can be categorised as acute exercise or chronic exercise. An acute bout of exercise is a single session of exercise.[70] Chronic exercise on the other hand includes a series of acute bouts of exercise, with multiple sessions per week, over the course of time (typically 6 weeks or more), with specific aim of improving physical fitness, performance or general health.[70] While both acute and chronic exercise have been extensively used in research concerning exercise and cognition in both animal and human models, they must be distinguished because they induce different changes.[71] The former transient in nature, modulating neural networks after a state of heighten arousal,[72] while the latter is thought to elicit structural changes in the brain through neurogenesis and proliferation.[71] The behavioural and psychological changes induced by a single bout of acute exercise generally appear quite rapidly after the beginning of exercise (seconds to minutes) and disappear relatively quickly after its cessation (minutes to hours).[71] In contrast, chronic effects of exercise reflect structural and durable changes in the organism, like angiogenesis[73] synaptogenesis[74] or neurogenesis[75].

Acute intervention studies in adolescents though few have demonstrated mixed findings on the effect of exercise on cognition.[30] Amongst the eight study[76-82] examined in a recent systematic review[30], although each study reported at least one significant effect of acute exercise showing improvement in cognition, the majority of cognitive parameters (60%) indicated that the effect of exercise was either not significant or the control/resting condition was favoured.[30] Of the eight studies, only five studies reported using an exercise protocol of moderate-to-vigorous intensity[77-81]. Chronic intervention studies in adolescents, have also demonstrated mixed findings on the effect of exercise on cognition[30]. Only two chronic exercise studies in adolescent aged 13 to 18 were found[30]. One study showed that cognition measured in the form a psychometric assessment was found to improve after four months (four days per week; HR_{mean} = 147 beats per minute)[83], while the other did not find any significant improvement in attention and concentration after 25 weeks of exercise (exercise intensity and dose was not reported)[84]. However, in this particular study, participants aerobic fitness did not improve as well post intervention[84], suggesting that the intervention protocol may not be at a sufficient intensity and frequency to elicit any physical or cognitive change. In summary, the current literature pertaining to the effects of exercise and cognition in adolescents is limited in both quantity and quality.[30] As such, this thesis will add to the paucity of evidence as well as contribute to current recommendations involving exercise testing and cognitive assessment in the adolescent population.

Effect of aerobic and resistance exercise on cognition

Aside from differentiating between the effects of acute and chronic exercise on cognition, different exercise modalities and how they impact cognition should also be examined to fully understand the relationship between exercise and cognition. Thus far, the studies mentioned in this literature review have been with reference to aerobic exercise. Research pertaining to resistance exercise and cognition be it acute or chronic have been rather limited.[85,86] There have been numerous health benefits associated with resistance training in both the young[17] and elderly[87,88]. In the elderly, where older individuals are more likely to be unable to perform aerobic exercise such as jogging[89,90] due to limitations in their cardiorespiratory function as well as mobility-related issues, resistance exercise serves as an alternative exercise and physical activity intervention.[86]A recent meta-analysis of the effects of resistance exercise on cognition found 23/24 studies of which their participants' mean age was greater than 50 years. Only one study was found to be in young adults (mean age 20 years).[91] Alongside with other prior review,[92-

[94] there is a general consensus in findings that resistance exercise is beneficial to cognition. A recent study in adolescents (mean age 13.7 ± 0.5 years) found that participants performed significantly better in the cognitive assessment of the Stroop Test (a test of selective attention) after a bout of resistance exercise compared to a bout of aerobic exercise.[95] As such, by investigating the effects of different exercise type and modalities on cognitive function, this thesis adds to the database of limited research done in the adolescent population.

Exercise-induced Cognitive Enhancement

The mechanism of how exercise can elicit cognitive improvement still remain unclear. However recent research with humans have suggested that the increased expression of BDNF (Brain-Derived Neurotohpic Factor) after an acute bout of exercise, may confer cognitive improvements.[96-98] BDNF is a protein classified under the family of neurotrophins expressed by the BDNF gene.[99] It plays an important role in neuron and synapse growth, and thus is crucial in the development and maintenance of neural circuitry and brain health.[99-102] There is evidence suggesting that serum BDNF levels were positively associated with the intensity of the exercise[96-98]. Because BDNF is able to cross the blood-brain barrier[103] the implication is that these increases in serum levels of BDNF are indicative of increases in BDNF in the brain and, hence, have long-term implications for brain health and cognitive performance[97]. Chronic exercise is thought to also enhance cognition through BDNF but does so through a series of gene expression and signal cascading events known as the PGC1a/FCDN5/BDNF pathway.[104] Refer to Figure 1 for proposed exercise-induced cognitive enhancement mechanism elucidated from current literature findings.

Brain Training, physical activity and cognitive enhancement

Brain or cognitive training consists of practising and learning skills and techniques (e.g. use of mnemonics to aid recall) to manage cognitively demanding situations.[105] Similar to the way running can increase cardiovascular fitness, brain training like-wise has been found to result in the transfer of practised cognitive skills to what has been termed 'fluid intelligence'.[106] Fluid intelligence, defined as the ability to drive abstract reasoning and problem solving[106] has also been found to be predictive of academic and professional success.[107] As such, brain training is emerging as an alternative approach to improve academic success.[95] Although brain training has been reported as effective in some studies in adults and the elderly,[108,109] there are few studies in healthy children or adolescents, where most studies have targeted clinical populations, particularly those with attention deficit hyperactivity disorder (ADHD).[110] Evidence for the effectiveness of brain training in healthy children has only recently been reported.[107,111,112] These studies demonstrated that although brain training can be effective, it is unclear which training tasks and processes contribute most to cognitive enhancements, or what duration of training may be required for optimum improvements.[107] The one study in typically developing adolescent populations,[110] showed little support for any benefit. More research is required in healthy populations, particularly adolescents, to evaluate its effectiveness and the transfer to academic improvement.

Although there have been many studies demonstrating the benefits of brain training[108,109] and physical activity[113-116] on cognition, it has been postulated that when it comes to improving cognitive functions, cognitive training appears to have a narrow transfer where the training produced transient specific training effects that do not generalise[117]. For instance, computerised working memory training improved working memory but not impulsivity, creativity or flexibility in decision making[117-119]. Diamond and Ling concluded in their systematic review that the wide transfer to untrained cognitive skills has not been demonstrated in either types of interventions (brain training or exercise and physical activity)[120]. Furthermore it was found that aerobic exercise, or resistance training, without a cognitive component produced little or no cognitive benefits. There have been evidence suggesting skill acquisition may play a crucial role in clarifying the beneficial effects of exercise on cognitive function[121].

In general, literature supporting the beneficial effect of exercise on cognitive function and academic performance in the adolescent phase is lacking in both quality and quantity.[30] This conclusion can be attributed to several limitations such as poorly reported exercise dose, non-standardised definition and assessment of cognitive function, as well as small sample sizes.[21,29,30] Given that adolescence is an opportune phase for investigating potential influences to cognitive function due to its neuroplasticity, an in depth examination into the relationship underpinning exercise and cognition is warranted.

Figure 1: Proposed model of exercise-induced cognitive enhancement mechanism

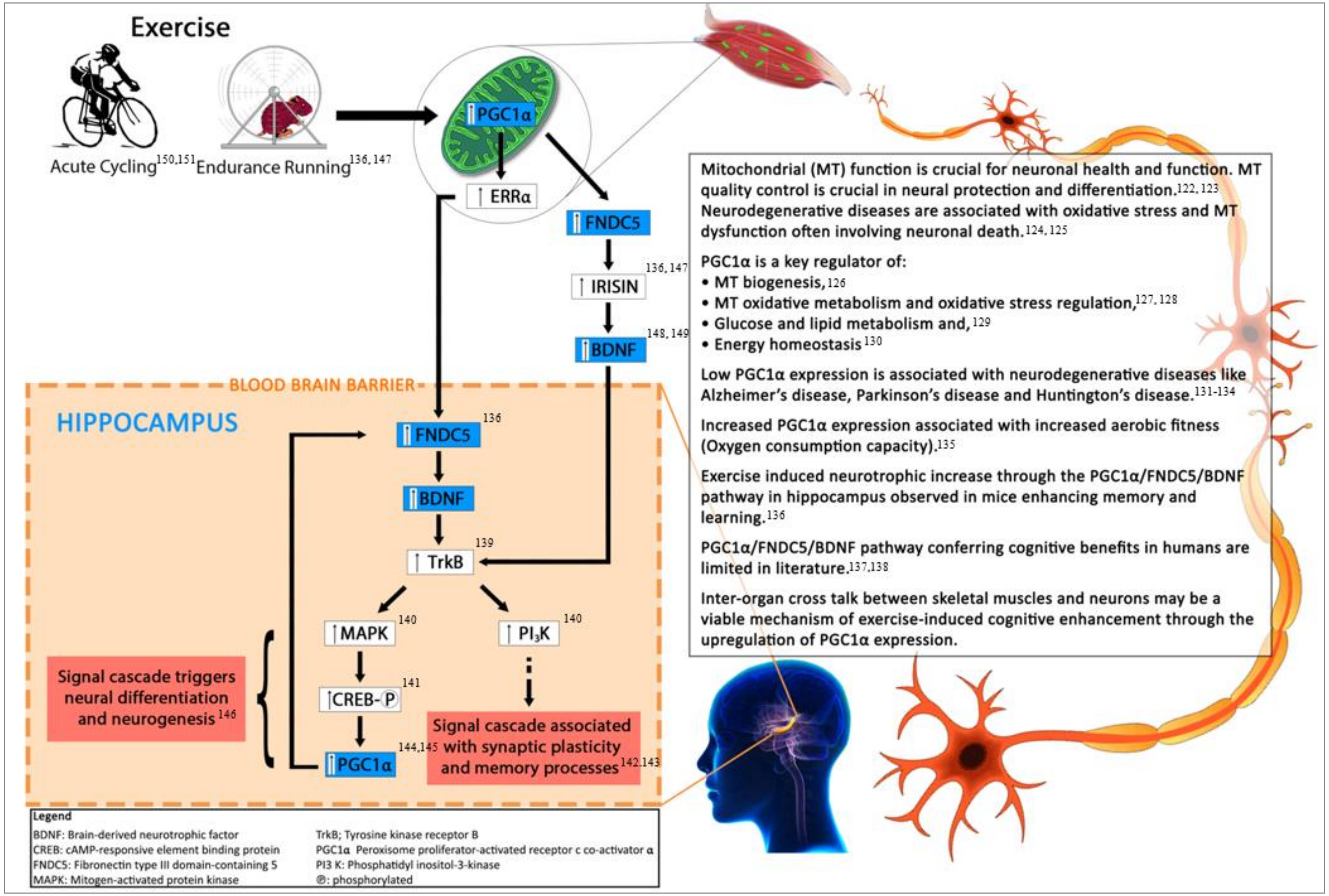


Figure 1 illustrates the postulated mechanism of how exercise can induce cognitive enhancement via the PGC1α/FCDN5/BDNF pathway. This model hypothesizes that inter-organ cross talk helps to facilitate the pathway and the respective upregulation of signal cascades conferring neurogenesis, neuronal differentiation and synaptogenesis. The crosstalk is such that upregulation in skeletal PGC1α can in turn upregulate hippocampal PGC1α gene as well through the upregulation of both skeletal and hippocampal BDNF since BDNF can cross the blood brain barrier. This coupling results in a positive feedback loop and the increase in PGC1α signalling.

RATIONALE AND HYPOTHESES

This thesis aims to investigate the relationship between physical fitness, physical activity (PA) and cognitive function (CF) and academic performance (AP) in adolescent males. The secondary aim of this thesis includes establishing the feasibility and effectiveness of the intervention protocols used in both an Australian and Singapore high school setting. As such, this includes the study of cardiorespiratory fitness and enhancement, and its impact on CF and AP, as well as the correlation between body composition and CF and AP. Furthermore, this thesis seeks to investigate the different effects of chronic and acute exercise training has on CF and AP. Hence, a three-pronged approach was adopted to gain a holistic insight between exercise induced/related cognitive enhancements (Figure 1). Three studies, including (I) cross-sectional demographic study; (II) randomised controlled trial; and (III) acute dose-response study, were designed with the following hypotheses in mind:

(I) Cross-sectional Demographic Study:

1. Boys who have better physical fitness (cardiorespiratory fitness) would attain better CF and AP.
2. Body fat composition has a negative correlation with both CF and AP.

(II) Randomised Controlled Trial:

1. Chronic aerobic exercise and brain training will result in measurable improvement in CF and AP compared to boys who did not undergo either intervention.
2. Chronic aerobic exercise training will improve cognitive function, specifically executive function, and result in better transference to academic performance as compared to brain training.

(III) Acute Dose-response Study:

1. Acute aerobic and resistance training will elicit a measurable improvement in CF compared to calisthenics.
2. Acute bouts of aerobic exercise will have a greater impact on CF than acute bouts of resistance training.

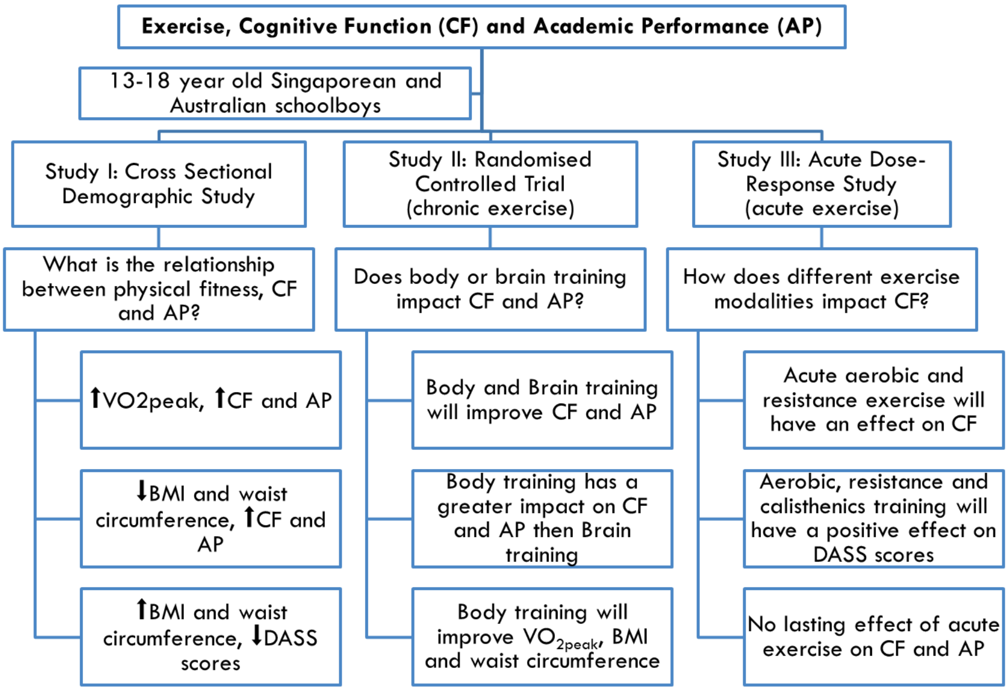


Figure 2: Summary of Aim and Hypotheses – A three pronged Approach. ↑: Higher or better; ↓ lower or poorer; BMI: Body Mass Index; DASS: Depression, Anxiety and Stress Scale; VO_{2peak}: Cardiorespiratory Fitness

REFERENCES

1 Fox, K., Riddoch, C., & Editors, S. (2004). *At Least Five A Week. Evidence on the Impact of Physical Activity and Its Relationship to Health*.

2 Physical Activity Guidelines Advisory Committee report, 2008. To the Secretary of Health and Human Services. Part A: executive summary. (2009). *Nutrition Reviews, 67*(2), 114-120.

3 Lee, I.-M. (2003). Physical activity and cancer prevention--data from epidemiologic studies. *Medicine and Science in Sports and Exercise, 35*(11), 1823-1827.

4 Shiroma, E. J., & Lee, I.-M. (2010). Physical activity and cardiovascular health: lessons learned from epidemiological studies across age, gender, and race/ethnicity. *Circulation, 122*(7), 743-752.

5 Laaksonen, D. E., Lindström, J., Lakka, T. A., Eriksson, J. G., Niskanen, L., Wikström, K., Aunola, S., Keinänen-Kiukaanniemi, S., Laakso, M., & Valle, T. T. (2005). Physical activity in the prevention of type 2 diabetes: the Finnish diabetes prevention study. *Diabetes, 54*(1), 158-165.

6 Voss, M. W., Nagamatsu, L. S., Liu-Ambrose, T., & Kramer, A. F. (2011). Exercise, brain, and cognition across the life span. *Journal of Applied Physiology, 111*(5), 1505-1513.

7 McAuley, E., Mullen, S. P., & Hillman, C. H. (2013). Physical activity, cardiorespiratory fitness, and cognition across the lifespan. In *Social Neuroscience and Public Health* (pp. 235-252). Springer.

8 Taylor, H. L. (1983). Physical activity: is it still a risk factor? *Preventive Medicine, 12*(1), 20-24.

9 Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Reports, 100*(2), 126.

10 Kim, S., Choi, J.-Y., Moon, S., Park, D.-H., Kwak, H.-B., & Kang, J.-H. (2019). Roles of myokines in exercise-induced improvement of neuropsychiatric function. *Pflügers Archiv-European Journal of Physiology, 471*(3), 491-505.

11 Arcoverde, C., Deslandes, A., Rangel, A., Rangel, A., Pavão, R., Nigri, F., Engelhardt, E., & Laks, J. (2008). Role of physical activity on the maintenance of cognition and activities of daily living in elderly with Alzheimer's disease. *Arquivos de Neuro-Psiquiatria, 66*(2B), 323-327.

12 Hoffmann, K., Frederiksen, K. S., Sobol, N. A., Beyer, N., Vogel, A., Andersen, B. B., Lolk, A., Gottrupp, H., Waldemar, G., & Hasselbalch, S. G. (2014). Impact of physical activity and cognition on Activities of Daily Living in home-dwelling patients with mild to moderate Alzheimer's disease. *Alzheimer's & Dementia, 10*(4), P761-P762.

13 Davis, C. L., Tomporowski, P. D., Boyle, C. A., Waller, J. L., Miller, P. H., Naglieri, J. A., & Gregoski, M. (2007). Effects of aerobic exercise on overweight children's cognitive functioning: a randomized controlled trial. *Research Quarterly for Exercise and Sport, 78*(5), 510-519.

14 Oertel-Knöchel, V., Mehler, P., Thiel, C., Steinbrecher, K., Malchow, B., Tesky, V., Ademmer, K., Prvulovic, D., Banzer, W., & Zopf, Y. (2014). Effects of aerobic exercise on cognitive performance and individual psychopathology in depressive and schizophrenia patients. *European Archives of Psychiatry and Clinical Neuroscience, 264*(7), 589-604.

15 Lee, Y. S. C., Ashman, T., Shang, A., & Suzuki, W. (2014). Brief report: Effects of exercise and self-affirmation intervention after traumatic brain injury. *NeuroRehabilitation, 35*(1), 57-65.

16 Hopkins, R. O., Suchyta, M. R., Farrer, T. J., & Needham, D. (2012). Improving post–intensive care unit neuropsychiatric outcomes: understanding cognitive effects of physical activity. *American Journal of Respiratory and Critical Care Medicine, 186*(12), 1220-1228.

17 Hillman, C. H., Erickson, K. I., & Kramer, A. F. (2008). Be smart, exercise your heart: exercise effects on brain and cognition. *Nature Reviews Neuroscience, 9*(1), 58-65.

18 Tomporowski, P. D., Davis, C. L., Miller, P. H., & Naglieri, J. A. (2008). Exercise and children's intelligence, cognition, and academic achievement. *Educational Psychology Review, 20*(2), 111-131.

19 Taras, H. (2005). Physical activity and student performance at school. *Journal of School Health, 75*(6), 214-218.

20 Keeley, T. J. H., & Fox, K. R. (2009). The impact of physical activity and fitness on academic achievement and cognitive performance in children. *International Review of Sport and Exercise Psychology, 2*(2), 198-214.

21 Singh, A. S., Saliasi, E., van den Berg, V., Uijtdewilligen, L., de Groot, R. H. M., Jolles, J., Andersen, L. B., Bailey, R., Chang, Y. K., Diamond, A., Ericsson, I., Etnier, J. L., Fedewa, A. L., Hillman, C. H., McMorris, T., Pesce, C., Pühse, U., Tomporowski, P. D., & Chinapaw, M. J. M. (2019). 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. *British Journal of Sports Medicine, 53*(10), 640-647.

22 Sibley, B. A., & Etnier, J. L. (2003). The relationship between physical activity and cognition in children: a meta-analysis. *Pediatric Exercise Science, 15*(3), 243-256.

23 Sibley, B. A., & Etnier, J. L. (2002). The effects of physical activity on cognition in children: A meta-analysis. *Medicine & Science in Sports & Exercise, 34*(5), S214.

24 Nesayan, A., Amani, M., & Gandomani, R. A. (2019). Cognitive profile of children and its relationship with academic performance. *Basic and Clinical Neuroscience, 10*(2), 165-174.

25 Chaddock-Heyman, L., Hillman, C. H., Cohen, N. J., & Kramer, A. F. (2014). III. The importance of physical activity and aerobic fitness for cognitive control and memory in children. *Monographs of the Society for Research in Child Development, 79*(4), 25-50.

26 Esteban-Cornejo, I., Tejero-Gonzalez, C. M., Sallis, J. F., & Veiga, O. L. (2015). Physical activity and cognition in adolescents: A systematic review. *Journal of Science and Medicine in Sport, 18*(5), 534-539.

27 Fedewa, A. L., & Ahn, S. (2011). The effects of physical activity and physical fitness on children's achievement and cognitive outcomes. *Research Quarterly for Exercise and Sport, 82*(3), 521-535.

28 Haapala, E. A. (2013). Cardiorespiratory fitness and motor skills in relation to cognition and academic performance in children - a review. *Journal of Human Kinetics, 36*, 55-68.

29 Ruiz-Ariza, A., Grao-Cruces, A., de Loureiro, N. E. M., & Martinez-Lopez, E. J. (2017). Influence of physical fitness on cognitive and academic performance in adolescents: A systematic review from 2005–2015. *International Review of Sport and Exercise Psychology, 10*(1), 108-133.

30 Li, J. W., O'Connor, H., O'Dwyer, N., & Orr, R. (2017). The effect of acute and chronic exercise on cognitive function and academic performance in adolescents: A systematic review. *Journal of Science and Medicine in Sport, 20*(9), 841-848.

31 Herting, M. M., & Chu, X. (2017). Exercise, cognition, and the adolescent brain. *Birth Defects Research, 109*(20), 1672-1679.

32 Esteban-Cornejo, I., Tejero-Gonzalez, C. M., Sallis, J. F., & Veiga, O. L. (2015). Physical activity and cognition in adolescents: A systematic review. *Journal of Science and Medicine in Sport, 18*(5), 534-539.

33 Holder, M. K., & Blaustein, J. D. (2014). Puberty and adolescence as a time of vulnerability to stressors that alter neurobehavioral processes. *Frontiers in Neuroendocrinology, 35*(1), 89-110.

34 Marshall, W. A., & Tanner, J. M. (1986). Puberty. In *Postnatal Growth Neurobiology* (pp. 171-209). Springer.

35 Almey, A., Milner, T. A., & Brake, W. G. (2015). Estrogen receptors in the central nervous system and their implication for dopamine-dependent cognition in females. *Hormones and Behavior, 74*, 125-138.
36 Hara, Y., Waters, E. M., McEwen, B. S., & Morrison, J. H. (2015). Estrogen effects on cognitive and synaptic health over the lifecourse. *Physiological Reviews, 95*(3), 785-807.
37 Arain, M., Haque, M., Johal, L., Mathur, P., Nel, W., Rais, A., Sandhu, R., & Sharma, S. (2013). Maturation of the adolescent brain. *Neuropsychiatric Disease and Treatment, 9*, 449-461.
38 Li, K., & Xu, E. (2008). The role and the mechanism of gamma-aminobutyric acid during central nervous system development. *Neuroscience Bulletin, 24*(3), 195-200.
39 Wahlstrom, D., Collins, P., White, T., & Luciana, M. (2010). Developmental changes in dopamine neurotransmission in adolescence: behavioral implications and issues in assessment. *Brain and Cognition, 72*(1), 146-159.
40 Giedd, J. N., Blumenthal, J., Jeffries, N. O., Castellanos, F. X., Liu, H., Zijdenbos, A., Paus, T., Evans, A. C., & Rapoport, J. L. (1999). Brain development during childhood and adolescence: a longitudinal MRI study. *Nature Neuroscience, 2*(10), 861-863.
41 Berman, S. M., Brown, K., Dittus, P., Ferdon, C. D., Gavin, L. E., Harrier, S., Kann, L., Liddon, N., MacKay, A. P., & Markowitz, L. (2009). Sexual and reproductive health of persons aged 10-24 years--United States, 2002-2007.
42 Dahl, R. (2003). Beyond raging hormones: The tinderbox in the teenage brain. *Cerebrum, 5*(3), 7-22.
43 Activities, C. (2002). PBS-Frontline: Inside the Teenage Brain.
44 World Health Organization. (2020). *Physical activity*. https://www.who.int/news-room/fact-sheets/detail/physical-activity.
45 Pate, R. R., O'neill, J. R., & Lobelo, F. (2008). The evolving definition of" sedentary". *Exercise and Sport Sciences Reviews, 36*(4), 173-178.
46 Pate, R. R., Mitchell, J. A., Byun, W., & Dowda, M. (2011). Sedentary behaviour in youth. *British Journal of Sports Medicine, 45*(11), 906-913.
47 Rennie, K. L., Johnson, L., & Jebb, S. A. (2005). Behavioural determinants of obesity. *Best Practice & Research Clinical Endocrinology & Metabolism, 19*(3), 343-358.
48 Zimmermann, M., Hess, S., & Hurrell, R. (2000). A national study of the prevalence of overweight and obesity in 6–12 y-old Swiss children: body mass index, body-weight perceptions and goals. *European Journal of Clinical Nutrition, 54*(7), 568-572.
49 Bundred, P., Kitchiner, D., & Buchan, I. (2001). Prevalence of overweight and obese children between 1989 and 1998: population based series of cross sectional studies. The *BMJ, 322*(7282), 326.
50 Moreno, L. A., Mesana, M. I., Fleta, J., Ruiz, J. R., González-Gross, M., Sarría, A., Marcos, A., & Bueno, M. (2005). Overweight, obesity and body fat composition in Spanish adolescents. *Annals of Nutrition and Metabolism, 49*(2), 71-76.
51 Prentice, A. M. (2006). The emerging epidemic of obesity in developing countries. *International Journal of Epidemiology, 35*(1), 93-99.
52 de Onis, M., Blössner, M., & Borghi, E. (2010). Global prevalence and trends of overweight and obesity among preschool children. *The American Journal of Clinical Nutrition, 92*(5), 1257-1264.
53 World Health Organization. (2019). *New WHO-led study says majority of adolescents worldwide are not sufficiently physically active, putting their current and future health at risk*. https://www.who.int/news/item/22-11-2019-new-who-led-study-says-majority-of-adolescents-worldwide-are-not-sufficiently-physically-active-putting-their-current-and-future-health-at-risk.
54 Tomkinson, G. R., Lang, J. J., & Tremblay, M. S. (2019). Temporal trends in the cardiorespiratory fitness of children and adolescents representing 19 high-income and upper middle-income countries between 1981 and 2014. *British Journal of Sports Medicine, 53*(8), 478-486.

55 Etnier, J. L., & Chang, Y.-K. (2019). Exercise, cognitive function, and the brain: Advancing our understanding of complex relationships. *Journal of Sport and Health Science, 8*(4), 299.

56 Etnier, J. L., Salazar, W., Landers, D. M., Petruzzello, S. J., Han, M., & Nowell, P. (1997). The influence of physical fitness and exercise upon cognitive functioning: A meta-analysis. *Journal of Sport and Exercise Psychology, 19*(3), 249-277.

57 McMorris, T. (2009). Exercise and cognitive function: a neuroendocrinological explanation. *Exercise and Cognitive Function*, 41-68.

58 Abarca-Gómez, L., Abdeen, Z. A., Hamid, Z. A., Abu-Rmeileh, N. M., Acosta-Cazares, B., Acuin, C., Adams, R. J., Aekplakorn, W., Afsana, K., & Aguilar-Salinas, C. A. (2017). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128· 9 million children, adolescents, and adults. *The Lancet, 390*(10113), 2627-2642.

59 Twig, G., Ben-Ami Shor, D., Furer, A., Levine, H., Derazne, E., Goldberger, N., Haklai, Z., Levy, M., Afek, A., & Leiba, A. (2017). Adolescent body mass index and cardiovascular disease–specific mortality by midlife. *The Journal of Clinical Endocrinology & Metabolism, 102*(8), 3011-3020.

60 Ross, N., Yau, P. L., & Convit, A. (2015). Obesity, fitness, and brain integrity in adolescence. *Appetite, 93*, 44-50.

61 Verstynen, T. D., Weinstein, A., Erickson, K. I., Sheu, L. K., Marsland, A. L., & Gianaros, P. J. (2013). Competing physiological pathways link individual differences in weight and abdominal adiposity to white matter microstructure. *Neuroimage, 79*, 129-137.

62 Davis, C. L., Tkacz, J. P., Tomporowski, P. D., & Bustamante, E. E. (2015). Independent associations of organized physical activity and weight status with children's cognitive functioning: a matched-pairs design. *Pediatric Exercise Science, 27*(4), 477-487.

63 Li, Y., Dai, Q., Jackson, J. C., & Zhang, J. (2008). Overweight is associated with decreased cognitive functioning among school-age children and adolescents. *Obesity, 16*(8), 1809-1815.

64 Tandon, P., Thompson, S., Moran, L., & Lengua, L. (2015). Body mass index mediates the effects of low income on preschool children's executive control, with implications for behavior and academics. *Childhood Obesity, 11*(5), 569-576.

65 Wirt, T., Schreiber, A., Kesztyüs, D., & Steinacker, J. M. (2015). Early life cognitive abilities and body weight: cross-sectional study of the association of inhibitory control, cognitive flexibility, and sustained attention with BMI percentiles in primary school children. *Journal of Obesity, 2015*.

66 Pontifex, M. B., Kamijo, K., Scudder, M. R., Raine, L. B., Khan, N. A., Hemrick, B., Evans, E. M., Castelli, D. M., Frank, K. A., & Hillman, C. H. (2014). V. The differential association of adiposity and fitness with cognitive control in preadolescent children. *Monographs of the Society for Research in Child Development, 79*(4), 72-92.

67 Datar, A., Sturm, R., & Magnabosco, J. L. (2004). Childhood overweight and academic performance: national study of kindergartners and first-graders. *Obesity Research, 12*(1), 58-68.

68 Sardinha, L. B., Marques, A., Martins, S., Palmeira, A., & Minderico, C. (2014). Fitness, fatness, and academic performance in seventh-grade elementary school students. *BMC Pediatrics, 14*(1), 1-9.

69 Torrijos-Niño, C., Martínez-Vizcaíno, V., Pardo-Guijarro, M. J., García-Prieto, J. C., Arias-Palencia, N. M., & Sánchez-López, M. (2014). Physical fitness, obesity, and academic achievement in schoolchildren. *The Journal of Pediatrics, 165*(1), 104-109.

70 Kenney, W., Wilmore, J., & Costill, D. (2012). *Physiology of sport and exercise fifth edition*. Human Kinetics .

71 McMorris, T. E., Tomporowski, P. E., & Audiffren, M. E. (2009). *Exercise and cognitive function*. Wiley-Blackwell.

72 Audiffren, M., Tomporowski, P. D., & Zagrodnik, J. (2008). Acute aerobic exercise and information processing: energizing motor processes during a choice reaction time task. *Acta Psychologica, 129*(3), 410-419.
73 Swain, M. (2013). The inseparability of cognition and emotion in second language learning. *Language Teaching, 46*(2), 195-207.
74 Chu, C. J., & Jones, T. A. (2000). Experience-dependent structural plasticity in cortex heterotopic to focal sensorimotor cortical damage. *Experimental Neurology, 166*(2), 403-414.
75 Van Praag, H., Christie, B. R., Sejnowski, T. J., & Gage, F. H. (1999). Running enhances neurogenesis, learning, and long-term potentiation in mice. *Proceedings of the National Academy of Sciences, 96*(23), 13427-13431.
76 Cooper, S. B., Bandelow, S., Nute, M. L., Morris, J. G., & Nevill, M. E. (2012). The effects of a mid-morning bout of exercise on adolescents' cognitive function. *Mental Health and Physical Activity, 5*(2), 183-190.
77 Budde, H., Voelcker-Rehage, C., Pietrassyk-Kendziorra, S., Machado, S., Ribeiro, P., & Arafat, A. M. (2010). Steroid hormones in the saliva of adolescents after different exercise intensities and their influence on working memory in a school setting. *Psychoneuroendocrinology, 35*(3), 382-391.
78 Stroth, S., Kubesch, S., Dieterle, K., Ruchsow, M., Heim, R., & Kiefer, M. (2009). Physical fitness, but not acute exercise modulates event-related potential indices for executive control in healthy adolescents. *Brain Research, 1269*, 114-124.
79 Travlos, A. K. (2010). High intensity physical education classes and cognitive performance in eighth-grade students: An applied study. *International Journal of Sport and Exercise Psychology, 8*(3), 302-311.
80 Soga, K., Shishido, T., & Nagatomi, R. (2015). Executive function during and after acute moderate aerobic exercise in adolescents. *Psychology of Sport and Exercise, 16*, 7-17.
81 Hogan, M., Kiefer, M., Kubesch, S., Collins, P., Kilmartin, L., & Brosnan, M. (2013). The interactive effects of physical fitness and acute aerobic exercise on electrophysiological coherence and cognitive performance in adolescents. *Experimental Brain Research, 229*(1), 85-96.
82 Gu, H. M., Shin, D. S., Lee, K. H., Choi, J. S., & Yu, J. (1992). The relationship between physical exercise and cognitive ability (II). *Korean Journal of Sports Science, 4*, 70-78.
83 Ardoy, D. N., Fernández-Rodríguez, J. M., Jiménez-Pavón, D., Castillo, R., Ruiz, J. R., & Ortega, F. B. (2014). A physical education trial improves adolescents' cognitive performance and academic achievement: the EDUFIT study. *Scandinavian Journal of Medicine & Science in Sports, 24*(1), e52-61.
84 Zervas, Y., Danis, A., & Klissouras, V. (1991). Influence of physical exertion on mental performance with reference to training. *Perceptual and Motor Skills, 72*(3 Pt 2), 1215-1221.
85 Pontifex, M. B., Hillman, C. H., Fernhall, B., Thompson, K. M., & Valentini, T. A. (2009). The effect of acute aerobic and resistance exercise on working memory. *Medicine & Science in Sports & Exercise, 41*(4), 927-934.
86 Landrigan, J.-F., Bell, T., Crowe, M., Clay, O. J., & Mirman, D. (2020). Lifting cognition: a meta-analysis of effects of resistance exercise on cognition. *Psychological Research, 84*(5), 1167-1183.
87 Latham, N. K., Bennett, D. A., Stretton, C. M., & Anderson, C. S. (2004). Systematic review of progressive resistance strength training in older adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 59*(1), M48-M61.
88 Cavani, V., Mier, C. M., Musto, A. A., & Tummers, N. (2002). Effects of a 6-week resistance-training program on functional fitness of older adults. *Journal of Aging and Physical Activity, 10*(4), 443-452.
89 Ouellette, M. M., LeBrasseur, N. K., Bean, J. F., Phillips, E., Stein, J., Frontera, W. R., & Fielding, R. A. (2004). High-intensity resistance training improves muscle strength,

self-reported function, and disability in long-term stroke survivors. *Stroke, 35*(6), 1404-1409.

90 Yerokhin, V., Anderson-Hanley, C., Hogan, M. J., Dunnam, M., Huber, D., Osborne, S., & Shulan, M. (2012). Neuropsychological and neurophysiological effects of strengthening exercise for early dementia: A pilot study. *Aging, Neuropsychology, and Cognition, 19*(3), 380-401.

91 Goekint, M., De Pauw, K., Roelands, B., Njemini, R., Bautmans, I., Mets, T., & Meeusen, R. (2010). Strength training does not influence serum brain-derived neurotrophic factor. *European Journal of Applied Physiology, 110*(2), 285-293.

92 Chang, Y.-K., Pan, C.-Y., Chen, F.-T., Tsai, C.-L., & Huang, C.-C. (2012). Effect of resistance-exercise training on cognitive function in healthy older adults: a review. *Journal of Aging and Physical Activity, 20*(4), 497-517.

93 Heyn, P., Abreu, B. C., & Ottenbacher, K. J. (2004). The effects of exercise training on elderly persons with cognitive impairment and dementia: a meta-analysis. *Archives of Physical Medicine and Rehabilitation, 85*(10), 1694-1704.

94 Li, Z., Peng, X., Xiang, W., Han, J., & Li, K. (2018). The effect of resistance training on cognitive function in the older adults: a systematic review of randomized clinical trials. *Aging Clinical and Experimental Research, 30*(11), 1259-1273.

95 Harveson, A. T., Hannon, J. C., Brusseau, T. A., Podlog, L., Papadopoulos, C., Hall, M. S., & Celeste, E. (2019). Acute Exercise and Academic Achievement in Middle School Students. *International Journal of Environmental Research and Public Health, 16*(19), 3527.

96 Etnier, J. L., Wideman, L., Labban, J. D., Piepmeier, A. T., Pendleton, D. M., Dvorak, K. K., & Becofsky, K. (2016). The effects of acute exercise on memory and Brain-Derived Neurotrophic Factor (BDNF). *Journal of Sport and Exercise Psychology, 38*(4), 331-340.

97 Ferris, L. T., Williams, J. S., & Shen, C. L. (2007). The effect of acute exercise on serum brain-derived neurotrophic factor levels and cognitive function. *Medicine & Science in Sports & Exercise, 39*(4), 728-734.

98 Chang, Y. K., Alderman, B. L., Chu, C. H., Wang, C. C., Song, T. F., & Chen, F. T. (2017). Acute exercise has a general facilitative effect on cognitive function: A combined ERP temporal dynamics and BDNF study. *Psychophysiology, 54*(2), 289-300.

99 Bath, K. G., & Lee, F. S. (2006). Variant BDNF (Val66Met) impact on brain structure and function. *Cognitive, Affective, & Behavioral Neuroscience, 6*(1), 79-85.

100 Arancibia, S., Silhol, M., Mouliere, F., Meffre, J., Höllinger, I., Maurice, T., & Tapia-Arancibia, L. (2008). Protective effect of BDNF against beta-amyloid induced neurotoxicity in vitro and in vivo in rats. *Neurobiology of Disease, 31*(3), 316-326.

101 Scharfman, H., Goodman, J., Macleod, A., Phani, S., Antonelli, C., & Croll, S. (2005). Increased neurogenesis and the ectopic granule cells after intrahippocampal BDNF infusion in adult rats. *Experimental Neurology, 192*(2), 348-356.

102 Tolwani, R., Buckmaster, P., Varma, S., Cosgaya, J., Wu, Y., Suri, C., & Shooter, E. (2002). BDNF overexpression increases dendrite complexity in hippocampal dentate gyrus. *Neuroscience, 114*(3), 795-805.

103 Pan, W., Banks, W. A., Fasold, M. B., Bluth, J., & Kastin, A. J. (1998). Transport of brain-derived neurotrophic factor across the blood–brain barrier. *Neuropharmacology, 37*(12), 1553-1561.

104 Wrann, C. D., White, J. P., Salogiannnis, J., Laznik-Bogoslavski, D., Wu, J., Ma, D., Lin, J. D., Greenberg, M. E., & Spiegelman, B. M. (2013). Exercise induces hippocampal BDNF through a PGC-1α/FNDC5 pathway. *Cell Metabolism, 18*(5), 649-659.

105 O'Connor, A. R., Han, S., & Dobbins, I. G. (2010). The inferior parietal lobule and recognition memory: expectancy violation or successful retrieval? *Journal of Neuroscience, 30*(8), 2924-2934.

106 Shipstead, Z., Harrison, T. L., & Engle, R. W. (2016). Working memory capacity and fluid intelligence: Maintenance and disengagement. *Perspectives on Psychological Science, 11*(6), 771-799.

107 Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Shah, P. (2012). Cogmed and working memory training—Current challenges and the search for underlying mechanisms. *Journal of Applied Research in Memory and Cognition, 1*.

108 Rebok, G. W., Ball, K., Guey, L. T., Jones, R. N., Kim, H. Y., King, J. W., Marsiske, M., Morris, J. N., Tennstedt, S. L., & Unverzagt, F. W. (2014). Ten-year effects of the advanced cognitive training for independent and vital elderly cognitive training trial on cognition and everyday functioning in older adults. *Journal of the American Geriatrics Society, 62*(1), 16-24.

109 Bauer, A. C. M., & Andringa, G. (2020). The potential of immersive virtual reality for cognitive training in elderly. *Gerontology, 66*(6), 614-623.

110 Zinke, K., Einert, M., Pfennig, L., & Kliegel, M. (2012). Plasticity of executive control through task switching training in adolescents. *Frontiers in Human Neuroscience, 6*, 41.

111 Karbach, J., & Kray, J. (2009). How useful is executive control training? Age differences in near and far transfer of task-switching training. *Developmental Science, 12*(6), 978-990.

112 Loosli, S. V., Buschkuehl, M., Perrig, W. J., & Jaeggi, S. M. (2012). Working memory training improves reading processes in typically developing children. *Child Neuropsychology, 18*(1), 62-78.

113 Etnier, J. L., Nowell, P. M., Landers, D. M., & Sibley, B. A. (2006). A meta-regression to examine the relationship between aerobic fitness and cognitive performance. *Brain Research Reviews, 52*(1), 119-130.

114 Kramer, A. F., & Erickson, K. I. (2007). Capitalizing on cortical plasticity: influence of physical activity on cognition and brain function. *Trends in Cognitive Sciences, 11*(8), 342-348.

115 Blumenthal, J. A., Emery, C. F., Madden, D. J., George, L. K., Coleman, R. E., Riddle, M. W., McKee, D. C., Reasoner, J., & Williams, R. S. (1989). Cardiovascular and behavioral effects of aerobic exercise training in healthy older men and women. *Journal of Gerontology, 44*(5), M147-M157.

116 Davis, C. L., Tomporowski, P. D., McDowell, J. E., Austin, B. P., Miller, P. H., Yanasak, N. E., Allison, J. D., & Naglieri, J. A. (2011). Exercise improves executive function and achievement and alters brain activation in overweight children: a randomized, controlled trial. *Health Psychology, 30*(1), 91.

117 Melby-Lervåg, M., & Hulme, C. (2013). Is working memory training effective? A meta-analytic review. *Developmental Psychology, 49*(2), 270.

118 Harrison, T. L., Shipstead, Z., Hicks, K. L., Hambrick, D. Z., Redick, T. S., & Engle, R. W. (2013). Working memory training may increase working memory capacity but not fluid intelligence. *Psychological Science, 24*(12), 2409-2419.

119 Thorell, L. B., Lindqvist, S., Bergman Nutley, S., Bohlin, G., & Klingberg, T. (2009). Training and transfer effects of executive functions in preschool children. *Developmental Science, 12*(1), 106-113.

120 Diamond, A., & Ling, D. S. (2016). Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental Cognitive Neuroscience, 18,* 34-48.

121 Tomporowski, P. D., & Pesce, C. (2019). Exercise, sports, and performance arts benefit cognition via a common process. *Psychological Bulletin, 145*(9), 929.

122 Onyango, I. G., Lu, J., Rodova, M., Lezi, E., Crafter, A. B., & Swerdlow, R. H. (2010). Regulation of neuron mitochondrial biogenesis and relevance to brain health. *Biochimica et Biophysica Acta (BBA)-Molecular Basis of Disease, 1802*(1), 228-234.

123 Jodeiri Farshbaf, M., Ghaedi, K., Megraw, T. L., Curtiss, J., Shirani Faradonbeh, M., Vaziri, P., & Nasr-Esfahani, M. H. (2016). Does PGC1α/FNDC5/BDNF elicit the

beneficial effects of exercise on neurodegenerative disorders? *Neuromolecular medicine*, *18*(1), 1-15.

124 Albers, D. S., & Flint Beal, M. (2000). Mitochondrial dysfunction and oxidative stress in aging and neurodegenerative disease. *Journal of neural transmission. Supplementum, 59(1), 133–154*.

125 Islam, M. T. (2017). Oxidative stress and mitochondrial dysfunction-linked neurodegenerative disorders. *Neurological research*, *39*(1), 73-82.

126 Scarpulla, R. C. (2008). Transcriptional paradigms in mammalian mitochondrial biogenesis and function. *Physiological reviews*, *88*(2), 611-638.

127 Kotiadis, V. N., Duchen, M. R., & Osellame, L. D. (2014). Mitochondrial quality control and communications with the nucleus are important in maintaining mitochondrial function and cell health. *Biochimica et Biophysica Acta (BBA)-General Subjects*, *1840*(4), 1254-1265.

128 Tsunemi, T., Ashe, T. D., Morrison, B. E., Soriano, K. R., Au, J., Roque, R. A., Lazarowski, E. R., Damian, V. A., Masliah, E., & La Spada, A. R. (2012). PGC-1α rescues Huntington's disease proteotoxicity by preventing oxidative stress and promoting TFEB function. *Science translational medicine*, *4*(142), 97.

129 Wanders, R. J., & Waterham, H. R. (2006). Peroxisomal disorders: the single peroxisomal enzyme deficiencies. *Biochimica et Biophysica Acta (BBA)-Molecular Cell Research*, *1763*(12), 1707-1720.

130 Villena, J. A. (2015). New insights into PGC-1 coactivators: redefining their role in the regulation of mitochondrial function and beyond. *The FEBS journal*, *282*(4), 647-672.

131 Qin, W., Haroutunian, V., Katsel, P., Cardozo, C. P., Ho, L., Buxbaum, J. D., & Pasinetti, G. M. (2009). PGC-1α expression decreases in the Alzheimer disease brain as a function of dementia. *Archives of neurology*, *66*(3), 352-361.

132 Katsouri, L., Parr, C., Bogdanovic, N., Willem, M., & Sastre, M. (2011). PPARγ co-activator-1α (PGC-1α) reduces amyloid-β generation through a PPARγ-dependent mechanism. *Journal of Alzheimer's Disease*, *25*(1), 151-162.

133 Zheng, B., Liao, Z., Locascio, J. J., Lesniak, K. A., Roderick, S. S., Watt, M. L., Eklund, A. C., Zhang-James, Y., Kim, P. D., Hauser, M. A., Grünblatt, E., Moran, L. B., Mandel, S. A., Riederer, P., Miller, R. M., Federoff, H. J., Wüllner, U., Papapetropoulos, S., Youdim, M. B., Cantuti-Castelvetri, I., … Global PD Gene Expression (GPEX) Consortium (2010). PGC-1α, a potential therapeutic target for early intervention in Parkinson's disease. *Science translational medicine*, *2*(52), 73-102

134 Johri, A., Chandra, A., & Flint Beal, M. (2013). PGC-1α, mitochondrial dysfunction, and Huntington's disease. *Free radical biology & medicine*, *62*(1), 37–46.

135 Vargas-Ortiz, K., Perez-Vazquez, V., Diaz-Cisneros, F. J., Figueroa, A., Jiménez-Flores, L. M., Rodriguez-DelaRosa, G., & Macias, M. H. (2015). Aerobic training increases expression levels of SIRT3 and PGC-1α in skeletal muscle of overweight adolescents without change in caloric intake. *Pediatric Exercise Science*, *27*(2), 177-184.

136 Wrann, C. D., White, J. P., Salogiannnis, J., Laznik-Bogoslavski, D., Wu, J., Ma, D., Lin, J. D., Greenberg, M. E., & Spiegelman, B. M. (2013). Exercise induces hippocampal BDNF through a PGC-1α/FNDC5 pathway. *Cell metabolism*, *18*(5), 649-659.

137 Dinas, P. C., Lahart, I. M., Timmons, J. A., Svensson, P. A., Koutedakis, Y., Flouris, A. D., & Metsios, G. S. (2017). Effects of physical activity on the link between PGC-1a and FNDC5 in muscle, circulating Irisin and UCP1 of white adipocytes in humans: A systematic review. *F1000Research*, *6*(286)

138 Fatouros I. G. (2018). Is irisin the new player in exercise-induced adaptations or not? A 2017 update. *Clinical chemistry and laboratory medicine*, *56*(4), 525–548.

139 Tapia-Arancibia, L., Rage, F., Givalois, L., & Arancibia, S. (2004). Physiology of BDNF: focus on hypothalamic function. *Frontiers in neuroendocrinology*, *25*(2), 77-107.
140 Huang, E. J., & Reichardt, L. F. (2001). Neurotrophins: roles in neuronal development and function. *Annual review of neuroscience*, *24*(1), 677-736.
141 Pizzorusso, T., Ratto, G. M., Putignano, E., & Maffei, L. (2000). Brain-derived neurotrophic factor causes cAMP response element-binding protein phosphorylation in absence of calcium increases in slices and cultured neurons from rat visual cortex. *Journal of Neuroscience*, *20*(8), 2809-2816.
142 Chapman, P. F., White, G. L., Jones, M. W., Cooper-Blacketer, D., Marshall, V. J., Irizarry, M., Younkin, L., Good, M. A., Bliss, T. V., Hyman, B. T., Younkin, S. G., & Hsiao, K. K. (1999). Impaired synaptic plasticity and learning in aged amyloid precursor protein transgenic mice. *Nature neuroscience*, *2*(3), 271-276.
143 Reichardt, L. F. (2006). Neurotrophin-regulated signalling pathways. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *361*(1473), 1545-1564.
144 Volakakis, N., Kadkhodaei, B., Joodmardi, E., Wallis, K., Panman, L., Silvaggi, J., Spiegelman, B. M., & Perlmann, T. (2010). NR4A orphan nuclear receptors as mediators of CREB-dependent neuroprotection. *Proceedings of the National Academy of Sciences*, *107*(27), 12317-12322.
145 Giampà, C., Montagna, E., Dato, C., Melone, M. A., Bernardi, G., & Fusco, F. R. (2013). Systemic delivery of recombinant brain derived neurotrophic factor (BDNF) in the R6/2 mouse model of Huntington's disease. *PloS one*, *8*(5), e64037.
146 Carlezon Jr, W. A., Duman, R. S., & Nestler, E. J. (2005). The many faces of CREB. *Trends in neurosciences*, *28*(8), 436-445.
147 Young, M. F., Valaris, S., & Wrann, C. D. (2019). A role for FNDC5/Irisin in the beneficial effects of exercise on the brain and in neurodegenerative diseases. Progress in cardiovascular diseases, *62*(2), 172–178.
148 Cotman, C. W., & Engesser-Cesar, C. (2002). Exercise enhances and protects brain function. Exercise and sport sciences reviews, *30*(2), 75–79.
149 Rhodes, J. S., van Praag, H., Jeffrey, S., Girard, I., Mitchell, G. S., Garland, T., Jr, & Gage, F. H. (2003). Exercise increases hippocampal neurogenesis to high levels but does not improve spatial learning in mice bred for increased voluntary wheel running. *Behavioral neuroscience*, *117*(5), 1006–1016.
150 García-Suárez, P. C., Rentería, I., Moncada-Jiménez, J., Fry, A. C., & Jiménez-Maldonado, A. (2020). Acute systemic response of BDNF, lactate and cortisol to strenuous exercise modalities in healthy untrained women. *Dose-Response*, *18*(4), 1559325820970818.
151 Vega, S. R., Strüder, H. K., Wahrmann, B. V., Schmidt, A., Bloch, W., & Hollmann, W. (2006). Acute BDNF and cortisol response to low intensity exercise and following ramp incremental exercise to exhaustion in humans. *Brain research*, *1121*(1), 59-65.

CHAPTER 2

Methodology

METHODOLOGY OF OUTCOME MEASURES

The outcome measures for this study comprised of a battery of assessments to obtain data on anthropometry, cardiorespiratory fitness, physical activity level, cognitive function and academic performance.

Anthropometric testing

Anthropometric measurements included stature height and body mass for the calculation of both Body Mass Index (BMI) and Age Peak Height Velocity (APHV); sitting height for the calculation of APHV; waist circumference as an indicator of body fat composition through Waist to Height Ratio (WtHR) as a benchmark of future development of cardiovascular disease. Each measurement was recorded twice and a triplicate was taken if the error margin exceeded 0.03%[1] (refer to Manual of Procedures, Appendix 1 for data sheet).

The experimenter understood the standard procedures and rigour required to take measurements of the highest quality and have adhered to the International Society for the Advancement of Kinanthropometry (ISAK)'s manual of procedure for the respective anthropometric measurements. However, it should be noted that due to the high number of participants and the limited time each participant had due to restrictions by the school's curriculum (experiment was conducted during the one-hour physical education class), certain alterations, which varied slightly from the ISAK guideline, had to be made. These alterations were made after weighing the options of obtaining maximal participation as well as obtaining a complete data set from each participant. Said alterations were made specifically to the measurement of stature height in Studies I and II whereby a portable stadiometer was not available, instead an electronic height and weight machine was used in place. To ensure the reliability of measurements, the machine was regularly serviced, and calibrated before each study took place.

Stature Height

Height was measured for the calculation of BMI and APHV. In Study I and II an electronic height and weight measuring machine for schools was used (Avamech B1000-S) with an accuracy of ± 0.005m and a resolution of 0.01m. A Secca 217 Stadiometer was used in Study III with an accuracy of ± 0.005m and a resolution of 0.01m. Two different types of equipment were used due to different availability of equipment in these schools in the two different countries. Participants were instructed to take a deep breath while his head was in the Frankfort plane. Steps were taken to ensure that the participants' head was lifted (gently but firmly) to maximum height while holding on to their breath. Measurements were then recorded.

Body Mass

Body mass was measured for the calculation of BMI and APHV. In Study I and II an electronic height weight measuring machine for schools was used (Avamech B1000-S) with an accuracy of ± 0.05kg and a resolution of 0.1kg. The Tanita's BWB-800P Doctors Scale was used in Study III and recorded weight to an accuracy of ± 0.05kg and a resolution of 0.1kg. Participants were instructed to remove their shoes and to stand as still as possible with their hands by their side looking straight ahead. Measurements were then recorded.

Sitting Height

Sitting height was measured for the calculation of APHV, whereby leg length was a required measurement derived from subtracting sitting height form stature height. In Study I and II a measuring tape was securely fixed onto a wall, with an accuracy of ± 0.005m and a resolution of 0.01m was cross checked with a metre rule and a Lufkin Executive Thinline tape measure. A spirit level was also used to ensure that the tape was aligned and fixed to the wall accurately. It should be noted that many schools in Singapore used an electronic height-weight measuring scale and it was difficult to procure a manual stadiometer given the time period and location in which the study was conducted. As such alternative measures were taken to ensure that sitting height measurement was possible and conducted methodologically. Participants were instructed to sit with their back against the wall and with their legs crossed. Similar steps were taken to ensure that the participants' head was lifted (gently but firmly) to maximum height while holding on to their breath. Measurements were then recorded.

Waist circumference

Waist circumference was used to calculate the Waist to Height Ratio (WtHR) of participants and was an outcome measure of body fat composition. A Lufkin Executive Thinline tape measure, with an accuracy of ± 0.005m and a resolution of 0.01m, was used across the three studies. Waist circumference was measured using the International Diabetes Federation guidelines.[2] This is the circumference of the abdomen at its midpoint point between the lower costal (10th rib) border and the top of the iliac crest, perpendicular to the long axis of the trunk. Participants were instructed to breathe in and out normally and measurements were taken on the exhale. Participants were categorised into "normal" or having "excess central adiposity", depending if WtHR exceeded 0.5 where a value greater than 0.5 would place participants in the latter group.[3]

Fitness testing

A key indicator of cardiorespiratory fitness throughout the three studies was the oxygen uptake during peak exercise (VO_{2peak}) estimated from the 20m shuttle run using Leger and Lamberts' equation.[4] The 20m shuttle run test was downloaded into both the experimenter's laptop and phone (backup) and played using portable speakers. The test was conducted in indoor sports halls across all three studies. Participants were briefed on the proceedings of the test together with a demonstration of how the test works. Participants were also given a quick trial of stages one, four, eight, and ten in order to familiarise them with the speed required at different stages which would help to manage their pacing strategies. Participants were paired and given recording sheets where they would tick off each lap once their partner reached the marked line at each beep. The experimenter together with the class teacher (if present) would supervise each test ensuring that students adhered to the test guidelines and to instruct participants when they have missed the beep. Participants were also instructed to stop, when they failed the test. In studies I and II, each test sessions would consist of about eight to ten students performing the test together, while their assigned partners ticked off the recording sheet. Participants would then swap over, where the runner becomes the recorder and vice-versa. In study III, participant numbers varied across test session ranging from 2 to 10 participants performing the test at once. Leger and Lambert's equation was used to calculate VO_{2peak} based on the beep test level which were than used to categorised participants into “Healthy Fitness Zone (HFZ)” and “Needs Improvement Zone (NIZ)” according to the cutoffs from Welks et al[5].

Physical activity level

The Adolescent Physical Activity Recall Questionnaire (APARQ)[6] was a self-reported questionnaire used in Study I to provide an indication of participants self-perceived physical activities (classified as organised and non-organised sport) frequency throughout the school year. The APARQ ascribes an average rate of energy expenditure (Metabolic Equivalent of Task (MET)) score to each activity and an average MET output per week was calculated for each participant. Participants were then categorised into “Sufficiently Active (SA)” where they met weekly the PA guideline or “Insufficiently Active (IA) where their activity levels were below the weekly PA guideline. The recommended weekly PA guideline is at least seven hours of moderate-to-vigorous physical activities, with an accumulated average of 1h per day.[7]

Cognitive function testing

Findings from the systematic review[8] (Chapter 3) conducted by the researchers, were used to inform the selection of a comprehensive but relatively accessible cognitive testing platform to best capture the cognitive abilities of participants. WebNeuro™, purchased from the Brain Research Company (BRC). WebNeuro™ is a web-delivered set of questions and tasks that assesses the constructs of various brain function established in (Table 1), selected to assess CF across all three studies. Similar tools (also from BRC) have been used in another study, “Influence of iron deficiency on cognition, mood, and quality of life in young normal weight and obese women”, and have gained ethical approval from both The University of Sydney [Database No: 13330] and Sydney Local Health District (RPAH Zone)[Protocol No. X10-0259 & HREC/10/RPAH/455]. The test-retest reliability has been reported to be acceptable for each of the cognitive test.[9-11] Additionally, these cognitive assessments have been validated (convergent and divergent[12,13]) and meticulously selected with the agreement from key researchers and published international guidelines.[14,15]

Because of its holistic approach in trying to capture CF through these four domains, coupled with its relatively short assessment time (45minutes) for a wide range of cognitive outcome measures, WebNeuro™ was selected as the cognitive assessment tool across all three studies. The assessment consists of nine cognitive tasks and two questionnaires (Brief Risk-Resilience Index for Screening (BRISC)[16] and the Depression Anxiety Stress Scale (DASS)[17] designed to assess participants in the four domains of Thinking, Self-regulation, Feeling and Emotion. However, certain technical difficulties were experienced during the measurement of the Emotion domain during the initial phase of testing, leading it to be excluded from the subsequent experimental protocol across all three studies. Below is a short description[18] of the three domains and its respective subdomains:

Domains	Descriptive
Thinking Domain	Selective awareness of information processing so we can know and remember.
Response Variability	The degree of consistency in the speed of responding.
Impulsivity	Balance between responding quickly and suppressing your responses as the situation changes.
Sustained Attention	Focusing on the main task and resisting distraction over time.
Information Processing	Capacity to connect information correctly, logically and flexibly as well as perceive changes under time constraints.
Memory	Capacity to remember and retrieve factual information.
Executive Function	Capacity to plan ahead and learn from mistakes to shape behaviour.
Self-Regulation	Shaping and planning of our thinking and emotion over time to maximize our well being.
Negativity Bias	The tendency to see yourself and your world as negative (lower scores) versus positive (higher scores). Associated with sensitivity versus hardiness to daily stresses.
Emotional Resilience	Capacity for coping and feeling confident, with self-esteem and self-efficacy.

	Social Skills	Capacity for building and keeping relationships, associated with extraversion and empathy.
Feeling		Your conscious experience of emotions that relies on feedback from your body reactions.
	Depression	Ranges from feeling extremely low (lower scores) to an absence of sadness (higher scores).
	Anxiety	Ranges from feeling extreme worry or panic (lower scores) to an absence of worry (higher scores).
	Stress	Ranges from feeling extremely irritable and jumpy (lower scores) to feeling calm (higher scores).

Table 1: Description of the cognitive domains of Thinking, Feeling and Self-regulation and their respective subdomains

The thinking domain consisted of nine tasks (motor tapping, choice reaction time, memory recognition, digit span forward, verbal interference, switching of attention, go/no-go, continuous performance test, maze). The domain of self-regulation involves the shaping and planning of an individual's thinking and emotion over time to maximise their well-being and is assessed via the BRISC, a 10-minute screening questionnaire. Feeling, defined as the conscious experience of emotions that relies on the feedback from body reactions, was assessed using the DASS. Participants were given 45 minutes to complete both tests. The scores obtained from each task which reflects the subdomain of cognition (thinking, feeling and self-regulation) are adjusted for age, education and sex using internal regression methods based on BRC's extensive normative databank[10].

It should be noted that a few modifications had to be made after a pilot study was carried out.

a. BRISC, the questionnaire designed to assess the domains of self-regulation and feelings incorporate DASS which was worded specifically for children, had to be shifted from the front of the WebNeuro™ assessment to the back to help facilitate attention span and maintain interest and enthusiasm while attempting the test. This facilitates maximal test effort from participants.

b. A portable non-web version was specifically created for Study III as participants did not have internet access. The construct and tasks still remained the same but the data of each participant had to be manually uploaded to the BRC's server in order for researches to receive the test results.

Academic Performance Testing

AP is hypothesised to be a secondary outcome measure which would benefit from cardiovascular improvement. During the pilot study the University of New South Wales International Competitions and Assessments for Schools (UNSW ICAS) test in mathematics and English were used to access AP. Each test required 50 – 60 minutes to complete depending on age group, making it a total of 2.5 to 3h for both cognitive and academic testing. This was detrimental during the pilot study as participants readily grew restless and could not sustain their attention. Many found the test too difficult and had difficulties complying with the test conditions. As such the ACER General Ability Test (AGAT)[18] was found to be more suitable as it includes assessment for abstract reasoning, numerical reasoning and verbal reasoning and collectively the assessment battery took only 20 to 30 minutes for participants to complete. Additionally, the AGAT was also a standardised general ability test that is web-delivered, and results were also electronically delivered.

METHODOLOGY OF INTERVENTIONS

Interventions implemented could be categorised under either body training (comprising of both chronic and acute exercise prescription) or brain training. Below are the respective outline of each type of training.

Body training

As exercise was proposed to affect CF and AP through two differing mechanisms, namely that acute and chronic exercise would work through different pathways to impact production of certain cognitive enhancing proteins. The body training programme used in both the acute and chronic study were specifically designed for adolescents and were piloted and received positively by the participants before the actual studies took place.

The chronic exercise training program took place over 8 weeks, twice a week, during the 1h physical education lesson (curriculum time) during Term 1 of the school year. Each 1h session consisted of 5 minutes of warmup, 30 minutes of focus exercise at moderate-high intensity, 20 minutes of games and five minutes of warm down (refer to appendix for manual of procedures). Make-up sessions were conducted after school for participants who were not able to attend their allocated training session. Due to limited resources, 10 participants (rostered) were given heart rate monitors at the start of each session and average heart rate (HR_{mean}) was recorded 3 times during each exercise/activity, where HR_{mean} together with Rating of Perceived Exhaustion (RPEs) were indicators of exercise intensity. These monitors were then collected and washed/sanitised after each session in preparation for the next class of participants. Each session was carried out by the researcher and the class teacher and as such, maximal effort during participation was highly encouraged. Due to public holidays disrupting week three and six of the training program, participants had four make-up sessions in total after school and during recess time. Participants data were excluded from the statistical analysis if attendance rate dropped below 90% at the end of 8 weeks (refer to Appendices, page 227 for detailed program).

The acute training program consisted of investigating the effects of three different exercise types and its effect on CF and AP. As a result, three different 30 minutes exercise sessions were designed comprising of, aerobic exercise (steady state cycling at 75-80%HR_{max}), resistance exercise (body weight exercises at 75-80%HR_{max}) and stretching (designed as a sham control with foam rolling and stretching exercises at less than 55%HR_{max}). Each participant was randomly allocated the order of which the exercise type they would perform each week. HR_{mean} were measured using HR monitors every five minutes during the aerobic session, while during the resistance and stretching session, HR_{mean} was measured during each exercise. Each session was conducted by the experimenter.

Brain training

MyBrainSolutions© is a Software designed and purchased from the BRC as well and specifically targets the enhancement of the four domains; thinking, feeling, emotions and self-regulation. Just as how muscle strength is thought to be trainable and improved through exercise, brain training is hypothesised to be able to improve CF. This software was used in Study II for participants allocated into the brain training group for eight weeks. The brain training took place twice a week, during the one hour physical education lesson (curriculum time). Due to public holidays and school holidays disrupting week 3 and 6 of the training program, participants had four make up sessions in total after school and during recess time. Refreshments were provided after these make-up sessions to encourage attendance rate during these sessions. Participants' data were excluded from the statistical analysis if attendance rate dropped below 90% at the end of 8 weeks.

Figure 2 provides a summary of the methods and study design of the three studies conducted.

	Study I (n=250)	Study II (n=133)	Study III (n=38)
Study design	Cross-sectional	Randomised control trial	Controlled cross-over trial
Location	Singapore		Australia
Duration	2 weeks, 3 sessions	10 weeks, 20 sessions	5 weeks, 5 sessions
Study timeline	N.A.	Baseline testing, Intervention period, Post-testing	
Types of Intervention	N.A.	"Body" "Brain", "Control"	"Aerobic", "Resistance", "Stretching"
Exercise intensity and type	N.A.	(75-80%HR_{max}), included both aerobic and body weight exercise, games and team sport	(75-80% HR_{max}), steady state cycling, body weight resistance training< 55% HR_{max}, foam rolling and stretching
Investigating physical fitness/ exercise?	Association between aerobic fitness and body composition	Chronic effect of exercise (8 weeks)	Acute effect of exercise (30mins)
Statistical Analyses (STATISTICA, Comprehensive Meta-Analysis)	Linear regression (for preliminary exploration of data) One-way factorial analyses of variance (ANOVAs), Repeated measures ANOVA, Effect size		
Outcome measures	VO_{2peak}, BMI, Waist circumference, WebNeuro – an assessment of Cognitive Function, AGAT- an assessment of Academic Performance, APARQ – an assessment of Physical Activity levels (only for Study I)		

Figure 2: Summary of Methods. (AGAT): Acer General Ability Test; (APARQ); Adolescent Physical Activity Recall Questionnaire; (BMI): Body Mass Index; (HR_{max}): Maximum Heart Rate; (VO2peak): Peak rate of oxygen consumption.

STUDY DESIGNS

Study I:

This study is a Cross-sectional Study where participants (n = 250) were recruited from two elite high schools in Singapore The experiment was conducted across two weeks in three sessions of approximately one-hour in each school. The order of sessions was as follows: anthropometry measurements, cognitive and academic testing, 20m shuttle run test. Most participants took part in the experiment together with their classmates, with class size ranging from 18 to 30. Additional sessions were scheduled within the same month if participants missed a session. The experiment took place within the premises of the high school, with a teacher assigned to each class to help with supervision and compliance during experimental activities.

Outcome Measure Assessments:

i) Cognitive Function: Cognitive testing sessions (approximately 45min long) using the WebNeuro™ platforms from the BRC.

ii) Aerobic fitness: measured using the 20m shuttle run (Beep Test).

iii) Academic performance: measured using the ACER General Ability Tests (AGAT).

v) Anthropometric measurement: Height, weight, sitting height, and waist circumference were measured.

vi) Self-reported Physical Activity: assessed via APARQ.

Participants underwent the above assessments in the following order: cognitive and academic testing, APARQ, anthropometric measurements and the Beep Test.

Study II:

This study is a Randomised Controlled Trial (RCT) where participants (n = 133) were recruited from an elite high school, in Singapore. The experiment was conducted across 10 weeks in 20 sessions approximately in one-hour sessions. After recruitment, participants were block randomised according to their classes into three groups, two intervention groups ("Body" and "Brain") and one control group. This was done by the experimenter using the free online randomisation software http://www.graphpad.com/quickcalcs/index.cfm, to randomly assign the six participating classes into the three groups. Participants were informed of their group via the teacher-in-charge. Blinding of both the experimenter and the participants were not possible in this case. All participants took part in pre and post-testing.

Weeks 1 and 10 (Pre and Post-testing): The order of testing were as follow: cognitive and academic testing, anthropometric measurements, Beep Test.

Weeks 2 to 9 (intervention): Participants in the "Body" group completed eight weeks of mainly aerobic and coordinative exercises specially designed for adolescent males. Participants in the "Brain" group completed eight weeks of brain training using a computer-based software MyBrainSolutions© purchased from the BRC. Participants in the control group were told to go about their daily activities.

The intervention was carried out during the Physical Education period of each class involved in the study. The experiment took place within the premises of the high school, with a teacher assigned to each class to help with supervision and compliance during experimental activities.

Outcome Measure Assessments: A total of two testing sessions were conducted across the span of the study; Baseline Testing 1(week 0) and Post Testing (Week 10). The outcome measures during each testing session include:

i) Cognitive Function: Cognitive testing sessions (approximately 45min long) using the WebNeuro™ platforms from the BRC.

ii) Aerobic fitness: measured using the 20m shuttle run (Beep Test)

iii) Academic performance: measured using the ACER General Ability Tests (AGAT).

v) Anthropometric measurement: Height, weight, sitting height, and waist circumference were measured.

Study III:

This study is an acute dose-response study where participants (n=38) were recruited from an elite high school in Sydney, Australia. The experiment was conducted across five weeks in five sessions approximately in two-hour blocks for pre and post testing, and one-hour blocks for the intervention.

Week 1 (Pre-testing): The order of testing was as follow: cognitive and academic testing, anthropometric measurements, Beep Test.

Week 2 to 4 (intervention): The intervention protocol consisted of three different exercise modalities, steady-state aerobic exercise, resistance exercise and stretching (active control). The order in which participants took part in the three different intervention training sessions was randomized by the experimenter using the free online randomisation software http://www.graphpad.com/quickcalcs/index.cfm[19], to randomly assign the sequence of the different acute exercise intervention. Participants were only informed of the type of exercise they had to perform that particular week when they attended the testing sessions. They were able to conclude the remaining exercise intervention protocol upon completion of the second intervention session. Cognitive testing was conducted after each intervention session.

Week 5 (Post-Testing): Participants were required to complete the same cognitive and academic testing they did in Week 1. The 20m shuttle run test will only be carried out in Week 1 as cardiorespiratory fitness was not hypothesized to improve after these acute exercise bouts. Additional sessions were scheduled within the same week if participants missed a session. The study took place within the premises of the high school.

Outcome Measure Assessments:

i) Cognitive Function: Five cognitive testing sessions (approximately 45min long) using the WebNeuro™ platforms from the BRC were completed across the span of five weeks.

ii) Aerobic fitness: measured once using the 20m shuttle run (Beep Test) during pre-testing

iii) Academic performance: measured twice using the ACER General Ability Tests (AGAT) during pre- and post-testing.

v) Anthropometric measurement: Height, weight, sitting height, and waist circumference were measured once during pre-testing.

REFERENCES

1 Norton, K. I. (2018). Standards for anthropometry assessment. In *Kinanthropometry and Exercise Physiology* (pp. 68-137). Routledge.

2 World Health Organization. (1999). Definition, diagnosis and classification of diabetes mellitus and its complications : report of a WHO consultation. Part 1, Diagnosis and classification of diabetes mellitus.

3 Garnett, S., Baur, L., & Cowell, C. (2008). Waist-to-height ratio: a simple option for determining excess central adiposity in young people. *International Journal of Obesity, 32*(6), 1028-1030.

4 Leger, L. A., & Lambert, J. (1982). A maximal multistage 20-m shuttle run test to predict VO_2 max. *European Journal of Applied Physiology and Occupational Physiology, 49*(1), 1-12.

5 Welk, G. J., Maduro, P. F. D. S.-M., Laurson, K. R., & Brown, D. D. (2011). Field evaluation of the new FITNESSGRAM® criterion-referenced standards. *American Journal of Preventive Medicine, 41*(4), S131-S142.

6 Booth, M. L., Okely, A. D., Chey, T. N., & Adrian, B. (2002). The reliability and validity of the Adolescent Physical Activity Recall Questionnaire. *Medicine and Science in Sports and Exercise, 34*(12), 1986-1995.

7 World Health Organization. (2019). *New WHO-led study says majority of adolescents worldwide are not sufficiently physically active, putting their current and future health at risk.* https://www.who.int/news/item/22-11-2019-new-who-led-study-says-majority-of-adolescents-worldwide-are-not-sufficiently-https://www.who.int/news/item/22-11-2019-new-who-led-study-says-majority-of-adolescents-worldwide-are-not-sufficiently-physically-active-putting-their-current-and-future-health-at-risk.

8 Li, J. W., O'Connor, H., O'Dwyer, N., & Orr, R. (2017). The effect of acute and chronic exercise on cognitive function and academic performance in adolescents: A systematic review. *Journal of Science and Medicine in Sport, 20*(9), 841-848.

9 Paul, R. H., Lawrence, J., Williams, L. M., Richard, C. C., Cooper, N., & Gordon, E. (2005). Preliminary validity of "integneuro": a new computerized battery of neurocognitive tests. *International Journal of Neuroscience, 115*(11), 1549-1567.

10 Sugarman, R. (2007). IntegNeuro™ User Manual Version 3. New South Wales, Australia: Brain Resource Company.

11 Williams, L. M., Simms, E., Clark, C. R., Paul, R. H., Rowe, D., & Gordon, E. (2005). The test-retest reliability of a standardized neurocognitive and neurophysiological test battery: "neuromarker". *International Journal of Neuroscience, 115*(12), 1605-1630.

12 Paul, R. H., Lawrence, J., Williams, L. M., Richard, C. C., Cooper, N., & Gordon, E. (2005). Preliminary validity of "integneuroTM": a new computerized battery of neurocognitive tests. *International Journal of Neuroscience, 115*(11), 1549-1567.

13 Silverstein, S. M., Berten, S., Olson, P., Paul, R., Williams, L. M., Cooper, N., & Gordon, E. (2007). Development and validation of a World-Wide-Web-based neurocognitive assessment battery: WebNeuro. *Behavior Research Methods, 39*(4), 940-949.

14 Gordon, E. (2000). *Integrative neuroscience: Bringing together biological, psychological and clinical models of the human brain*. CRC Press.

15 Gordon, E. (2003). Integrative neuroscience. *Neuropsychopharmacology, 28*(1), S2-S8.

16 Williams, L. M., Cooper, N. J., Wisniewski, S. R., Gatt, J. M., Koslow, S. H., Kulkarni, J., DeVarney, S., Gordon, E., & John Rush, A. (2012). Sensitivity, specificity, and predictive power of the "Brief Risk-resilience Index for SCreening," a brief pan-diagnostic web screen for emotional health. *Brain and Behavior, 2*(5), 576-589.

17 Lovibond, S. H., & Lovibond, P. F. (1995). *Manual for the Depression Anxiety Stress Scales* (2nd ed.). Sydney: Psychology Foundation of Australia.

18 Masters, G. N., & Forster, M. (2000). *The assessments we need*. Australian Council for Educational Research.

19 Suresh, K. (2011). An overview of randomization techniques: an unbiased assessment of outcome in clinical research. *Journal of Human Reproductive Sciences, 4*(1), 8.

CHAPTER 3

The effect of acute and chronic exercise on cognitive function and academic performance in adolescents: A systematic review

FOREWORD

Chapter 3 has been published in the Journal of Science and Medicine in Sport (Appendix 5).

Li, J. W., O'Connor, H., O'Dwyer, N., & Orr, R. (2017). The effect of acute and chronic exercise on cognitive function and academic performance in adolescents: A systematic review. Journal of science and medicine in sport, 20(9), 841–848.

Author Attributions

JL: determined search criteria and aims of the Systematic Review, conducted the searches, extracted and analysed data, performed quality ratings of the studies, prepared the manuscript and compiled revisions.

RO: determined search criteria and aims of the Systematic Review, performed data extraction provided guidance for searches, data extraction and analysis, manuscript preparations and revisions.

NOD: determined search criteria and aims of the Systematic Review, provided guidance for searches, data extraction and analysis, quality ratings, manuscript preparations and revisions.

HOC (deceased): determined search criteria and aims of the Systematic Review, provided guidance for searches, data extraction and analysis, quality ratings, manuscript preparations and revisions.

ABSTRACT

Objectives: To investigate whether exercise, proposed to enhance neuroplasticity and potentially cognitive function (CF) and academic performance (AP), may be beneficial during adolescence when important developmental changes occur.

Design: Systematic review evaluating the impact of acute or chronic exercise on CF and AP in adolescents (13-18 years).

Methods: Nine databases (AMED, AusportMed, CINAHL, COCHRANE, Embase, Medline, Scopus, SPORTdiscus, Web of Science) were searched, from earliest records to April 2016, using keywords related to exercise, CF, AP and adolescents. Eligible studies included controlled trials examining the effect of any exercise intervention on CF, AP or both. Effect size (ES) (Hedges g) were calculated where possible.

Results: Ten papers (11 studies) were reviewed. Cognitive domains included: executive function (n=4), memory (n=4), attention/concentration (n=2), visuo-motor speed (n=1), logical sequencing (n=1) and psychometric aptitude (n=1). All papers, 9/10 being acute studies, reported at least one parameter showing a significant effect of exercise in improving CF and AP. However, the CF parameters displayed substantial heterogeneity, with only 37% favouring acute and chronic exercise. Where ES could be calculated, 52% of the acute CF parameters favoured rest. Memory was the domain most consistently improved by exercise. Academic performance demonstrated a significant improvement with exercise in 1/2 acute studies and the only chronic study ($p \leq 0.001$).

Conclusion: The evidence for the effect of exercise on CF and AP in adolescents is equivocal and limited in quantity and quality. Given its potential benefit, well-designed research is warranted to determine the benefits of exercise in enhancing CF and AP and reducing sedentary behaviour during adolescence.

Keywords: physical activity, physical fitness, learning, executive function, thinking, school achievements

INTRODUCTION

Adolescence, identified as the period in human growth which occurs during ages 13 to 18 years[1], is a time marked by considerable hormonal, behavioural and physical changes[2-4]. Significant cognitive re-organisation and development also occur at this life stage and neuroimaging studies show that the pre-frontal cortex (PFC) is the last brain region to mature[5]. This region is responsible for highly integrative cognitive functions (CFs) such as executive control and evidence indicates that it continues to myelinate into early adulthood[6,7]. Given the protracted period of frontal lobe plasticity, the impact of environmental factors is hypothesised to be greater in this brain region. Lifestyle factors such as exercise and nutrition, may therefore play a major role in supporting and ideally optimising frontal lobe cognitive development during adolescence.

Over the past decade, there has been increased interest in the influence of exercise or physical activity (PA), particularly aerobic activity, on CF in both elderly and primary school-aged populations. In school-aged children, there is also research on exercise and academic performance (AP). Two recent critical reviews[8,9] have identified that there is limited research in adolescents, with four studies confined to participants aged 13-18y[10-13]. These four studies highlighted the inconsistent effects of exercise on CF, whereby both exercise and the control condition were observed to improve cognitive tasks in participants. None of the four studies assessed AP[10-13].

Given that adolescents mostly remain enrolled at school, a number of intervention studies at this age stage have involved acute, single bouts of exercise designed to deliver a more immediate impact on CF or AP. Acting via the noradrenergic and dopaminergic pathways, acute exercise can be viewed as an arousing stressor somewhat akin to a psychoactive stimulant, potentially affecting arousal, attention and effort[14]. This effect may have merit in a school setting where increasing the functional capacity of students during set times throughout the day might improve their ability to learn. A number of studies in children (5-12y) have also used this design to examine whether learning is improved in the immediate post-exercise period[15,16]. Clearly, the mechanism(s) responsible for cognitive or learning enhancement are likely different for acute compared to chronic exercise. Acute exercise will not result in significant fitness changes while chronic exercise will likely increase fitness, as well as deliver other adaptations such as potential improvements in metabolic health, systemic inflammation and psychological function including better mental health and self-esteem[17-19].

Given evidence that levels of PA are declining during adolescence in Australia[20] and internationally[21], and that PA at school is increasingly eroded by pressure to increase classroom learning and AP[21], research supporting a positive role on CF and AP would advocate for maintaining, if not increasing, the inclusion of PA in the school curriculum. Hence, particularly in view of the potential health and cognitive benefits, especially in relation to neuroplasticity at this age stage, it was deemed crucial to remain current with a thorough understanding of literature through updating developments on this topic in adolescents. Therefore, this study aimed to systematically review studies examining the relationship between both acute and chronic exercise and cognition and/or AP in adolescents (13-18y).

METHODS

Literature Search

Electronic searches were performed across nine databases: AMED, AusportMed, CINAHL, COCHRANE, Embase, Medline, Scopus, SPORTdiscus and Web of Science from earliest records to 30th April 2016. The search strategy consisted of three main elements: (1) exercise, (2) cognition and (3) population. The respective keywords for each of these categories were (1) *'exercise', 'physical fitness', 'physical activit*', 'body training,' 'physical training', 'sport*'; (2) 'cognition', 'cognitive function*', 'executive function*', 'learning', 'mental process*', 'attention', 'academic performance', 'academic achievement'; (3) 'adolescen*', 'child*', 'boy*', 'girl*'.* Reference lists of all eligible studies and systematic reviews were searched manually for other potentially eligible studies.

Eligibility (inclusion/exclusion) criteria

Studies were included if they were interventions examining the relationship between PA and CF in healthy adolescents (mean age 13-18y or within a one-year age range of these limits). Eligible studies described either a chronic (defined number of bouts over a set period) or acute (single bout) structured exercise intervention (or both) and employed at least one CF or AP measure. Exclusion criteria were:

adolescent populations with known learning disorders, non-English language papers, reviews, abstracts or theses.

Selection and Quality Assessment

After removal of duplicates, search results were screened independently by two reviewers (JL, RO) and eliminated by title and abstract using the eligibility criteria. All potential and relevant studies were further assessed by reading the full manuscript. Studies not meeting the eligibility criteria were excluded (Figure 1). The quality of the included studies was independently assessed by two researchers (JL, RO) using the Physiotherapy Evidence Database (PEDro) scale[22] which scores each paper according to 10 criteria.

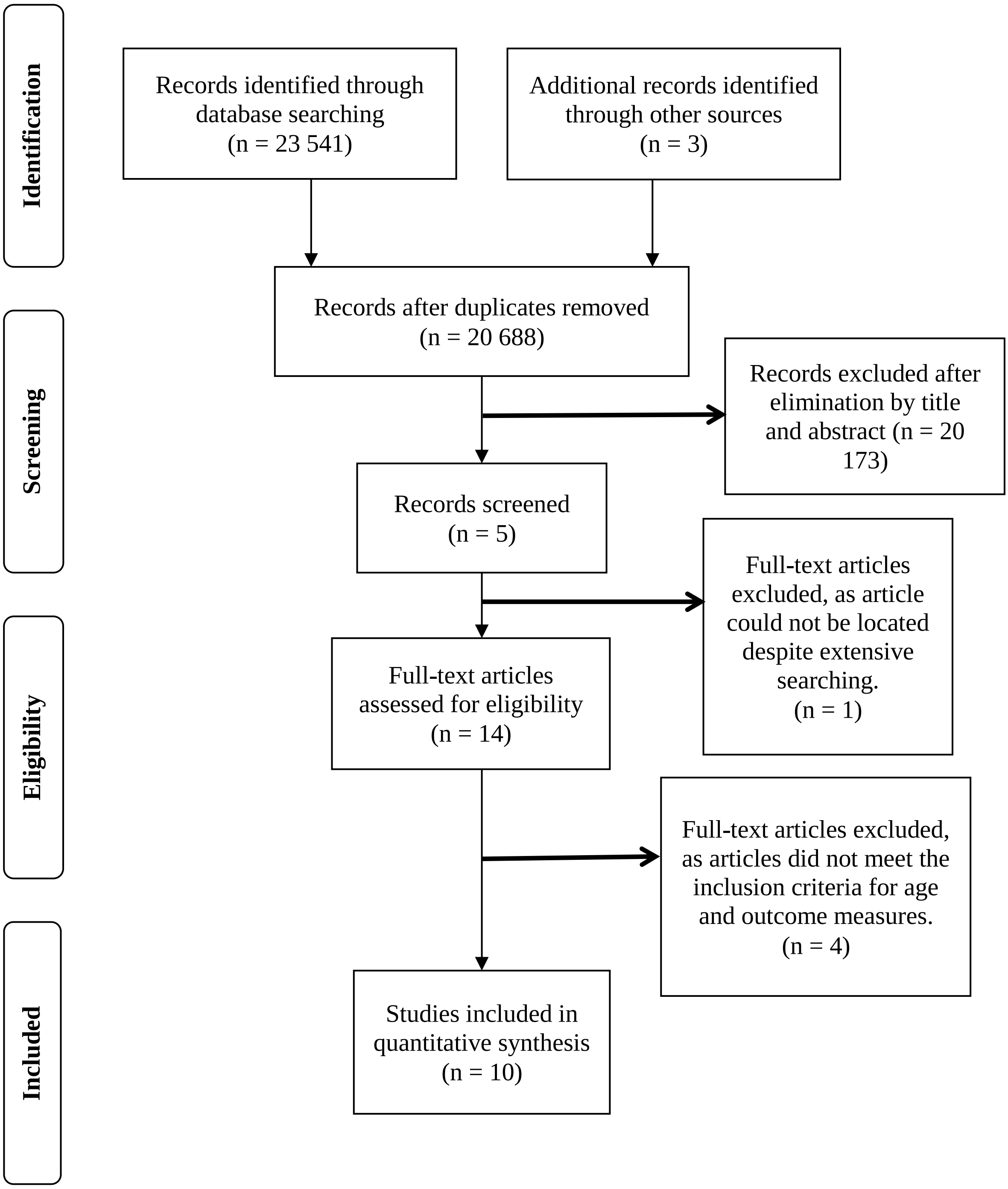
Data Extraction

Data relating to the participant (e.g., mean age, sex, fitness etc) and study (e.g., design, sample size, intervention type) characteristics, and CF and AP assessments were independently extracted by two researchers (shared by JL, RO, NOD).

Statistical Analysis

Data extracted were reported as mean ± standard deviation (SD). Studies reporting data with standard errors (SE) were converted to SD using the equations: SD=SE x √sample size. Comprehensive Meta-Analysis (CMA) Software (Biostat Inc. Englewood, New Jersey, USA) was used to calculate effect sizes (ES) from the published data (unadjusted for confounders) when possible and reported as standardised mean differences (SMD). ES was determined by subtracting the mean change in cognitive outcomes in the intervention group from that in the control group and dividing the difference by the pooled baseline SD of both groups. ES was then corrected for small-sample bias (Hedges g) with 95% confidence intervals (CI) and categorised as trivial (<0.02), small (0.02-0.6), moderate (0.6-1.2), large (1.2-2.0) or very large (>2.0)[23]. Positive ES favoured exercise while negative favoured rest/control.

Figure 1: Prisma Flowchart



RESULTS

Identification and selection of studies

The initial search netted 23,541 papers plus four identified by hand searching. After removal of duplicates and ineligible manuscripts, 10 papers (published from 1991–2015) were eligible for inclusion. The flow of papers from potentially relevant to inclusion is displayed in Figure 1. The 10 papers identified[10-13,24-29] described 11 studies, as one paper[10] included both an acute and chronic exercise intervention. Of the nine acute studies[10-13,25-29], eight[10-13,26-29] examined CF while two[25,28] examined AP. The remaining two studies described chronic exercise interventions, of which one examined CF[10] while one examined both CF and AP[24] (Table 1).

Methodological Quality

The included studies had a PEDro score ranging from 3 (poor) to 8 (good) (Table A1). The major limitations included failure to report details of participant and assessor blinding (all 10 studies) as well as insufficient information on allocation concealment (all but two studies[11,24]).

Participants Characteristics

The included studies recruited 588 healthy adolescent participants (62.9% male) aged from 13.0-15.8 years, with a BMI ranging from 17.8 to 23.8 kg·m^{-2} and aerobic fitness from 42.4 to 50.7 ml·kg^{-1}min^{-1} (Table A2).

Table 1: Study design characteristics

Author, Year	Study Design, Country, Sample recruited	Intervention Details		Control Details		Drop-outs/ exclusions
		Sample analysed (n)	Dose: Frequency (F), Intensity (I), Type (T), Time (t)	Sample analysed (n)	Dose: Frequency (F), Intensity (I), Type (T), Time (t)	
Acute						
Soga et al, 2015[26]	RXT, Japan, (n=27)	25	(F): single session, (I): 70% HR_{max}, walking speed = 4.5 ± 0.4 km/h, treadmill gradient = 9.5 ± 2.2%, (T): treadmill walking, (t): NR	25	(F): single session, (I): HR_{mean} = 85.6 ± 9.6 bpm, (T): sitting on chair placed on stationary treadmill, (t): NR	2
Hogan et al, 2013[27]	CXT, Germany, (n=30)	30	(F): single session, (I): moderate but brisk: 60% HR_{max}, 50-60% VO_{2max}, (T): cycle ergometer, (t): 20mins	30	(F): single session, (I): rest, (T): watched movie, (t): 20mins	0
Cooper et al, 2012[29]	RXT, Britain, (n=60)	45	(F): single session, (I): 20m, 7 reps, 10 sets, 30s rest btw sets, vel = 8 $km.h^{-1,}$ 172 ± 17 bpm, (T): running, (t): 10mins	45	(F): single session, (I): rest, (T): NR, (t): NR	15
Budde et, al, 2010[11]	RCT, Germany, (n=60)	38	(F): single session, (I): EG1: 50-60% HR_{max}, EG2: 70-85% HR_{max}, (T): running on a 400m-track, (t): 12mins	21	(F): single session, (I): rest, (T): being sedentary, (t): 12mins	1
Travlos, 2010[25]	CXT, Greece, (n=48)	48	(F) : 4 sessions, (I): > 85%HR_{max}, 4min run/4mins walking recovery, four intervals, (T): interval running around a basketball court, (t): 40mins	48	(F): 2 sessions, 1 week before and 1 week after intrv, (I): Low, (T): Normal sedentary classroom activities, (t): 60mins	NR
Stroth et al, 2009[13]	CXT, Germany, (n=35)	33	(F): single session, (I): 60% HR_{max}, (T): cycle ergometer, (t): 20mins	33	(F): single session, (I): rest, (T): watched movie, (t): 20mins	2
Budde et al, 2008[12]	RCT, Germany, (n=115)	47	(F): single session, (I): moderate HR measured, (T): coordinative exercises, (t): 8.75mins	52	(F): single session, (I): moderate HR measured (T): normal sport lesson, (t): 10min	16
Gu et al, 1992[28]	CT, Korea, (n=120)	60	(F): NR, (I): NR, (T): NR, (t): 30mins	60	(F): NR, (I): NR, (T): studying or reading, (t): 40mins	NR
Zervas et al, 1991[10]	CT, Greece, (n=26)	18	(F): single session, (I): warm-up: vel = 8 to 9km/h, intrv: 12-14km/h, at gradient 1%, 187 ± 11bpm, (T): treadmill running, (t): warm-up: 5mins, intrv: 20mins	8	(F): single session, (I): rest, (T): passive sitting down, (t): 60mins	0

Chronic						
Ardoy et al, 2014[24]	RCT, Spain, (n=67)	37	(F): 4 day/week, (I): EG1- HR_{mean} = 129bpm, HR_{max}= 177bpm; EG2- HR_{mean} = 147bpm, HR_{max} = 193bpm, (T): PE activities specially designed by teachers, (t): 55mins (includes organisation and changing/shower)	17	(F): 2 day/week, (I): HR_{mean} = 116bpm, HR_{max} = 174bpm, (T): normal PE lesson, (t): 55mins (includes organisation and changing/shower)	13
Zervas et al, 1991[10]	CT, Greece, (n=26)	8	(F): 3 day/week for 25 weeks (6months), (I): personalised speed based on anaerobic threshold of 4mmol/L, (T): interval or continuous running, (t): warm-up: 15mins, intrv: 60 ± 15mins	18	(F): 2 to 3 days/week, (I): "light physical activity", (T): normal school-based PE classes, (t): normal length of PE class	0

Data are presented as mean ± standard deviation: (bpm): beats per minute; (btw): between; (CT): controlled trials; (CXT): controlled cross-over trial; (EG): experimental group; (HR_{max}): maximum heart rate; (HR_{mean}): mean heart rate; (km/h): kilometres per hour; (mins): minutes; (NR): not reported; (RCT): randomised controlled trial; (reps): repetition; (rpm): revolutions per minute; (RXT): randomised cross-over trial; (s): seconds; (vel): speed; (W): watts.

Table 2: Summary of the effects of exercise on cognitive function and academic performance

	Acute studies (n=9)				Chronic studies (n=2)			
	Cognitive Function (n=8)		Academic Performance (n=2)		Cognitive Function (n=2)		Academic Performance (n=1)	
	Favours ex n (%)	Favours rest n (%)	Favours ex n (%)	Favours rest n (%)	Favours ex n (%)	Favours rest n (%)	Favours ex n (%)	Favours rest n (%)
Overall studies reporting at least one significant effect	8 (100)	0 (0)	1 (50)	1 (50)	1 (50)	1 (50)	1 (100)	0 (0)
Total number of parameters examined across studies	Cognitive Function (n=38)		Academic Performance (n=11)		Cognitive Function (n=5)		Academic Performance (n=2)	
	Favours ex n (%)	Favours rest n (%)	Favours ex n (%)	Favours rest n (%)	Favours ex n (%)	Favours rest n (%)	Favours ex n (%)	Favours rest n (%)
Significant effect	15 (40)	2 (5)	8 (73)	2 (18)	1 (20)	0 (0)	1 (50)	0 (0)
Non-significant effect	21 (55)	0 (0)	1 (9)	0 (0)	4 (80)	0 (0)	1 (50)	0 (0)
Overall studies where effect size* could be calculated for a parameter	Cognitive Function (n=6)		Academic Performance (n=1)		Cognitive Function (n=1)		Academic Performance (n=1)	
	Favours ex n (%)	Favours rest n (%)	Favours ex n (%)	Favours rest n (%)	Favours ex n (%)	Favours rest n (%)	Favours ex n (%)	Favours rest n (%)
	13 (48)	14 (52)	8 (80)	2 (20)	2 (100)	0 (0)	2 (100)	0 (0)

* Effect size was calculated when mean, standard deviation/error and sample size were available, ex = exercise.

Study Design

The studies included randomised controlled (n=3)[11,12,24], randomised cross-over (n=2)[26,29] and controlled cross-over (n=3)[13,25,27] trials. All studies had an intervention and control condition. In eight studies[10,11,13,25-29] the control phase was a resting condition (e.g., watching television, reading and sitting quietly), whereas the control condition was a 'normal PE (Physical Education) lesson' in three studies[10,12,24].

Acute Studies

The nine acute studies used a range of aerobic exercise modalities: outdoor or treadmill running (n=4)[10,11,25,29], cycle ergometer (n=2)[13,27], treadmill walking (n=1)[26] and coordinative exercises (n=1; aerobic exercise involving bilateral coordination)[12]. Eight studies[10-13,25-29] reported exercise intensity, with five quantifying intensity between 60-80% of maximum heart rate (HR_{max})[11,13,25-27]. One study[28] disclosed neither exercise intensity nor modality. Each study consisted of a single exercise session (9-40 minutes duration) and a control condition which ranged between 10-60 minutes (Table 1). Only five studies reported a pre-trial aerobic fitness test[10,11,13,26,27], using a shuttle run[11,26] or incremental cycle test[13,27] to quantify aerobic capacity as percentage of HR_{max}[11] or peak aerobic capacity (VO_{2peak})[26]. The remaining studies did not measure pre-trial aerobic fitness[12,25,28,29] (Supplementary Table 2).

Chronic Studies

The two chronic intervention studies[10,24] were conducted across six and four months, respectively. Exercise intensity was reported in one study[24] using mean heart rate (HR_{mean}) and HR_{max}. In the other study[10], exercise intensity (participant-specific) was established based on each participant's anaerobic threshold. Intervention details were reported as 'PE activities'[24] and 'interval or continuous running'[10]. Although exercise duration (ranging 55-60 mins) was reported[10,24], organisation and changing/shower time was included in the 'intervention' duration in one study[24]. The control activity in both studies was reported as 'normal PE lesson'[10,24] (Table 1).

Outcome measures and overall results in acute studies (CF and AP)

In the acute interventions, CF was measured in eight studies[10-13,26-29] while AP was measured in two studies[25,28]. CF was assessed using 12 different cognitive tasks. The domains assessed were executive function (n=4)[13,27-29], memory (n=4)[11,26,28,29], attention and concentration (n=2)[10,12], visuo-motor speed (n=1)[29] and logical sequencing (n=1)[28] (Table A1). Executive function and memory were the most popular domains assessed, with the Modified Eriksen Flanker task with a Go/NoGo paradigm being most commonly used[13,27]. AP was examined with arithmetic (standardisation/validation of arithmetic tasks was not clearly described in the studies)[25,28]. Although all eight studies[10-13,26-29] reported at least one significant effect of acute exercise showing improvement in CF, the majority of cognitive parameters indicated that the effect of exercise was either not significant or the control/resting condition was favoured. CF was assessed across 38 cognitive parameters of which only 15 (40%) showed a significant effect of acute exercise. In six of these studies[10-13,26,27] where an ES could be calculated, 52% of the parameters favoured rest. In the two studies that examined AP, only one reported significance, with 8/10 AP parameters favouring exercise when the ES was calculated[25] (Table 2).

Effect of acute exercise on executive function

Three studies[13,27,28] reported a significant beneficial effect of acute exercise on executive function ($p<0.01$) (Table A1). Two[13,27] studies additionally assessed the impact of participant fitness on executive function outcomes after acute exercise. Higher-fit participants showed significantly improved performance on the Eriksen Flanker paradigm for executive function[13,27], while lower-fit participants performed significantly better on the Go/NoGo task[13]. ES could be calculated for two studies (n=16 parameters)[13,28] (Supplementary Table 5). The effects on executive function favouring a bout of acute exercise ranged from small to large (ES=0.27 to 1.90; p=0.00 to 0.25). Overall however, 62.5% of the parameters favoured rest and the effect ranged from small to large (ES=-0.02 to -1.92; p=0.00 to 0.93).

Effect of acute exercise on memory

The four studies[11,26,28,29] that examined the effects of a bout of acute exercise on the domain of memory showed significant improvements in the n-back task[26], Sternberg paradigm[29], Letter Digit Span[11] and Immediate Recall List[28]. Additionally, one study separated participants into low and high performer groups, based on their pre-test Letter Digit Span scores[11], and examined the effects of exercise intensity (50-65% HR_{max} and 70-85% HR_{max}) on memory. Their results showed that only the lower intensity (50-65% HR_{max}), low performer group improved significantly after acute exercise. ES could only be calculated for two studies[11,26] (Table A5). The effects favouring exercise were small (ES=0.07 to 0.32; p=0.46 to 0.88), consistent with the observations that the low performer, lower intensity group improved in the memory task. The effects favouring rest ranged from trivial to small (ES =-0.01 to -0.19; p=0.64 to 0.97).

Effect of acute exercise on attention and concentration

Only two studies[10,12] examined the effects of acute exercise on the domain of concentration and attention. Both showed significant improvements following exercise in the accuracy of correct responses in their D2[12] and Cognitrone test[10] after exercise. The D2 test also showed significant improvements after acute exercise in two other test parameters of percentage errors and total number of responses (Table A1). ES ranged from moderate to large (ES=0.68 to 1.46; p=0.00 to 0.01)[10,12], favouring the acute exercise intervention in most (4/6) of the cognitive parameters. However, two cognitive parameters with effects ranging from small to large (ES:-0.09 to-1.57, p: 0.00 to 0.85) favoured rest[10] (Table A5).

Effect of acute exercise on visuo-motor speed and logical sequencing

The Visual Search Test (baseline and complex levels) was used to assess the domain of visuo-motor speed in one study[29]. Speed improved significantly after a bout of acute exercise only on the complex and not on the baseline level of test performance. No positive effect of exercise was demonstrated on logical sequencing[28]. ES could not be calculated in either study.

Effect of acute exercise on AP

Of the two studies[25,28] that examined arithmetic tasks, only one showed a significant improvement after a bout of acute exercise[25]. This study also examined the effects on AP during different time periods of the day. Greater improvements in arithmetic skills were reported after exercise in morning and early afternoon classes compared to the last class of the school day. The other acute study reported a trend to significance (p=0.053), with post-hoc analysis showing that only male participants' arithmetic scores improved significantly after exercise[28]. ES could be calculated for one study with 8/10 of the AP parameters favouring exercise and ranged from small to large (ES=0.43 to 1.20; p=0.00 to 0.13). The two remaining parameters favoured rest and ranged from small to moderate (ES=-0.92 to -0.45; p=0.01 to 0.11)[25].

Outcome measures and overall results in chronic studies (CF and AP)

Only two studies[10,24] examined the effects of a chronic exercise intervention on CF (n=2)[10,24] and AP (n=1)[24]. CF was assessed using an overall psychometric aptitude (general ability) test and the Cognitrone test (attention and concentration). School-based subject grades were used to assess AP. Only one[24] study found a significant effect of chronic exercise in improving CF. Of the five parameters that examined CF in the two studies, only one showed significance. ES could only be calculated for one study with both of its parameters favouring exercise[24]. Only one study examined the effect of chronic exercise on AP and showed significance[24]. Although both of its parameters favoured exercise, only one was reported to be significant (Table 2).

Effect of chronic exercise on CF

One study[24] examined the effect of a four-month training programme on psychometric aptitude. Exercise frequency and intensity were also examined. Overall psychometric aptitude was found to have improved significantly only for the high-frequency/high-intensity (4 day/week; HR_{mean}=147 beats per minute (bpm)) group and correlated significantly with improvements in cardiorespiratory fitness. The ES favouring exercise training was very large (ES =4.87; p=0.00). The moderate ES for the high-frequency/normal-intensity (4 day/week; HR_{mean}=129 bpm) group (ES=1.06; p=0.00) also favoured exercise. In the other chronic exercise study, no significant effects on the Cognitrone test were observed after 25 weeks of exercise[10], although it is important to note that aerobic fitness also did not change significantly with the chronic exercise intervention .

Effect of chronic exercise on AP

Similar to the trend observed with CF, overall AP was significantly improved only in the high-frequency/high-intensity group after four months of exercise training[19]. The ES favouring exercise training was small (ES=0.33; p=0.29). The ES also favouring exercise for the high-frequency/normal-intensity group was trivial (ES=0.00; p=1.00).

DISCUSSION

This review identified a small (10 papers, 11 studies) but relatively recent body of relevant literature, with overall quality ranging from poor to good. All 10 papers, the majority being acute studies[10-13,26-30], reported at least one parameter showing a significant effect of exercise in improving CF and/or AP in adolescents. However, in six studies where effect sizes could be calculated, only 48% of CF parameters favoured acute exercise[10-13,26,27]. Of the one chronic study which allowed for ES calculations, both of the CF parameters favoured chronic exercise[24]. Furthermore, only 37% of all CF parameters across studies offered support for the efficacy of exercise in improving CF. Overall, the evidence for a positive benefit on CF from acute and/or chronic exercise training in adolescents was equivocal, highlighting the need for robust studies focussed on this age stage. The inconsistent effect of exercise on measures of CF in this review may be explained by the heterogeneity of cohorts, wide disparity in CF assessments and an inadequate or ineffective dose of exercise to provide a stimulus. By contrast, AP was observed to improve significantly after acute and chronic exercise, with 69% of the total AP parameters favouring exercise.

Exercise is proposed to enhance CF by a number of potential mechanisms. These include acute exercise acting as an arousal stimulus, as well as exercise promoting the release of brain-derived neurotrophic factor (BDNF). Both acute and chronic exercise have been reported to upregulate BDNF, resulting from exercise-induced activation of a key complex pathway PGC1α/FNDC5/BDNF (Peroxisome proliferator-activated receptor co-activator alpha/Fibronectin type III domain-containing5/BDNF), identified as an initiator of neuroplasticity[31] via enhanced neuro/synaptogenesis and angiogenesis[32]. This pathway may subsequently promote long-term neural remodelling in brain regions such as the hippocampus[32-34]. Furthermore, BDNF is also reported to play an integral role in mediating persistent network activity and maintaining normal PFC function[35-38]. Interactions between the PFC and hippocampus are facilitated by limbic connections allowing these two brain regions to mediate different levels of cognitive control in the domains of memory and planning/executive function[39,40].

Increased BDNF levels in the hippocampus are reported after acute exercise which likely confers specific benefits integral to learning and memory performance[41]. Interestingly, in this review, memory[11,26,28,29] showed the most consistent significant improvements from acute exercise. Memory has also been demonstrated to improve after six weeks of moderate intensity aerobic exercise[42]. The results for executive function[13,27-29] and attention and concentration[10,12] domains were mixed, with some tests favouring rest and some exercise. It has been suggested that a transient bout of acute exercise may have a selective influence on CF, specifically enhancing some domains such as information processing but potentially impairing others like executive function which requires more coordinated cognitive processess[43]. Because adolescence is the period where the PFC and the hippocampus remain highly plastic, future research in the cognitive domains which are associated with the function of these two brain regions may prove beneficial.

Since different exercise doses recruit different muscle masses and hence require different cardiac output[44-46], the variability of exercise intensity especially may have a correlation to the increased blood flow and BDNF-induced stimulation of the hippocampus and PFC[47]. Exercise dose components such as frequency, intensity, type and duration are likely to directly impact cognitive (and even AP) outcomes. In this review, exercise protocols and intensity were poorly reported, which did not allow for the clear contribution of exercise to be determined and possibly contributed to the inconsistent findings. Significant increases in BDNF levels have been reported following 30 minutes of moderate intensity cycling as well as a ramp protocol to exhaustion [48,49]. The importance of this dose-response relationship between exercise and cognition is further highlighted in one of the chronic studies reviewed. Participants who completed high-frequency/high-intensity training improved in their cardiorespiratory fitness, which correlated with improvements in their CF[24], suggesting the need for a sufficient intensity to elicit benefits. This study was consistent with other studies where chronic aerobic exercise has been observed to enhance CF in populations outside of the adolescent age stage, supporting a dose-response relationship, with a higher exercise dose (volume, intensity or both) required to elicit benefits[16,50]. These preliminary findings clearly underscore the need for further research using protocols with clearly-defined exercise intensity.

In this review, academic performance measured by arithmetic skills significantly improved with acute[25,28] and chronic exercise[24]. Similar to CF, acute exercise has been postulated to enhance arousal and facilitate improved classroom attention[9,51,52]. However, the timing of the exercise may be an important consideration. The effect of undertaking the exercise in either the first, third, fifth or last period of the school day was investigated. AP was shown to be better (compared with rest) after acute exercise for all but the last period[25]. Hence, it may be more effective to intervene with acute exercise earlier in the day when students are less fatigued. While limited conclusions can be drawn from the few included studies, evidence for the potential benefits of chronic aerobic exercise on AP in primary schoolchildren has been demonstrated by an improvement in or maintenance of AP[53,54]. However, it should be noted that AP can also be influenced by a wide range of non-cognition related factors including social-emotional functioning, motivation, school demographic characteristics and classroom practices[55,56]. Future studies examining the role of aerobic fitness in the exercise-AP relationship, taking into consideration the abovementioned confounders, are warranted.

The key strength of this review is its tight focus on inclusion of studies conducted only in adolescents. Previous reviews have included studies which were predominantly in children under 12 years. Furthermore, this is the first review to examine the impact of both acute and chronic exercise on AP in adolescents. Other strengths include the systematic search of literature, use of PRISMA guidelines and calculation of effect sizes. The review evaluated the outcomes of a range of cognitive tasks assessing different cognitive domains, the majority of which were validated.

The main limitation of this study is the quality and quantity of the identified papers. Only half of the studies (n=5) reported exercise intensity using recommended guidelines[57] (HR_{max} or VO_{2max}). Not all acute studies used a cross-over design (56%). Other limitations include bias towards the early adolescent years (13-14y, seven studies) and sex (63% male). Maturation stage was only reported in one study[24]. Some studies (n=2)[25,28] used cognitive and academic assessments that were not validated and the effects of exercise on AP were focused on the arithmetic domain[25,28]. Sample sizes were also relatively small (n<120). Familiarisation to the exercise stimulus (n=0) and cognitive tests (n=5)[10,13,26,27,29] was not always used and therefore learning effects may have confounded the results. Additionally, the absence of a resting condition (one acute, two chronic studies) and the use of a "normal PE lesson" (exercise dose poorly quantified) limited the capacity to make comparisons between groups and studies. The diversity and complexity of CF measures makes comparison between studies more difficult, in respect of which it has been recommended that researchers seek consensus on a focused range of cognitive assessments that include measures of key cognitive domains with clinical and scientific importance[30].

CONCLUSION

In conclusion, this systematic review demonstrates that there is limited literature in adolescents addressing the effect of either acute or chronic exercise on CF and AP. Although there is strong theoretical evidence for exercise being beneficial particularly during adolescence due to neural plasticity, there is as yet limited and inadequate evidence to support its efficacy. Future studies would benefit from collaboration between neuroscientists with expertise in cognition and its assessment and exercise scientists with expertise in the prescription and measurement of exercise. Although all the papers reviewed reported a significant effect of acute or chronic exercise in improving some aspect of CF and AP, it should also be noted that more than half (55%) of all cognitive and AP parameters either were not significant or were significantly improved for the rest condition. Eliminating possible noise (variability of exercise protocols and cognitive assessments) in the data may improve the quality of future research and support the maintenance and importance of adequate physical activity throughout the school years.

REFERENCES

1 World Health Organization. (2015). *Adolescent health*. http://www.who.int/topics/adolescent_health/en/
2 Blakemore, S.-J., & Choudhury, S. (2006). Development of the adolescent brain: implications for executive function and social cognition. *The Journal of Child Psychology and Psychiatry and Allied Disciplines, 47*(3/4), 296.
3 Coleman, J. C., & Hendry, L. B. (1990). *The nature of adolescence* (Vol. 2nd). Routledge.
4 Feldman, S. S., & Elliott, G. R. (1992). At the threshold: the developing adolescent. *The Journal of Nervous and Mental Disease, 180*(3), 213.
5 Sowell, E. R., Peterson, B. S., Thompson, P. M., Welcome, S. E., Henkenius, A. L., & Toga, A. W. (2003). Mapping cortical change across the human life span. *Nature Neuroscience, 6*(3), 309-315.
6 Fuster, J. M. (2008). *Chapter 2- Anatomy of the prefrontal cortex*. Academic Press.
7 Giedd, J. N., Blumenthal, J., Jeffries, N. O., Castellanos, F. X., Liu, H., Zijdenbos, A., Paus, T., Evans, A. C., & Rapoport, J. L. (1999). Brain development during childhood and adolescence: a longitudinal MRI study. *Nature Neuroscience, 2*(10), 861-863.
8 Haapala, E. (2012). Physical activity, academic performance and cognition in children and adolescents: A systematic review. *Baltic Journal of Health and Physical Activity, 4*(1), 53-61.
9 Lees, C., & Hopkins, J. (2013). Effect of aerobic exercise on cognition, academic achievement, and psychosocial function in children: A systematic review of randomized control trials. *Preventing Chronic Disease, 10*, E174.
10 Zervas, Y., Danis, A., & Klissouras, V. (1991). Influence of physical exertion on mental performance with reference to training. *Perceptual and Motor Skills, 72*(3 Pt 2), 1215-1221.
11 Budde, H., Voelcker-Rehage, C., Pietrassyk-Kendziorra, S., Machado, S., Ribeiro, P., & Arafat, A. M. (2010). Steroid hormones in the saliva of adolescents after different exercise intensities and their influence on working memory in a school setting. *Psychoneuroendocrinology, 35*(3), 382-391.
12 Budde, H., Voelcker-Rehage, C., Pietraßyk-Kendziorra, S., Ribeiro, P., & Tidow, G. (2008). Acute coordinative exercise improves attentional performance in adolescents. *Neuroscience Letters, 441*(2), 219-223.
13 Stroth, S., Kubesch, S., Dieterle, K., Ruchsow, M., Heim, R., & Kiefer, M. (2009). Physical fitness, but not acute exercise modulates event-related potential indices for executive control in healthy adolescents. *Brain Research, 1269*, 114-124.
14 Meeusen, R., & De Meirleir, K. (1995). Exercise and brain neurotransmission. *Sports Medicine, 20*(3), 160.
15 Hillman, C. H., Pontifex, M. B., Raine, L. B., Castelli, D. M., Hall, E. E., & Kramer, A. F. (2009). The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. *Neuroscience, 159*(3), 1044-1054.
16 Howie, E. K., Schatz, J., & Pate, R. R. (2015). Acute effects of classroom exercise breaks on executive function and math performance: a dose-response study. *Research Quarterly for Exercise and Sport, 86*(3), 217-224.
17 Garber, C. E., Blissmer, B., Deschenes, M. R., Franklin, B. A., Lamonte, M. J., Lee, I. M., Nieman, D. C., & Swain, D. P. (2011). Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Medicine and Science in Sports and Exercise, 43*(7), 1334-1359.
18 McAuley, E., Mihalko, S. L., & Bane, S. M. (1997). Exercise and self-esteem in middle-aged adults: multidimensional relationships and physical fitness and self-efficacy influences. *Journal of Behavioral Medicine, 20*(1), 67-83.
19 Karstoft, K., & Pedersen, B. K. (2016). Exercise and type 2 diabetes: focus on metabolism and inflammation. *Immunology and Cell Biology, 94*(2), 146.
20 Australian Bureau of Statistics. (2013). *Australian health survey: physical activity (2011-12)*. http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/4364.0.55.004Chapter1002011-12.

21 Pate, R. R., & Hohn, R. C. (1994). *Health and fitness through physical education*. Human Kinetics Publishers.

22 Sherrington, C., Herbert, R. D., Maher, C. G., & Moseley, A. M. (2000). PEDro. A database of randomized trials and systematic reviews in physiotherapy. *Manual Therapy, 5*(4), 223-226.

23 Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise, 41*(1), 3-13.

24 Ardoy, D. N., Fernández-Rodríguez, J. M., Jiménez-Pavón, D., Castillo, R., Ruiz, J. R., & Ortega, F. B. (2014). A Physical Education trial improves adolescents' cognitive performance and academic achievement: the EDUFIT study. *Scandinavian Journal of Medicine and Science in Sports, 24*(1), e52-e61.

25 Travlos, A. (2010). High intensity physical education classes and cognitive performance in eighth-grade students: An applied study. *International Journal of Sport and Exercise Psychology, 8*(3), 302.

26 Soga, K., Shishido, T., & Nagatomi, R. (2015). Executive function during and after acute moderate aerobic exercise in adolescents. *Psychology of Sport and Exercise, 16*, 7-17.

27 Hogan, M., Kiefer, M., Kubesch, S., Collins, P., Kilmartin, L., & Brosnan, M. (2013). The interactive effects of physical fitness and acute aerobic exercise on electrophysiological coherence and cognitive performance in adolescents. *Experimental Brain Research, 229*(1), 85-96.

28 Gu, H. M., Shin, D. S., Lee, K. H., Choi, J. S., & Yu, J. (1992). The relationship between physical exercise and cognitive ability (II). *Korean Journal of Sports Science, 4*, 70-78.

29 Cooper, S. B., Bandelow, S., Nute, M. L., Morris, J. G., & Nevill, M. E. (2012). The effects of a mid-morning bout of exercise on adolescents' cognitive function. *Mental Health and Physical Activity, 5*(2), 183-190.

30 Young, J., Angevaren, M., Rusted, J., & Tabet, N. (2015). Aerobic exercise to improve cognitive function in older people without known cognitive impairment. *Cochrane Database of Systematic Reviews, 4*(4), CD005381.

31 Wrann, C. D., White, J. P., Salogiannnis, J., Laznik-Bogoslavski, D., Wu, J., Ma, D., Lin, J. D., Greenberg, M. E., & Spiegelman, B. M. (2013). Exercise induces hippocampal BDNF through a PGC-1α/FNDC5 pathway. *Cell Metabolism, 18*(5), 649-659.

32 Vaynman, S., Ying, Z., & Gomez-Pinilla, F. (2004). Hippocampal BDNF mediates the efficacy of exercise on synaptic plasticity and cognition. *The European Journal of Neuroscience, 20*(10), 2580-2590.

33 Neeper, S. A., Góauctemez-Pinilla, F., Choi, J., & Cotman, C. (1995). Exercise and brain neurotrophins. *Nature, 373*(6510), 109-109.

34 Vaynman, S., Ying, Z., & Gomez-Pinilla, F. (2003). Interplay between brain-derived neurotrophic factor and signal transduction modulators in the regulation of the effects of exercise on synaptic-plasticity. *Neuroscience, 122*(3), 647-657.

35 Hashimoto, T., Volk, D. W., & Lewis, D. A. (2005). Cortical inhibitory neurons and schizophrenia. *Nature Reviews Neuroscience, 6*(4), 312-324.

36 Savitz, J., Solms, M., & Ramesar, R. (2006). The molecular genetics of cognition: dopamine, COMT and BDNF. *Genes, Brain and Behavior, 5*(4), 311-328.

37 Woo, N. H., & Lu, B. (2006). Regulation of cortical interneurons by neurotrophins: From development to cognitive disorders. *The Neuroscientist, 12*(1), 43-56.

38 Galloway, E. M., Woo, N. H., & Lu, B. (2008). Persistent neural activity in the prefrontal cortex: a mechanism by which BDNF regulates working memory? *Progress in Brain Research, 169*, 251-266.

39 Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*, 167.

40 Cohen, J., & O'Reilly, R. (1996). A preliminary theory of the interactions between prefrontal cortex and hippocampus that contribute to planning and prospective memory. *Prospective Memory: Theory and Applications* (pp. 267-296). Lawrence Erlbaum Associates.

41 Griffin, É. W., Mullally, S., Foley, C., Warmington, S. A., O'Mara, S. M., & Kelly, Á. M. (2011). Aerobic exercise improves hippocampal function and increases BDNF in the serum of young adult males. *Physiology and Behavior*, *104*(5), 934-941.

42 Fu, H.-J., Sheu, F.-R., & Shih, M.-L. (2014). Can aerobic exercise improve memory? *Research Quarterly for Exercise and Sport*, *85*(S1), A62.

43 Audiffren, M., Tomporowski, P. D., & Zagrodnik, J. (2008). Acute aerobic exercise and information processing: energizing motor processes during a choice reaction time task. *Acta Psychologica, 129*(3), 410-419.

44 McArdle, W. D., Katch, F. I., & Katch, V. L. (2007). *Exercise physiology: energy, nutrition, and human performance*. 6th Edition, Williams & Williams, Maryland.

45 Warburton, D. E. R., Gledhill, N., & Quinney, H. A. (2000). Blood volume, aerobic power, and endurance performance: potential ergogenic effect of volume loading. *Clinical Journal of Sport Medicine, 10*(1), 59-66.

46 Warburton, D. E. R., Haykowsky, M. J., Quinney, H. A., Blackmore, D., Teo, K. K., Taylor, D. A., McGavock, J., & Humen, D. P. (2004). Blood volume expansion and cardiorespiratory function: effects of training modality. *Medicine and Science in Sports and Exercise, 36*(6), 991-1000.

47 Kramer, A. F., Hillman, C. H., & Erickson, K. I. (2008). Be smart, exercise your heart: exercise effects on brain and cognition. *Nature Reviews Neuroscience, 9*(1), 58-65.

48 Rojas Vega, S., Strüder, H. K., Vera Wahrmann, B., Schmidt, A., Bloch, W., & Hollmann, W. (2006). Acute BDNF and cortisol response to low intensity exercise and following ramp incremental exercise to exhaustion in humans. *Brain Research, 1121*(1), 59-65.

49 Gold, S. M., Schulz, K.-H., Hartmann, S., Mladek, M., Lang, U. E., Hellweg, R., Reer, R., Braumann, K.-M., & Heesen, C. (2003). Basal serum levels and reactivity of nerve growth factor and brain-derived neurotrophic factor to standardized acute exercise in multiple sclerosis and controls. *Journal of Neuroimmunology*, *138*(1), 99-105.

50 Vidoni, E. D., Johnson, D. K., Morris, J. K., Sciver, A. V., Greer, C. S., Billinger, S. A., Donnelly, J. E., & Burns, J. M. (2015). Dose-response of aerobic exercise on cognition: a community-based, pilot randomized controlled trial. *PLOS One, 10*(7).

51 Keeley, T. J. H., & Fox, K. R. (2009). The impact of physical activity and fitness on academic achievement and cognitive performance in children. *International Review of Sport and Exercise Psychology, 2*(2), 198-214.

52 Rasberry, C. N., Lee, S. M., Robin, L., Laris, B. A., Russell, L. A., Coyle, K. K., & Nihiser, A. J. (2011). The association between school-based physical activity, including physical education, and academic performance: A systematic review of the literature. *Preventive Medicine, 52*, S10-S20.

53 Sallis, J. F., McKenzie, T. L., Kolody, B., Lewis, M., Marshall, S., & Rosengard, P. (1999). Effects of health-related physical education on academic achievement: project SPARK. *Research Quarterly for Exercise and Sport, 70*(2), 127.

54 Donnelly, J. E., Greene, J. L., Gibson, C. A., Smith, B. K., Washburn, R. A., Sullivan, D. K., DuBose, K., Mayo, M. S., Schmelzle, K. H., Ryan, J. J., Jacobsen, D. J., & Williams, S. L. (2009). Physical Activity Across the Curriculum (PAAC): a randomized controlled trial to promote physical activity and diminish overweight and obesity in elementary school children. *Preventive Medicine, 49*(4), 336-341.

55 Wang, M. C., Haertel, G. D., & Walberg, H. J. (1993). Toward a knowledge base for school learning. *Review of Educational Research*, *63*(3), 249-294.

56 Gustafsson, J.-E., & Balke, G. (1993). General and specific abilities as predictors of school achievement. *Multivariate Behavioral Research, 28*(4), 407-434.

57 American College of Sports Medicine. (2013). *ACSM's guidelines for exercise testing and prescription*. Lippincott Williams & Wilkins.

APPENDICES

Table A1: Methodological quality of included studies

		Author, year									
		Soga et al, 2015[26]	**Ardoy et al, 2014[24]**	**Hogan et al, 2013[27]**	**Cooper et al, 2012[29]**	**Budde et al, 2010[11]**	**Travlos 2010[25]**	**Stroth et al, 2009[13]**	**Budde et al, 2008[12]**	**Gu et al, 1992[28]**	**Zervas et al, 1991[10]**
Methodological Quality	**Randomization**	1	1	0	1	1	0	1	1	NR	1
	Allocation concealed (assessor)	0	1	0	0	1	0	0	0	NR	0
	Groups similar at baseline regarding most important prognostic indicators	1	1	NR	NR	NR	NR	1	1	NR	1
	Subject blinding	NR	NR	0	0	0	0	0	0	NR	0
	Investigator delivering intervention blinding	NR	1	0	0	NR	0	0	0	NR	0
	Assessor blinding in at least 1 key outcome	NR	NR	0	0	NR	0	0	0	NR	0
	Measurements of at least 1 key outcome obtained from ≥ 85% subjects initially allocated to group	1	1	1	1	1	1	1	1	1	1
	All subjects received treatment or data for at least 1 key outcome and were analysed by intention-to-treat	1	1	1	1	1	1	1	1	1	1

Results of between-group statistical comparisons are reported for at least 1 key outcome	1	1	1	1	1	1	1	1	1	1
Point measurement and measurements of variability for at least 1 key outcome	1	1	1	1	1	1	1	1	0	1
PEDro score	6	8	4	5	6	4	6	6	3	6

NR = not reported, PEDro = Physiotherapy Evidence Database,[22] PEDro scoring: Yes = 1, No = 0, NR = 0; (NR):not reported

The higher the PEDro score, the better the quality of the study. The following cut-points are used to describe the quality of papers: 9-10 (excellent); 6-8 (good); 4-5 (fair); <3 (poor)[23].

Table A2: Participant characteristics

Author	School Type	Mean age ± SD (years)	Gender (%)	Health Status	Participants Baseline Fitness Level	BMI (kg.m^{-2})
Soga et al, 2015[26]	Local college of technology	15.8 ± 0.4	M: 66.7% F: 33.3%	NR	20m Shuttle run for estimated VO_{2peak} (ml/min/kg) M: 50.7 ± 4.4 F: 42.4 ± 6.9 O: 47.9 ± 6.6	M: 20.6 ± 2.7 F: 21.7 ± 4.3 O: 20.9 ± 3.3
Ardoy et al, 2014[24]	Local secondary schools	13.0 ± 0.8	M: 64.2% F: 35.8%	No previous history of CVD, no cognitive dysfunction, able to actively participate in PE classes	20m Shuttle Run Standing Long Jump 4 × 10m Shuttle Run	CG: 23.8± 5.9 EG1: 22.2 ± 5.6 EG2: 21.1 ± 2.9 O: 22.3 ± 4.9
Hogan et al, 2013[27]	Local secondary schools	14.2 ± 0.5	M: 63.3% F: 36.7%	Healthy, all right-handed, normal or corrected vision	Maximal incremental bike test (W/BMI) HF: 8.9 ± 1.2 LF: 6.8 ± 0.9	HF: 19.5 ± 3.4 LF: 19.9 ± 3.2
Cooper et al, 2012[29]	Local secondary school	13.3 ± 0.3	M: 33.3% F: 66.7%	Healthy, with 33% overweight and 11% obese	Waist Circumference (cm) M: 65.0 ± 4.3 F: 68.1 ± 8.3 O: 67.1 ± 7.3	M: 17.8 ± 2.0 F: 20.7 ± 4.1 O: 19.7 ± 3.7
Budde et al, 2010[11]	Local secondary school	14.4 ± 0.5	M: 55.9% F: 44.1%	Healthy, no dyslexia, BMI not above 25, no mental or physical impairments, no history of psychoactive substance use	20m Shuttle Run (HR_{max}) O: NR PA (mins/wk): EG1: 196.9 ± 59.1 EG2: 289.4 ± 94.9 CG: 185.0 ± 65.5	EG1: 19.6 ± 0.6 EG2: 19.8 ± 0.4 CG: 21.6 ± 0.9
Travlos, 2010[25]	Two public schools in Athens	13.7 ± 0.6	M: 75.0% F: 25.0%	Healthy, no illness and all had physician’s	NR	NR

				permission to exercise at high intensity		
Stroth et al, 2009[13]	Local secondary schools	14.2 ± 0.5	M: 60.6 % F: 39.4%	Healthy, all right-handed, normal or corrected vision	Maximal incremental bike test (W/BMI ratio) HF: 8.8 ± 1.2 LF: 6.7 ± 0.9	HF: 19.6 ± 3.6 LF: 20.6 ± 4.0
Budde et al, 2008[12]	Elite performance school	15.0 ± 0.8	M: 80.8% F: 19.2%	Healthy, no dyslexia	NR	≤ 25
Gu et al, 1992	NR	NR	M: 50% F: 50%	NR	NR	NR
Zervas et al, 1991[10]	NR	Experimental: 13.1 ± 1.02 Control: 12.7 ± 0.52	M: 100%	NR	Pre and Post VO_{2peak} (ml/min/kg) Pre-T: 52.1 ± 3.6 Pre-UT: 54.0 ± 3.9 CG: NR Post-T: 57.5 ± 3.6 Pre-UT: 55.4 ± 3.3 CG: NR	NR

Data are presented as mean ± standard deviation: (BMI): Body Mass Index; (CG): control group; (cm): centimetres; (EG): experimental group; (F): females; (HF): higher fit group; (HR_{max}): maximum heart rate; (LF): lower fit group; (M): males; (NR): not reported; (O): overall; (PA): physical activity; (SD): standard deviation; (T): trained boys (UT): untrained boys; (VO_{2peak}): peak aerobic capacity; (W): watts.

Table A3: Effect of exercise on the different domains of cognitive function

Executive function									
Type of test	**Author**	**Test parameters**	**Higher Fit Group**			**Lower Fit Group**			**Between Group**
			Rest	**Exercise**	**p-value**	**Rest**	**Exercise**	**p-value**	
Eriksen Flanker Paradigm	Hogan et al, 2013[27]	Congruent RT (ms)	279.81 ± 4.81	259.62 ± 11.54	0.05	261.54 ± 7.69	275.62 ± 5.77	0.07	NS
		Incongruent RT (ms)	305.77 ± 7.69	297.12 ± 10.58		307.69 ± 8.65	320.19 ± 7.69		
	Stroth et al, 2009[13]	Congruent RT (ms)	283.63 ± 19.51	262.83 ± 43.91	<0.001	263.10 ± 28.0	275.06 ± 18.9	<0.001	>0.25
		Incongruent RT (ms)	313.75 ± 40.24	301.81 ± 43.52		308.98 ± 32.9	320.56 ± 29.8		
Go/NoGo Task	Hogan et al, 2013[27]	Go (Error rates/%)	18.54 ± 1.88	17.29 ± 2.08	NS	15.00 ± 1.67	18.75 ± 2.50	NS	NS
		NoGo (Error rates/%)	20.31 ± 2.71	22.60 ± 4.38		28.54 ± 4.58	21.46 ± 3.33		
	Stroth et al, 2009[13]	Go (Error rates/%)	13.8 ± 9.5	14.0 ± 8.4	NS	9.5 ± 8.0	11.9 ± 11.2	NS	>0.27
		NoGo (Error rates/%)	19.4 ± 10.5	21.5 ± 12.9		21.2 ± 12.6	27.1 ± 18.2		
			Intervention Group			**Control Group**			**p-value**
			Pre	**Post**	**Δ (post-pre)**	**Pre**	**Post**	**Δ (post-pre)**	
Stroop Test		Resp. Time (ms)	NR	NR	NR	NR	NR	NR	0.109

	Cooper et al, 2012[29]	ACC (% of Correct Resp)	NR	NR	NR	NR	NR	NR	0.307
Maze (Labyrinth) Test	Gu et al, 1992[28]	Maze T1	NR	NR	2.069 ± NR	NR	NR	0.287 ± NR	0.0001
		Maze T2	NR	NR	1.933 ± NR	NR	NR	1.733 ± NR	
		Maze T3	NR	NR	3.233 ± NR	NR	NR	1.867 ± NR	
		Maze T4	NR	NR	0.233 ± NR	NR	NR	-0.491 ± NR	
Memory									
			Intervention Group			**Control Group**			**p-value**
			Pre	**Post**	**Δ (post-pre)**	**Pre**	**Post**	**Δ (post-pre)**	
n-back task	Soga et al, 2015b[26]	RT (ms)	478.8 ± 94.6	425.1 ± 74.1	-53.7 ± 20.5	466.7 ± 113.3	414.2 ± 91.7	-52.5 ± 21.6	< 0.001
Sternberg Paradigm	Cooper et al, 2012[29]	Resp. Time (ms)	673.7 ± NR	666.4 ± NR	-7.3 ± NR	664.3 ± NR	673.7 ± NR	9.4 ± NR	0.01
		ACC (% of Correct Resp)	NR	NR	NR	NR	NR	NR	0.833
Letter Digit Span(LDS)	Budde et al, 2010[11]	Correct Resp, EG1_LP	9.9 ± 1.90	11.7 ± 2.94	1.8 ± 1.74	11.2 ± 1.16	12.8 ± 3.61	1.6 ± 3.42	0.01
		Correct Resp, EG2_LP	10.4 ± 1.42	12.6 ± 3.10	2.2 ± 3.48	11.2 ± 1.16	12.8 ± 3.61	1.6 ± 3.42	0.077
		Correct Resp, EG1_HP	14.4 ± 2.06	14.9 ± 2.57	0.5 ± 2.52	14.5 ± 0.98	14.3 ± 2.66	- 0.2 ± 2.09	NS
		Correct Resp, EG2_HP	14.2 ± 0.91	13.2 ± 2.81	-1.0 ± 2.50	14.5 ± 0.98	14.3 ± 2.66	- 0.2 ± 2.09	NS

Immediate recall of item list	Gu et al, 1992[28]	Working Memory T1	NR	NR	0.259 ± NR	NR	NR	-0.007 ± NR	0.027
		Working Memory T2	NR	NR	0.290 ± NR	NR	NR	0.035 ± NR	
		Working Memory T3	NR	NR	-0.176 ± NR	NR	NR	-0.273 ± NR	
		Working Memory T4	NR	NR	0.222 ± NR	NR	NR	−4.2 ± 6.8	
Attention and Concentration									
D2 Test	Budde et al, 2008[11]	Sustained Attention (% errors)	8.0 ± 4.2	4.0 ± 3.0	43 .2± 47.1	7.3 ± 4.2	5.8 ± 2.8	10.5 ± 36.7	<0.01
		Concentration (correct resp.)	97.4 ± 8.9	107.3 ± 7.7	10.6 ± 7.6	99.5 ± 10.1	103.3 ± 8.7	4.2 ± 6.8	< 0.01
		Working Speed (total no. of resp)	413.6 ± 70.5	473.1 ± 64.9	15.7 ± 12.7	430.4 ± 77.7	452.1 ± 63.2	6.4 ± 12.5	<0.01
Cognitrone Test	Zervas et al, 1991[10]	Correct Response TB	20.7 ± 1.9	23.4 ± 0.7	11.42%	22.4 ± 0.8*	23.0 ± 1.0*	2.30%	<0.02
		Correct Resp. UTB	22.0 ± 1.3	23.3 ± 1.3	5.52%				
		Wrong Resp. TB	3.9 ± 2.2	3.6 ± 2.9	NR	3.5 ± 1.7*	3.0 ± 1.0*	NR	NS
		Wrong Resp. UTB	4.6 ± 1.7	3.4 ± 3.9	NR				
		Decision Time in TB (ms)	139 ± 4	145 ± 14	NR	142 ± 15*	126 ± 13*	NR	NS
		Decision Time in UTB (ms)	125 ± 17	128 ± 12	NR				
Visuo-motor Speed									

			Intervention Group			Control Group			p-value
			Pre	Post	Δ (post-pre)	Pre	Post	Δ (post-pre)	
Visual Search Test (Baseline)	Cooper et al, 2012[29]	Resp. Time (ms)	610 ± NR	615 ± NR	5 ± NR	605 ± NR	625 ± NR	20 ± NR	0.131
		ACC (% of Correct Resp)	94.4 ± NR	93.2 ± NR	-1.2 ± NR	95.8 ± NR	93.8 ± NR	-2 ± NR	0.499
Visual Search Test (Complex)		Resp. Time (ms)	2620 ± NR	2180 ± NR	-440 ± NR	2220 ± NR	2090 ± NR	-130 ± NR	<0.001
		ACC (% of Correct Resp)	97.9 ± NR	93.9 ± NR	-4 ± NR	96.0 ± NR	93.8 ± NR	-2.2 ± NR	0.046
Logical Sequencing									
Logical Sequence Test	Gu et al, 1992[28]	Sequence T1	NR	NR	1.259 ± NR	NR	NR	0.119 ± NR	0.149
		Sequence T2	NR	NR	0.183 ± NR	NR	NR	0.533 ± NR	
		Sequence T3	NR	NR	-0.235 ± NR	NR	NR	-0.280 ± NR	
		Sequence T4	NR	NR	2.717 ± NR	NR	NR	2.439 ± NR	

Spanish Overall and Factorial Intelligence Test (IGF-M)

			Intervention Group			Control Group			p-value
			Pre	Post	Δ (post-pre)	Pre	Post	Δ (post-pre)	
Standardised general ability test	Ardoy et al, 2014[24]	EG1 Overall Score (100)	54.9 ± 6.8	53.9 ± 6.3	-8.4 ± 4.0	47.4 ± 6.4*	39.4 ± 6.3*	-11.8 ± 4.6*	NS
		EG2 Overall Score (100)	62.7 ± 6.5	84.9 ± 4.5	21.2 ± 4.2				<0.001

Data presented as mean ± standard deviation: (ACC): accuracy; (EG): experimental group; (HP): high performer; (LP): low performer; (ms): milliseconds; (NR): not reported; (NS): not significant; (no.): number; (Resp.): response; (RT): reaction time; (SD): standard deviation; (T): time point; (TB): trained boys; (UTB) untrained boys; (Δ): change; (%): percentage

* Values for control group only, note that in these cases there is one control group and two exercise intervention groups.

Table A4: Effect of exercise on academic performance

Type of Academic Test	Author	Test parameters	Rest	Exercise	Δ (ex-rest)	p-value
2mins Arithmetic Task	Travlos, 2010[25]	Speed (ans), FP	63.0 ± 7.5	71.2 ± 8.3	8.2 ± 0.8	< 0.001
		Speed (ans), TP	63.9 ± 6.1	72.3 ± 7.3	8.4 ± 1.2	< 0.001
		Speed(ans), FfP	65.2 ± 11.4	75.8 ± 9.9	10.6 ± 1.5	< 0.001
		Speed(ans), SP	62.6 ± 10.8	57.8 ± 9.7	-4.8 ± 1.1	< 0.005
		Speed(ans), mean	63.7 ± 9.0	69.3 ± 11.0	5.6 ± 2.0	< 0.001
		ACC, FP	60.0 ± 8.0	68.2 ± 8.7	8.2 ± 0.7	< 0.001
		ACC, TP	61.1 ± 6.4	69.8 ± 7.0	8.7 ± 0.6	< 0.001
		ACC, FfP	62.7 ± 11.2	73.6 ± 9.7	10.9 ± 1.5	< 0.001
		ACC, SP	59.6 ± 11.3	54.3 ± 10.5	-5.3 ± 0.8	< 0.005
		ACC, mean	60.9 ± 9.2	66.5 ± 11.5	5.6 ± 2.3	< 0.001

			Intervention Group Δ (post-pre)	Control Group Δ (post-pre)	p-value
Arithmetic	Gu et al, 1992[28]	Arithmetic T1	2.000 ± NR	-0.167 ± NR	0.053
		Arithmetic T2	0.100 ± NR	0.661 ± NR	
		Arithmetic T3	0.833 ± NR	1.383 ± NR	
		Arithmetic T4	1.4 ± NR	1.4 ± NR	

			Intervention Group			Control Group			p-value
			Pre	Post	Δ (post-pre)	Pre	Post	Δ (post-pre)	
School-based Academic Performance	Ardoy et al, 2014[24]	EG 1 Overall Subjects mean (10)	5.0 ± 1.5	4.9 ± 2.0	-0.1 ± 0.5	6.1 ± 0.8*	6.0 ± 0.4*	-0.2 ± 0.4*	NS
		EG 2 Overall Subjects mean (10)	6.2 ± 1.9	6.6 ± 1.9	0.5 ± 0.5				0.001

Data presented as mean ± standard deviation: (ACC): accuracy; (ans); number of answers completed; (ex): exercise; (FfP) after fifth period; (FP): after first period; (NR): not reported; (NS): not significant; (SD): standard deviation; (SP): after sixth period; (T): time point; (TP): after third period; (Δ): change;

* Values for control group only, note that in these cases there is one control group and two exercise intervention groups.

Table A5: Effect size calculations

Cognitive domains	Type of cognitive test	Author and outcome measure of cognitive test	p-value	ES Hedge's g	95% Confidence Interval	Size of effect	Outcome ES favours (exercise/rest)
Executive function	Eriksen Flanker Paradigm	Hogan HF_Con	0.000	1.90	1.13 to 2.90	large	exercise
		Hogan HF_InCon	0.003	0.86	0.31 to 1.52	moderate	exercise
		Hogan LF_Con	0.000	-1.92	-2.92 to -1.95	large	rest
		Hogan LF_InCon	0.000	-1.44	-2.27 to -0.78	large	rest
		Stroth HF_Con	0.036	0.52	0.04 to 1.05	small	exercise
		Stroth HF_InCon	0.250	0.27	-0.20 to 0.77	small	exercise
		Stroth LF_Con	0.067	-0.46	-1.00 to 0.03	small	rest
		Stroth LF_InCon	0.154	-0.35	-0.87 to 0.14	small	rest
	Go/NoGo Task	Hogan HF_Go	0.026	0.60	0.08 to 1.18	moderate	exercise
		Hogan HF_NoGo	0.033	-0.57	-1.15 to -0.05	small	rest
		Hogan LF_Go	0.000	-1.61	-2.49 to -0.91	large	rest
		Hogan LF_NoGo	0.000	1.63	0.93 to 2.53	large	exercise
		Stroth HF_Go	0.927	-0.02	-0.50 to 0.45	small	rest
		Stroth HF_NoGo	0.470	-0.17	-0.66 to 0.30	small	rest
		Stroth LF_Go	0.344	-0.23	-0.74 to 0.26	small	rest
		Stroth LF_NoGo	0.157	-0.35	-0.87 to 0.14	small	rest
Working memory	n-back Task	Soga RT	0.965	-0.012	-0.57 to 0.54	trivial	rest
	Letter Digit Span	Budde LP_EG1	0.531	0.29	-0.61 to 1.18	small	exercise
		Budde LP_EG2	0.461	0.32	-0.53 to 1.16	small	exercise
		Budde HP_EG1	0.875	0.07	-0.76 to 0.89	small	exercise
		Budde HP_EG2	0.644	-0.19	-1.02 to 0.63	small	rest
Attention and Concentration	D2 Test	Budde SusAtt	0.001	0.68	0.27 to 1.08	moderate	exercise
		Budde Conc	0.000	0.91	0.49 to 1.32	moderate	exercise
		Budde WorkSpeed	0.000	0.78	0.37 to 1.19	moderate	exercise
	Cognitrone Test	Zervas Correct Resp	0.005	1.46	0.43 to 2.49	large	exercise
		Zervas Wrong Resp	0.849	-0.09	-0.99 to 0.82	small	rest
		Zervas Decision Time	0.003	-1.57	-2.62 to -0.53	large	rest

Academic	Arithmetic	Travlos Speed FP	0.004	0.962	0.31 to 1.61	moderate	exercise
		Travlos Speed TP	0.001	1.152	0.45 to 1.85	moderate	exercise
		Travlos Speed FfP	0.005	-0.919	-1.56 to -0.28	moderate	rest
		Travlos Speed SP	0.125	0.434	-0.12 to 0.99	small	exercise
		Travlos Speed mean	0.000	0.543	0.24 to 0.84	small	exercise
		Travlos ACC FP	0.005	0.911	0.27 to 1.55	moderate	exercise
		Travlos ACC TP	0.001	1.204	0.49 to 1.92	large	exercise
		Travlos ACC FfP	0.004	0.963	0.31 to 1.62	moderate	exercise
		Travlos ACC SP	0.112	-0.451	-1.01 to 0.11	small	rest
		Travlos ACC mean	0.001	0.523	0.23 to 0.82	small	exercise
Standardised General Ability Test	IGF-M Overall Score	Ardoy Cog EG1	0.002	1.059	0.38 to 1.74	moderate	exercise
		Ardoy Cog EG2	0.000	4.872	3.56 to 6.18	very large	exercise
School-based Academic Performance	Overall Subject Mean	Ardoy Acad EG1	1.000	0.000	-0.59 to 0.59	trivial	exercise
		Ardoy Acad EG2	0.292	0.327	-0.28 to 0.94	small	exercise

(Acad): Academic; (ACC): accuracy; (Cog): Cognition; (Con): congruent; (EG): experimental group; (FfP) after fifth period; (FP): after first period; (HF): higher fit; (HP): high performer; (IGF-M): Spanish Overall and Factorial Intelligence Test; (InCon): incongruent; (LF): lower fit; (LP): low performer; (Resp); response; (SP): after sixth period; (TP): after third period;

**Effect sizes (ES) were categorized as trivial (<0.02), small (0.02-0.6), moderate (0.6-1.2), large (1.2-2.0) and very large (>2.0)[23]. Positive ES favoured exercise while negative ES favoured rest.

CHAPTER 4

The effect of aerobic fitness and body composition on cognitive function and academic performance in high-achieving Singaporean male adolescents: A cross-sectional study

FOREWORD

After conducting a systematic review (Chapter 3) of the current literature pertaining to exercise, cognition and academic performance in the adolescent population, a key finding was that literature supporting the hypothesis that exercise can induce cognitive benefits remains limited with inconclusive evidence to support the hypothesis. Thus, a more in depth investigation into the relationship between exercise, cognition and academic performance was warranted. As such, this chapter examines the relationship between physical fitness, inclusive of both cardiorespiratory fitness as well as body composition status, a broad range of cognitive function, and academic performance to present a more holistic understanding of how adolescent fitness and cognition as well as academic performance are associated. This is important as adolescent studies in this research field remain largely limited. In the following chapters, only male participants were recruited to limit any potential confounders that the female menstrual cycle might have on cognition.

ABSTRACT

Objectives: To investigate whether aerobic fitness and body composition are correlated to better cognitive function (CF) and academic performance (AP) in adolescent schoolboys of South-East Asian ethnicity.

Design: Cross-sectional study examining the relationship of body composition (body mass index and waist/height ratio), maximal aerobic fitness ($\dot{V}O_2$peak) and daily physical activity levels to CF and AP in Singaporean adolescents.

Methods: Male participants ($n = 250$, mean age 15.1 ± 1.0 years) were recruited across two elite Singaporean high schools. Anthropometric measurements were taken to obtain body mass index (BMI), waist circumference and waist/height ratio (WtHR). $\dot{V}O_2$peak was estimated using the 20m Shuttle Run Test. Levels of habitual physical activity (PA) were assessed via the validated, self-reported Adolescent Physical Activity Questionnaire. Thinking, Feeling and Self-regulation domains of CF were assessed using the WebNeuro™ platform. Academic performance (verbal, numeracy, abstract reasoning) was assessed using the Australian Council for Educational Research General Ability Test (AGAT). The cohort was divided into separate sub-groupings based on the four parameters of BMI, WtHR, $\dot{V}O_2$peak and PA. Data were reported as z-scores or percentages. Effect size (ES, Hedges g) was calculated where possible.

Results: The majority of the participants had a normal BMI (70%), WtHR (85%), and healthy cardiorespiratory fitness (69%) and just over half (56%) were sufficiently active. BMI and WtHR were strongly correlated ($r = 0.90$, $p < 0.0001$). Academic performance (AP) for the cohort was high (~80-85%) across the three domains (verbal, numeracy, abstract) and was almost identical for all sub-groups, regardless of grouping parameter (BMI, WtHR, $\dot{V}O_2$peak, PA), with no significant differences between groups. The entire cohort also performed strongly on Thinking, with z-scores all positive (> 0). Scores for Feeling and Self-regulation, however, were poor across the cohort, with z-scores generally at -0.5 or less. Body composition had no effect on Thinking performance, but overweight and obese participants had poorer Feeling (depression, anxiety and stress) and Self-regulation (negativity bias, emotional resilience) scores. In contrast, participants with higher $\dot{V}O_2$peak and PA performed more poorly across Thinking domains, while these parameters had no effect on Feeling or Self-regulation domains.

Discussion: Contrary to our hypotheses, fitter and more active boys had poorer Thinking scores. Also, body composition did not have an effect on Thinking or Academic performance. Plausible explanations for our findings include our participants being from academically selective elite schools which prioritised academic performance, and as such it may be more difficult to observe significant changes in CF and AP. The findings for Feeling and Self-regulation domains of cognition were congruent with our hypotheses whereby overweight and obese boys had poorer scores. This adds to the limited literature on the relationship between body composition and cognition in the adolescent population. A concerning and unexpected finding from this study was that all participants had negative depression, anxiety, stress and negativity bias scores. It is possible that this trend could be attributed to a possible overemphasis on academic performance.

Conclusion: Body composition did not have an effect on the cognitive domain of Thinking nor on AP. Also amongst high-achieving adolescent schoolboys, the hypothesised positive relationship between physical fitness and cognition and AP did not hold true. The findings of this study add to the limited literature on body composition and cognition in the adolescent population.

Keywords: physical fitness, body mass index, executive function, thinking, well-being, school achievement

INTRODUCTION

The purported benefits of exercise on cognition has been garnering increased interest in the past decade.[1,2] Attention has focused on the neuroprotective and neuroproliferative effects of exercise, in particular aerobic exercise, on anatomical and physiological adaptations that improve cognition.[3] The notion that exercise can be a non-invasive and non-pharmacological benefit to cognition[4] has contributed to the proliferation of research in this field across multiple cohorts and age groups, including older adults with Alzheimer's disease,[5,6] school-aged children with obesity[7] or depression,[8] and patients recovering from traumatic brain injury.[9,10]

Meta-analyses in school-aged children (4-18 years)[11] and across the lifespan (6-90 years)[12] have indicated that although physical activity and exercise have been shown to be beneficial in all life stages,[13,14] early intervention might be important for the improvement and maintenance of cognitive health and function throughout the lifespan.[15,16] However, the World Health Organization (WHO)[17] found that more than 80% of school-aged adolescents (1.6 million 11-17 year olds across 146 countries) failed to meet the current recommendations of at least one hour of moderate-to-vigorous physical activity per day. There has also been a worldwide trend of increasing body mass index (BMI) in children and adolescents,[18] presenting with risk factors for later-life cardiovascular disease[19]. This is a major health concern. Furthermore, studies have found that overweight and/or obese students have differing prefrontal cortex structures[20] and reduced white matter integrity[21] as well as poorer cognitive[22-26] and academic[27-29] outcomes, compared with their normal-weight counterparts. Thus, in addition to physical activity and exercise, body composition is an important consideration in regard to cognition and academic performance in adolescents.

While the mechanisms through which exercise, and physical activity more generally, confer cognitive benefits have not been established, it has been hypothesised that they stimulate the upregulation of brain-derived neurotrophic factor (BDNF),[30-32] which is thought to increase neurogenesis and synaptogenesis, and promote neuronal survival.[33-38] A specific BDNF genetic polymorphism[39], the Val66Met Polymorphism (valine to methionine substitution at codon 66), has been implicated in differential gene expression linked to poorer memory[40] and information processing outcomes.[41] Thus, physically fitter individuals may have higher cognitive functioning through increased production of peripheral BDNF.

Systematic reviews have reported increased peripheral BDNF after a bout of acute aerobic exercise[42,43], mixed results after chronic exercise[43,44] and no effect after resistance exercise[42,44]. A recent systematic review in adolescents concluded that chronic exercise intervention groups showed significant improvements in BDNF levels compared with controls.[45] Because adolescence is a period in human life where neuroplasticity has been observed in the volume of both the prefrontal cortex[46] and hippocampus,[47] it is an opportune period to examine the impact that exercise and physical activity may have on cognition. Moreover, since cognitive function has been thought to be correlated with academic performance in students,[48-51] examining the effects of exercise and physical activity on academic performance as well as cognition would provide a holistic understanding of how lifestyle habits may impact an adolescent's school life.

The aim of this study, therefore, was to investigate the effects of physical activity, aerobic fitness and body composition on cognitive function and academic performance in adolescent males. The study hypothesised that students with higher levels of physical activity and aerobic fitness would have better cognitive function and academic performance than those who were less fit and active. Similarly, a healthy body composition, measured by BMI and waist circumference, was hypothesised to be positively associated with cognitive and academic performance, such that normal weight students and those deemed to have a healthy waist circumference would have better performance compared to overweight and obese students and those with excess central adiposity.

METHODS

Participants

Adolescent males (n=251) aged 12.6 to 17.4 years (mean age 15.1 ± 1.0 years) from two elite high schools in Singapore participated in this study. These academically selective schools are the two highest ranking high schools for boys in Singapore, being ranked first and fourth internationally among high schools providing the highest volume of graduates who received an admission offer from the University of Cambridge in 2015.[52] Both schools provided access and facilities to conduct the study, which was approved by the Human Research Ethics Committee of The University of Sydney (Protocol: 15419). Before taking part, both parents and participants were fully informed of the experimental protocol and gave written informed consent. Inclusion criteria were healthy adolescent boys aged 13-18 years or within one standard deviation of these age limits. Exclusion criteria were any medical condition which put participants at increased risk of injury or illness after submaximal physical exertion, colour blindness, any mental or physical impairment/injury and consumption of psychoactive substances. One participant was excluded due to colour blindness.

Procedure

The experiment was conducted in groups of 18-30 participants, in three one-hour sessions, over two weeks in each school. The order of the three sessions was standardised: anthropometric measurements, cognitive and academic testing, 20 m shuttle run test. Additional makeup sessions were scheduled within the same month.

Anthropometry and maturation measures

The height and weight of participants were measured to calculate BMI. Participants were further categorised as normal weight, overweight, obese and thin according to the age- and sex-specific cut-offs of the International Obesity Task Force (IOTF).[53,54] Sitting height (height from the vertex of the head to the seated buttocks) was used to calculate leg length (total height minus sitting height), which in turn was used to compute the age of peak height velocity (APHV),[55] a measurement used to identify the approximate age of peak pubertal growth in participants. Waist circumference was measured at the mid-point between the lowest rib and the iliac crest, in accordance with International Diabetes Federation guidelines, to provide an indication of body fat composition using waist/height ratio (WtHR). Participants were classified into either a "normal" group or an "excess central adiposity" (ECA) group based on the cut-off of Garnett et al.[56] All measurements were carried out in duplicate by the same researcher to ensure consistency. A third measurement was taken if the difference between the two measurements exceeded 1%.

Aerobic fitness and physical activity measures

The 20 m shuttle-run test[57] was used to determine the peak aerobic capacity ($\dot{V}O_2$ peak) of participants. The test was carried out in the indoor sports gymnasium at both schools. Participants were classified into two aerobic fitness groups, "Healthy Fitness Zone" (HFZ) and "Needs Improvement Zone" (NIZ), based on the age and sex-specific cut-offs provided in a cross-sectional study in participants 8-18 years.[58]

Participants were asked to complete a validated self-reported questionnaire (Adolescent Physical Activity Questionnaire, APARQ)[59] in order to identify their average daily physical activity (PA) levels across a week. Participants were then classified into either a "Sufficiently Active" group (SA) if they participated in more than 60 minutes of moderate to vigorous physical activities daily, or alternatively, an "Insufficiently Active" group (IA).

Cognitive testing

Cognitive function was assessed using WebNeuro™ (©Brain Resource Company), a web-based battery of cognitive tasks designed to assess participants in the domain of Thinking, and two questionnaires to assess the domains of Self-regulation and Feeling. Collectively, the WebNeuro™ platform serves as a validated assessment method and protocol for the quantification of brain function with well-established validity, reliability, cross-cultural consistency and norms.[60-65] The respective subdomains were as follows:

- Thinking - response variability, impulsivity, sustained attention, information processing, memory, executive function;
- Self-regulation - negativity bias, emotional resilience, social skills; and
- Feeling - depression, anxiety, stress.

Participants were given 45 minutes to complete all tests and all participants completed within this time.

The Thinking domain, defined as the selective awareness of information processing allowing one to know and remember, consisted of nine tasks (motor tapping, choice reaction time, memory recognition, digit span forward, verbal interference, switching of attention, go/no-go, continuous performance test, maze). Results from the verbal interference task (Stroop test) were excluded from statistical analyses due to a poor compliance rate from participants during the test, despite the given instructions. The domain of Feeling, defined as the conscious experience of emotions that relies on the feedback from body reactions, was assessed using the DASS (Depression, Anxiety & Stress Scale)[60] questionnaire. It encompassed the three sub-domains of depressed mood - ranging from feeling extremely low (lower scores) to an absence of sadness (higher scores); anxiety - ranging from feeling extreme worry or panic (lower scores) to an absence of worry (higher scores); stress - ranging from feeling extremely irritable and jumpy (lower scores) to feeling calm (higher scores). The domain of Self-regulation involved the shaping and planning of an individual's thinking and emotion over time to maximise their well-being and was assessed via the BRISC (Brief Risk-Resilience Index for Screening)[61] scale, a 10-minute screening questionnaire. It encompassed the three sub-domains of negativity bias - a measure of cognitive bias toward negative (lower scores) versus positive (higher scores) appraisal of oneself and situations; emotional resilience – the capacity for coping and feeling confident, with self-esteem and self-efficacy; and social skills – the capacity for building and keeping relationships, associated with extraversion and empathy.

Normalised scores (z-scores) were presented for all cognitive domains. In each domain, the scores for the different tests were averaged to provide an overall normalised (z) score. Positive z-scores indicated strengths, negative scores indicated potential deficits (for impulsivity, positive scores reflected less impulsive behaviour whereas negative scores reflect more impulsive behaviour), while scores beyond ±2 were statistically significant.

Academic testing

Academic performance was assessed using the Australian Council for Educational Research General Ability Test (AGAT), a web-based test of three reasoning skill components: verbal, numeracy and abstract (visual). Scores were presented as percentages.

Statistical analyses

The study hypotheses were tested by comparing among the four groupings based on BMI (normal weight, overweight, obese and thin), WtHR (normal, ECA), aerobic fitness (HFZ, NIZ) and the APARQ (SA, IA). Statistical analyses were carried out using IBM® SPSS® Statistics (v.22) and Statistica (v.13, TIBCO Software Inc.).

One-way factorial analyses of variance (ANOVAs) were used to compare baseline characteristics of participants in age, maturation, anthropometry and aerobic fitness. ANOVAs also were used to compare outcome measures of cognitive function and academic performance across the BMI, WtHR, aerobic fitness and PA groups. In these analyses, there was one group factor based on the participant groupings listed above, and several repeated measures factors based on the subdomains for the cognitive and academic testing listed above. Tukey *post hoc* tests were carried to identify the locus of any significant effects observed in the omnibus tests.

Data extracted were reported as mean ± standard deviation (SD). Comprehensive Meta-Analysis (CMA) Software (Biostat Inc. Englewood, New Jersey, USA) was used to calculate effect sizes (ESs) and reported as standardised mean differences (SMDs). ES was determined by subtracting the mean in the normal weight, normal WtHR, HFZ or SA group from that in the respective other group(s) and dividing the difference by the pooled SD of both groups. ES was then corrected for small-sample bias using Hedges' g, reported with 95% confidence intervals (CIs), and categorised as trivial (<0.02), small (0.02-0.6), moderate (0.6-1.2), large (1.2-2.0) or very large (>2.0).[66] ESs favouring the normal weight, normal WtHR, HFZ or SA groups were reported as positive, while ESs favouring the other groups were reported as negative.

RESULTS

Participant characteristics

Participant characteristics are presented in Table 1. The majority of the 250 participants had a normal BMI (70%) and WtHR (85%), and were in the high fitness zone (69%). Of the 243 participants who completed the APARQ, just over half (56%) were sufficiently active. The age and maturation data indicated that, as a group, the participants had passed the age of peak pubertal growth.

Table 1. Participant Characteristics (n=250)

		Mean ± SD	p-value*
Age and maturation			
Decimal age (yrs)		15.1 ± 1.0	
Years from APHV (yrs)		1.2 ± 1.0	
Predicted age of puberty (yrs)		13.8 ± 0.7	
Anthropometric variables			
Height (m)		1.7 ± 0.1	
Weight (kg)		60.2 ± 12.2	
BMI ($kg.m^{-2}$)		20.8 ± 3.6	
	Normal weight (17.0 to 23.8): n =175 (70%)	19.9 ± 1.7	
	Overweight (23.0 to 28.2) : n = 39 (16%)	25.4 ± 1.4	<0.0001*
	Obese (28.4 to 36.0): n = 10 (4%)	31.2 ± 2.5	<0.0001*
	Thin (14.9 to 17.6): n = 26 (10%)	16.3 ± 0.7	<0.0001*
Waist circumference (cm)		74.1 ± 10.3	
WHtR		0.44 ± 0.06	
	Normal (0.22 to 0.50): n = 212 (85%)	0.42 ± 0.04	
	ECA (0.51 to 0.67): n = 38 (15%)	0.55 ± 0.04	<0.0001*
Aerobic Fitness			
$\dot{V}O_{2peak}$ ($ml.kg^{-1}min^{-1}$)		47.7 ± 5.6	
	HFZ (42.7 to 58.9): n = 173 (69%)	49.3 ± 3.7	
	NIZ (33.5 to 43.2): n = 77 (31%)	39.3 ± 2.8	<0.0001*
APARQ (n = 243)#			
Average weekly activities (METs/week)		5.7 ± 1.5	
	SA (3.6 to 11.1): n = 135 (56%)	6.1 ± 1.8	
	IA (3.5 to 8.5): n = 108 (44%)	5.2 ± 0.8	<0.0001*

$\dot{V}O_{2peak}$ was measured using the 20m shuttle run, BMI categories based on World Health Organization 2007 cut-offs for children and adolescents (age and gender specific). METs, defined as Metabolic Equivalents of the Task, is the amount of energy required to perform a specific task expressed as the ratio of work metabolic rate to a standard resting metabolic rate obtained during quiet sitting. *compared to normal weight, normal WtHR, HFZ or SA group. #7 participants did not complete the APARQ.

(APARQ): Adolescent Physical Activity Recall Questionnaire; (APHV): Age of Peak Height Velocity; (BMI): Body Mass Index; (ECA): Excess Central Adiposity; (HFZ): High Fitness Zone; (IA): Insufficiently Active; (NIZ): Needs Improvement Zone; (SA): Sufficiently Active; ($\dot{V}O_{2peak}$): Peak rate of Oxygen Consumption.

Aerobic fitness and physical activity as a function of body composition

Despite this high correlation between the two measures of body composition, BMI and WtHR (Table 2), it was decided to proceed with separate statistical analyses of the groups based on both classifications, because the BMI grouping identified participants who were below normal weight. Both BMI and WtHR were moderately negatively correlated with $\dot{V}O_{2peak}$ but not correlated with METs/week. Although METs/week and $\dot{V}O_{2peak}$ were only weakly though positively correlated, the SA group had significantly higher fitness than the IA group ($\dot{V}O_{2peak}$: 48.9 ± 4.7 vs 43.2 ± 5.0; $p < 0.0001$), while the HFZ group had significantly higher physical activity than the NIZ group (METs/week: 5.9 ± 1.6 vs 5.2 ± 1.1; $p < 0.0001$).

Table 2. Correlations (Pearson's r) between aerobic fitness and physical activity grouping variables

	BMI	WtHR	$\dot{V}O_{2peak}$	METs/week
BMI		0.90 (p < 0.0001)	-0.36 (p < 0.0001)	0.02 (p = 0.79)
WtHR			-0.40 (p < 0.0001)	0.01 (p = 0.87)
$\dot{V}O_{2peak}$				0.26 (p < 0.0001)

Cognitive function and academic performance as a function of BMI

Participants scored well across all Thinking domains, with mean z-scores above zero in each of the BMI groups (Figure 1). Contrary to the study hypothesis, there were no significant overall differences in scores across the domains between participants in the four BMI categories ($F_{3,246} = 0.09$, $p = 0.97$, $\eta^2 < 0.001$), nor was there any interaction between BMI groups and thinking domains ($F_{18,1476} = 0.82$, $p = 0.67$, $\eta^2 = 0.01$).

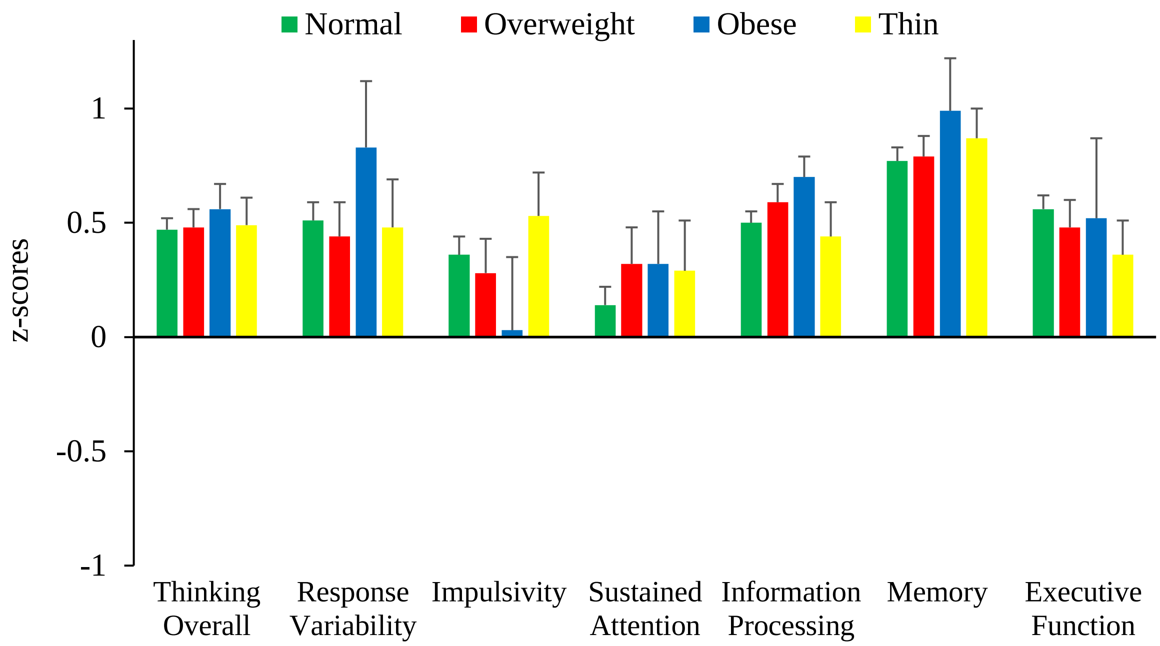


Figure 1: Group mean (± standard error) z-scores for the thinking domains in the BMI groups.

The entire cohort scored poorly on the Feeling tests, with scores below zero across all domains (Figure 2). The overweight and obese groups were especially poor, scoring below -1 on most domains, with the obese group scoring below -2 on anxiety. The thin group scored below the normal weight group but above the overweight and obese. These patterns were reflected in a significant overall difference between the BMI groups across all domains ($F_{3,246} = 4.12$, $p < 0.01$, $\eta_p^2 = 0.06$), where follow-up pairwise group comparisons showed, in line with the study hypothesis, that the normal weight group scored significantly better than the overweight ($F_{1,212} = 12.49$, $p = 0.001$, $\eta_p^2 = 0.06$) and obese ($F_{1,183} = 6.28$, $p = 0.013$, $\eta_p^2 = 0.03$) groups, though not the thin group ($F_{1,199} = 1.05$, $p = 0.31$, $\eta_p^2 = 0.005$). Univariate tests showed that the normal weight group scored significantly higher than the overweight group on feeling overall ($p < 0.001$), depression ($p < 0.0001$), anxiety ($p = 0.01$) and stress ($p < 0.01$); and significantly higher than the obese group on feeling overall ($p = 0.013$), anxiety ($p = 0.009$) and stress ($p = 0.006$), but not depression ($p = 0.29$). The effect sizes calculated for the significant effects are shown in the appendices (Table A1).

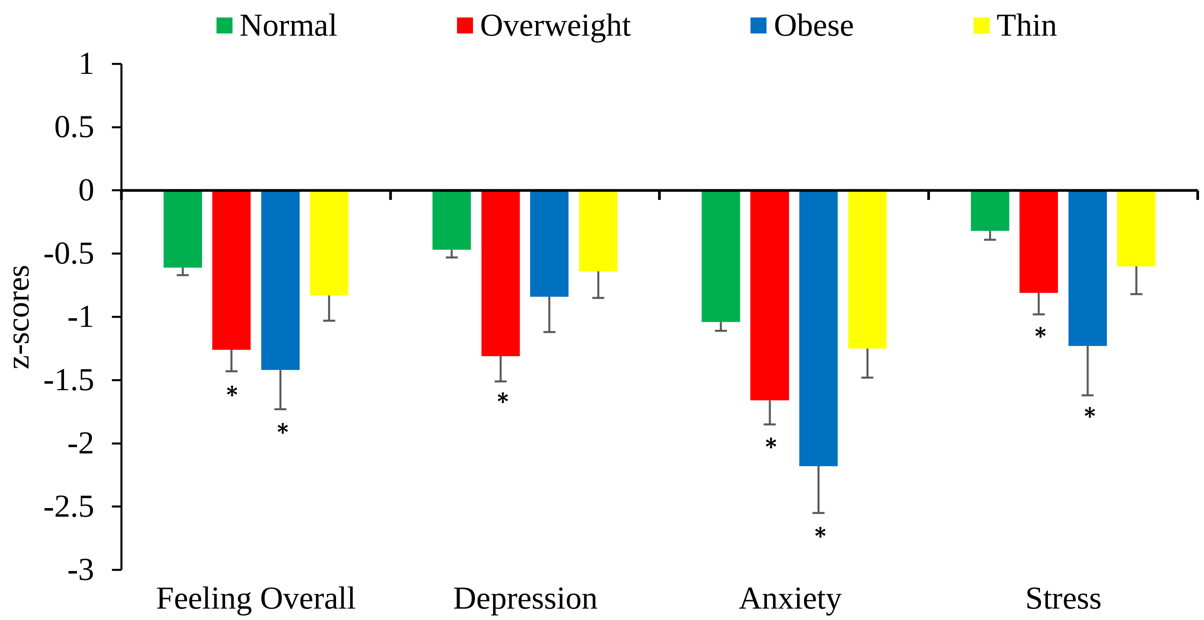


Figure 2: Group mean (±SE) z-scores for the feeling domains in the BMI groups. * indicates significantly different from normal weight group on univariate tests.

All BMI groups scored within the normal range (±1) in Self-regulation overall, emotional resilience and social skills, but all were well below the normal range (< -2) for negativity bias (Figure 3). There was a significant overall difference between the BMI groups across all domains ($F_{3,246} = 4.05$, $p = 0.008$, $\eta_p^2 = 0.05$). Follow-up pairwise group comparisons showed, in line with the study hypothesis, that the normal weight group scored significantly higher across domains than the overweight group ($F_{1,212} = 11.65$, $p < 0.001$, $\eta_p^2 = 0.05$), though with no significant difference with the obese ($F_{1,183} = 1.22$, $p = 0.27$, $\eta_p^2 = 0.006$) or thin ($F_{1,199} = 0.10$, $p = 0.75$, $\eta_p^2 = 0.0005$) groups. Univariate tests in these comparisons showed that the normal weight group scored significantly higher than the overweight group on Self-regulation overall ($p < 0.001$), negativity bias ($p = 0.002$), emotional resilience ($p = 0.002$) but not social skills ($p = 0.47$). The effect sizes calculated for these significant effects are shown in the appendices (Table A1).

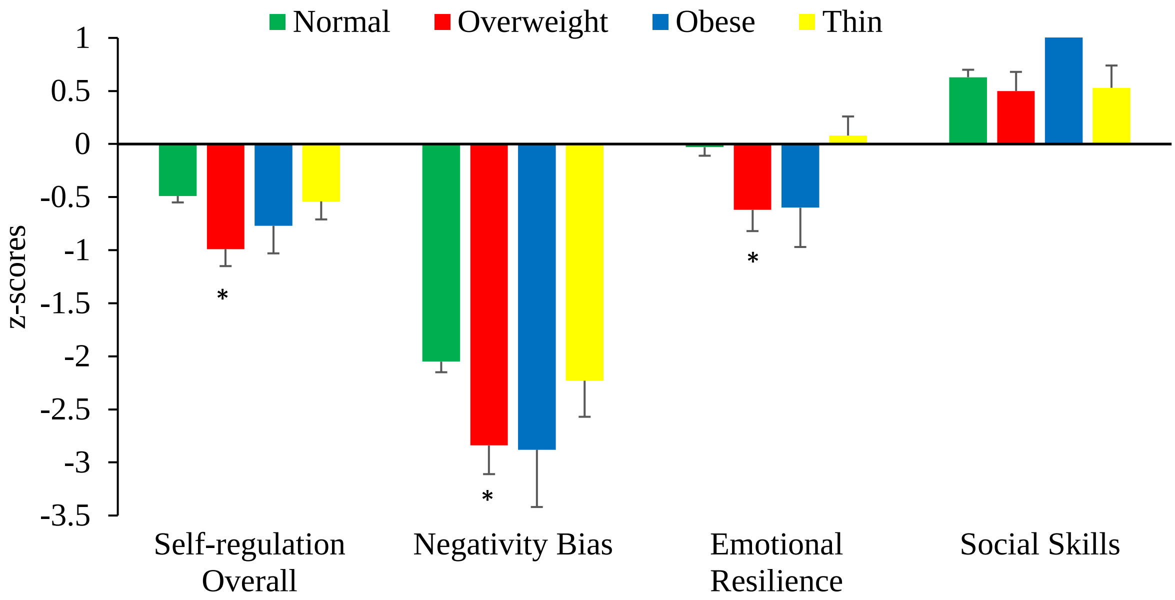


Figure 3: Group mean (±SE) z-scores for the Self-regulation domains in the BMI groups. * indicates significantly different from normal weight group on univariate tests.

All BMI groups scored highly on the AGAT, averaging close to or above 80% in all domains, with low within- and between-group variability (Figure 4). Contrary to the study hypothesis, there were no significant overall differences in scores across AGAT domains between participants in the four BMI categories ($F_{3,246} = 0.11$, $p = 0.96$, $\eta_p^2 = 0.001$), nor was there any interaction between BMI groups and domains ($F_{9,738} = 1.29$, $p = 0.24$, $\eta_p^2 = 0.02$). The effect sizes calculated for these significant effects are shown in the appendices (Table A1).

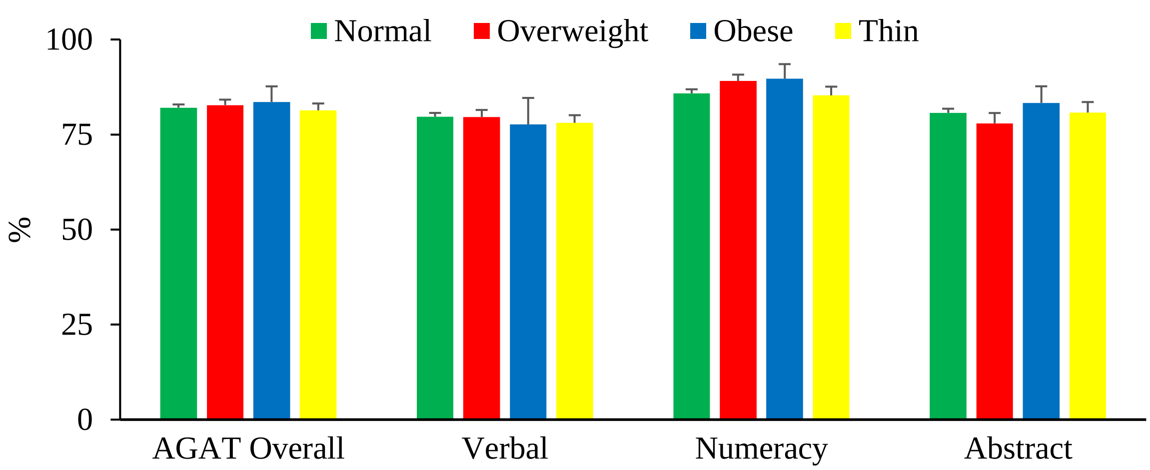


Figure 4: Mean (±SE) BMI group scores for the AGAT domains.

Cognitive function and academic performance as a function of WtHR

As with the BMI groups, the mean z-scores across Thinking domains for the two WtHR categories, ECA and normal, were all above positive (Figure 5). Again, contrary to the study hypothesis, there were no significant overall differences between the normal and ECA groups ($F_{1,248}$ = 0.20, p=0.66, η_p^2 = 0.0008), nor was there an interaction between groups and domains ($F_{6,1488}$ = 1.37, p = 0.22, = 0.005).

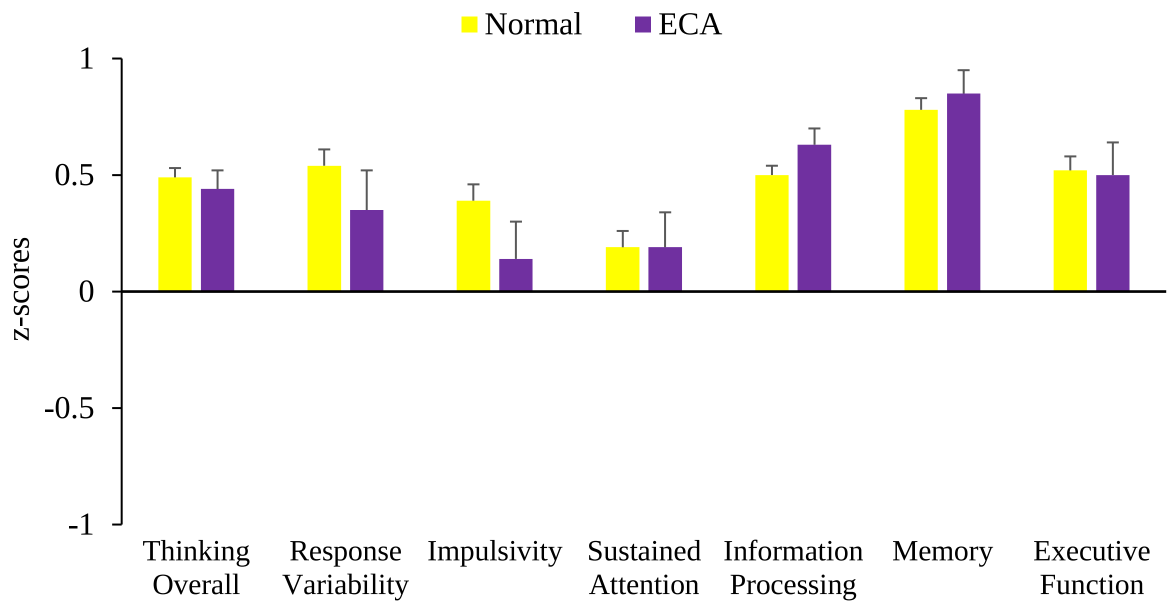


Figure 5: Mean (±SE) z-scores across the thinking domains for the WtHR groups. (ECA): Excess Central Adiposity

The Feeling scores for both WtHR groups were negative across all domains, but the ECA groups scored especially poorly, below -1 for all domains and below -2 for anxiety (Figure 6). This pattern was consistent with the study hypothesis and similar to that for the normal BMI groups compared with the overweight and obese groups. The pattern was reflected in a significant overall difference between the groups across all domains ($F_{1,248}$ = 28.73, p < 0.0001, η_p^2 = 0.10), with no significant interaction between groups and domains ($F_{3,744}$ = 1.06, p = 0.36, η_p^2 = 0.004). Univariate tests confirmed that the normal group scored significantly better than the ECA group on all domains (p < 0.0001). The effect sizes were moderate for Feeling overall, depression, and anxiety (ES = 0.79 to 0.92, p = 0.00 to 0.02), favouring participants in the ECA group (Table A3).

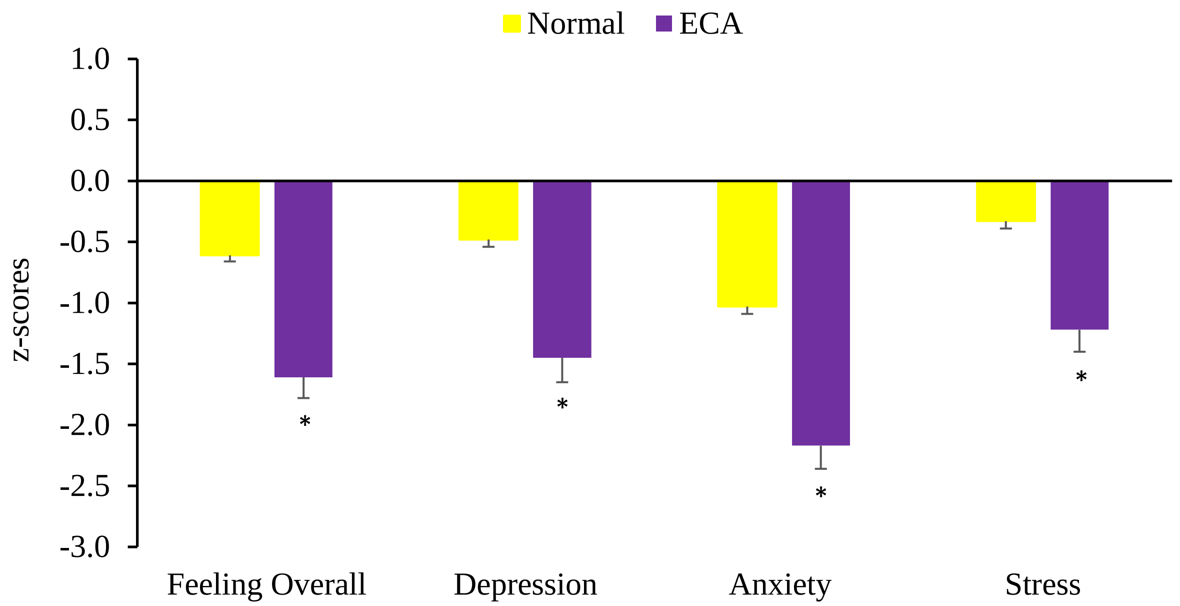


Figure 6: Mean (±SE) z-scores across the Feeling domains in the WtHR groups. * Significant group difference on univariate tests (all p < 0.0001). (ECA): Excess Central Adiposity

The normal group scored better in the Self-regulation domains than the ECA group (Figure 7), as shown by a significant overall group differences across domains ($F_{1,248} = 10.82$, $p = 0.001$, $\eta_p^2 = 0.04$), similar to the results for the normal BMI groups compared with the overweight and obese groups. As expected from the BMI groups, the scores for both groups were well below the normal range (< -2) for negativity bias. Post hoc tests on a significant interaction between groups and domains ($F_{3,744} = 12.09$, $p < 0.0001$, $\eta_p^2 = 0.05$) showed that the normal group was significantly better (less negative) than the ECA group (p < 0.0001). Univariate tests showed, in line with the study hypothesis, that the normal group scored significantly higher than the ECA group on Self-regulation overall (p < 0.01), negativity bias (p = 0.0001) and emotional resilience (p = 0.01), though not social skills (p = 0.37). Effect sizes were small for overall Self-regulation scores and moderate for negativity bias (ES = -0.58 to -0.77 [-0.23 to -1.12], p = 0.04 and 0.04), favouring participants in the normal group (Table A3).

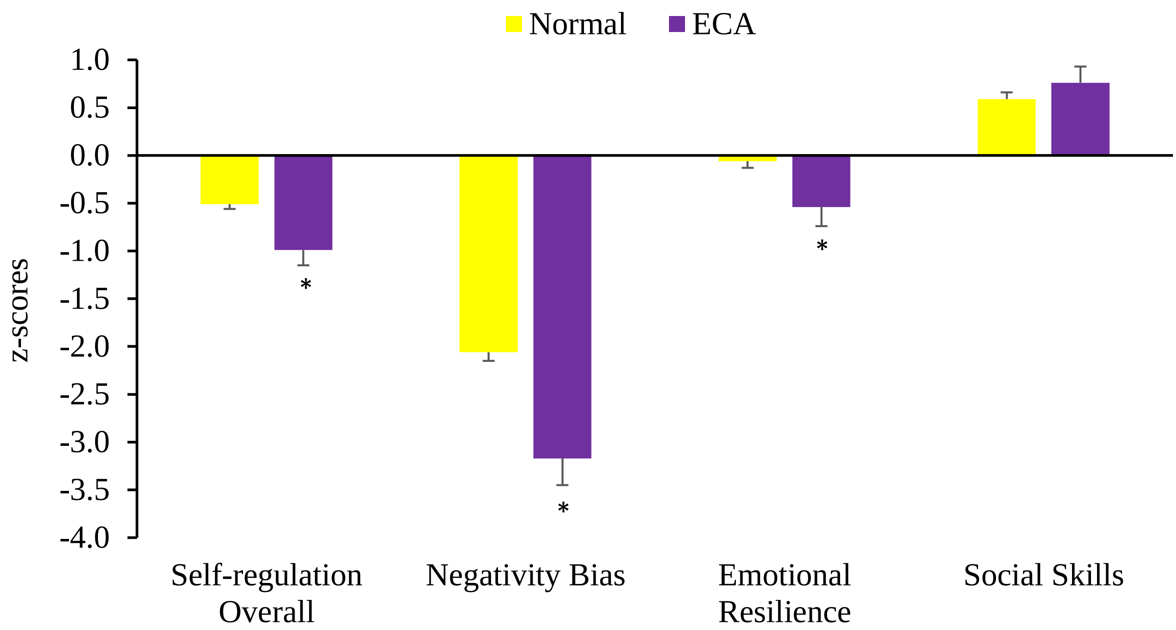


Figure 7: Mean (±SE) z-scores across the Self-regulation domains in the WtHR groups. * Significantly different from normal group on univariate tests ($p \leq 0.01$).

Both WtHR groups scored highly across all domains of the AGAT, with very low within- and between-group variability (Figure 8). Contrary to the study hypothesis, there were no significant overall group differences in scores across AGAT domains between participants in the WtHR groups ($F_{1,248} = 0.07$, $p = 0.79$, $\eta_p^2 = 0.0003$), nor was there any interaction between groups and domains ($F_{3,744} = 2.05$, $p = 0.11$, $\eta_p^2 = 0.008$).

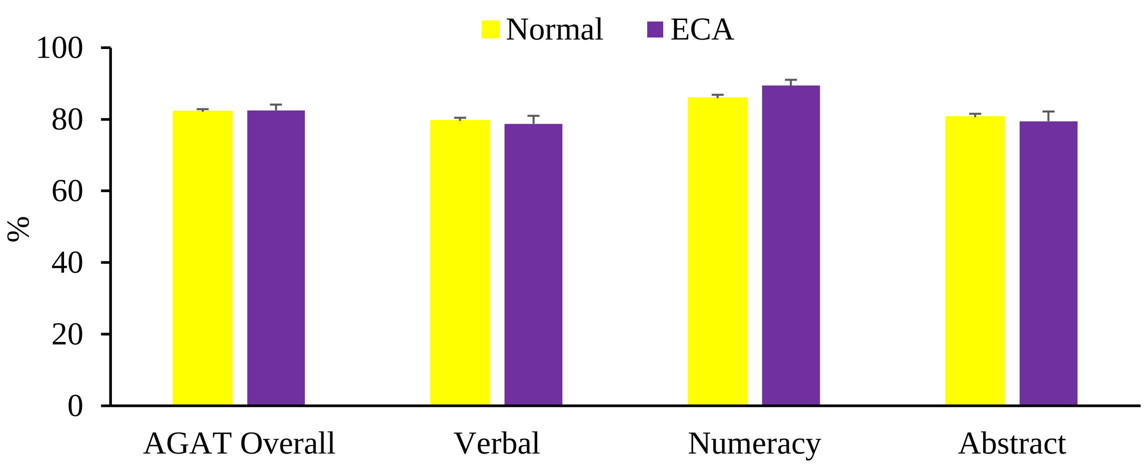


Figure 8: Mean (±SE) AGAT scores in the WtHR groups. (ECA): Excess Central Adiposity

Cognitive function and academic performance as a function of aerobic fitness

The mean z-scores across all Thinking domains were within the normal range (±1), and positive, in both fitness groups (Figure 9). Contrary to study hypothesis, the NIZ group scored significantly better overall than the HFZ group ($F_{1,248}$ = 4.62, p = 0.03, η_p^2 = 0.02), with no significant interaction between groups and domains ($F_{6,1488}$ = 0.57, p = 0.76, η_p^2 < 0.002). Thinking overall (ES = 0.30 [95% CI: 0.03 to 0.57], p = 0.03), information processing (ES = 0.47 [95% CI: 0.19 to 0.74], p = 0.0006) and memory (ES = 0.31 [95% CI: 0.04 to 0.58], p = 0.03) were significantly different on univariate tests. Effect size were small and favoured participants with lower aerobic fitness (NIZ) (Table A2).

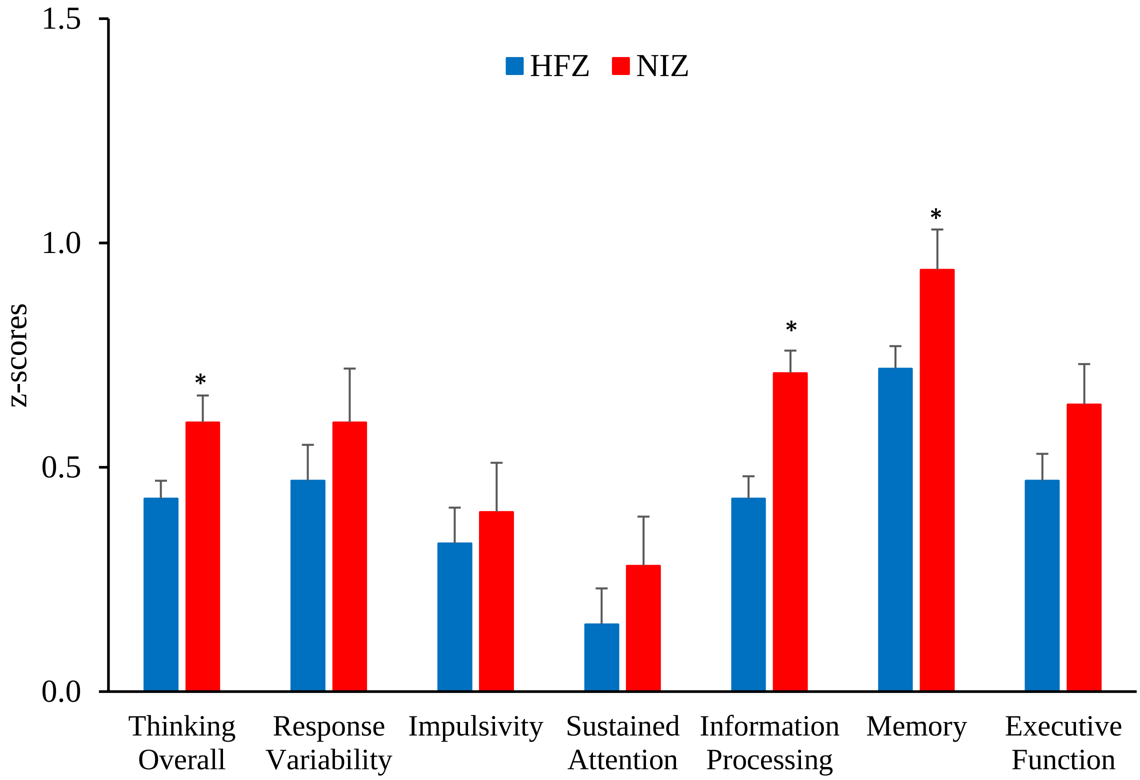


Figure 9: Mean (±SE) z-scores for Thinking domains in the fitness groups. * indicates significant group differences based on univariate tests. (HFZ): Healthy Fitness Zone; (NIZ): Needs Improvement Zone

Contrary to the study hypotheses, the Feeling domain scores were highly similar in both fitness groups (Figure 10), with no significant overall difference between groups ($F_{1,248}$ = 0.02, p = 0.90, η_p^2 = 0), nor any interaction between groups and domains ($F_{3,744}$ = 2.25, p = 0.08, η_p^2 = 0.009). Similar to the body composition groups results, Feeling scores for the fitness groups were all negative, at -0.5 or less.

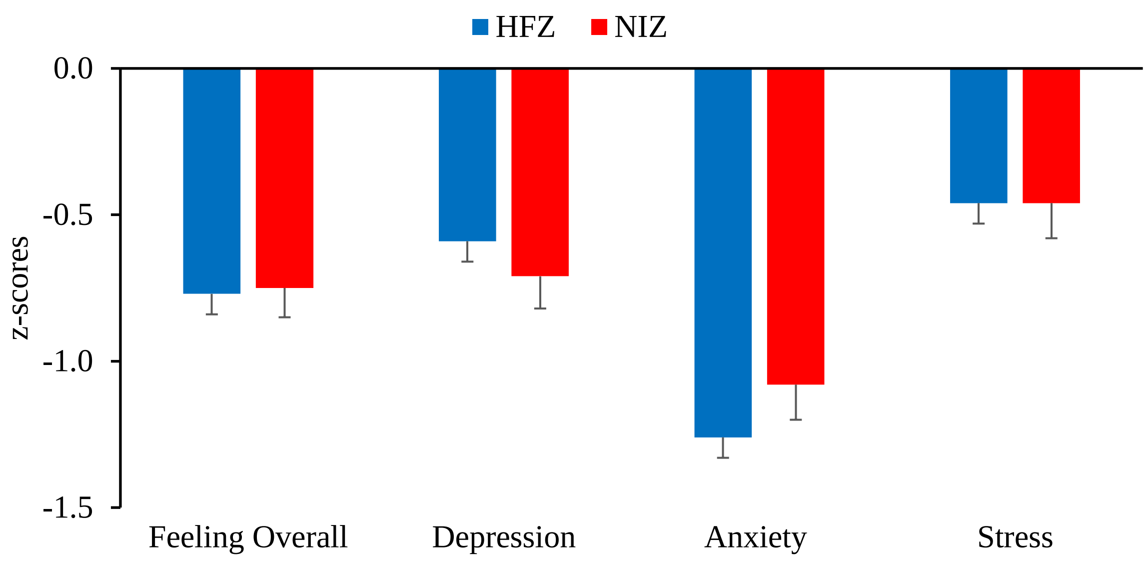


Figure 10: Mean (±SE) z-scores for Feeling domains in the fitness groups. Healthy Fitness Zone; (NIZ): Needs Improvement Zone

Similarly, the Self-regulation domain scores were highly similar in both fitness groups (Figure 11), with no significant overall difference between groups ($F_{1,248}$ = 1.85, p = 0.18, η_p^2 = 0.007), nor any interaction between groups and domains ($F_{3,744}$ = 0.60, p = 0.61, η_p^2 = 0.002). The scores for negativity bias in both groups were negative and outside the normal range (< -2).

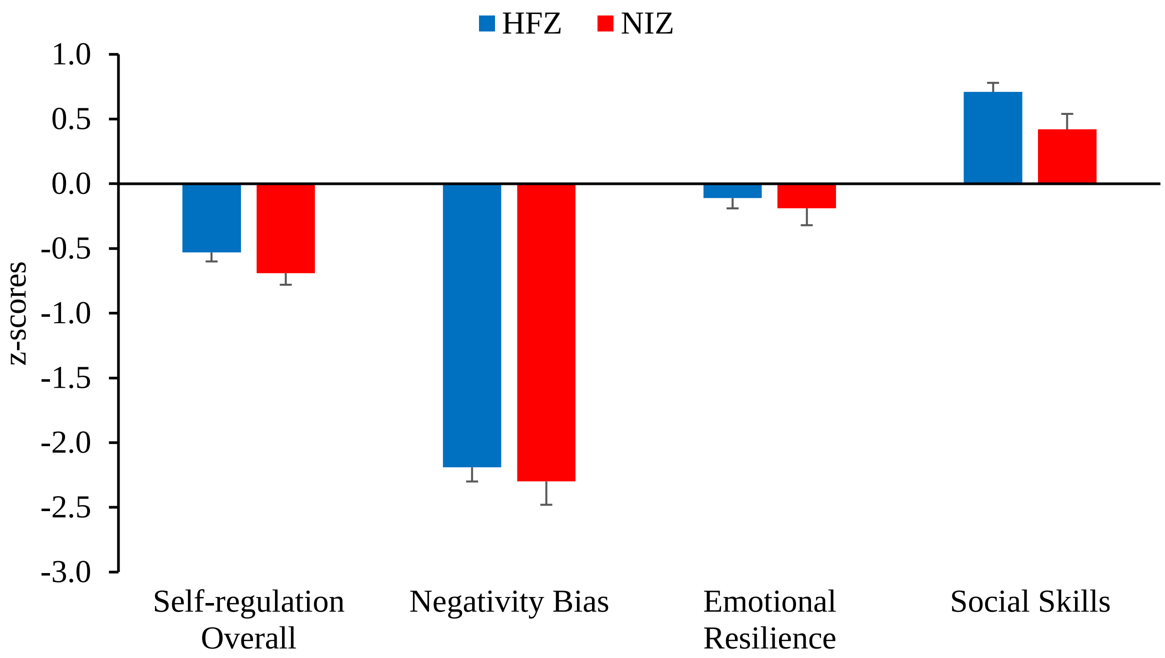


Figure 11: Mean (±SE) z-scores for Self-regulation domains in the fitness groups. Healthy Fitness Zone; (NIZ): Needs Improvement Zone

Both fitness groups scored highly (close to or above 80) on the AGAT, with closely similar domain scores and low within- and between-group variability (Figure 12). There was no significant overall difference between groups ($F_{1,248} = 0.24$, $p = 0.63$, $\eta_p^2 = 0.001$) and no interaction between groups and domains ($F_{3,744} = 1.16$, $p = 0.33$, $\eta_p^2 = 0.005$).

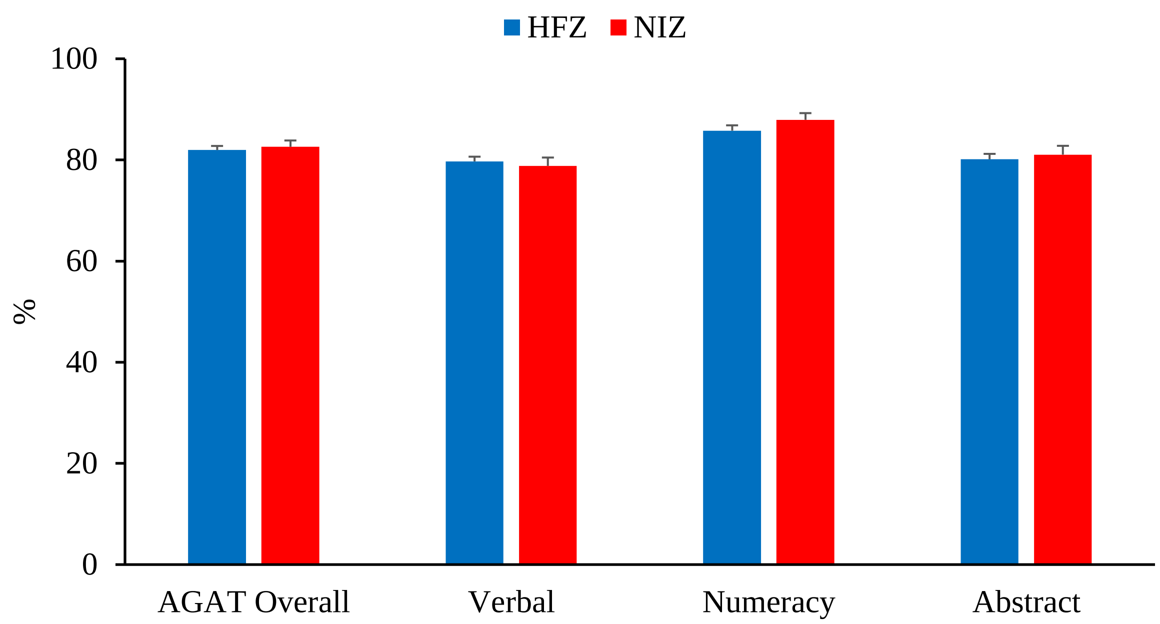


Figure 12: Mean (±SE) AGAT scores for the fitness groups. Healthy Fitness Zone; (NIZ): Needs Improvement Zone

Cognitive function and academic performance as a function of physical activity levels

The mean z-scores across all Thinking domains were within the normal range (±1), and above zero, in both physical activity groups (Figure 13). Contrary to study hypothesis, the IA group scored significantly better overall than the SA group ($F_{1,241}$ = 5.65, p = 0.02, η_p^2 = 0.02). There was no interaction between groups and domains ($F_{6,1446}$ = 1.29, p = 0.26, η_p^2 = 0.005). On univariate tests, IA scored significantly better on thinking overall (ES = 0.32 (0.06 to 0.57), p = 0.02), impulsivity (ES = 0.27 {0.02 to 0.53), p = 0.04) and sustained attention (ES = 0.28 (0.03 to 0.53), p = 0.04), with a trend towards a difference in memory (p = 0.05) and executive function (p = 0.06). Effect sizes were small favouring IA (Table A4).

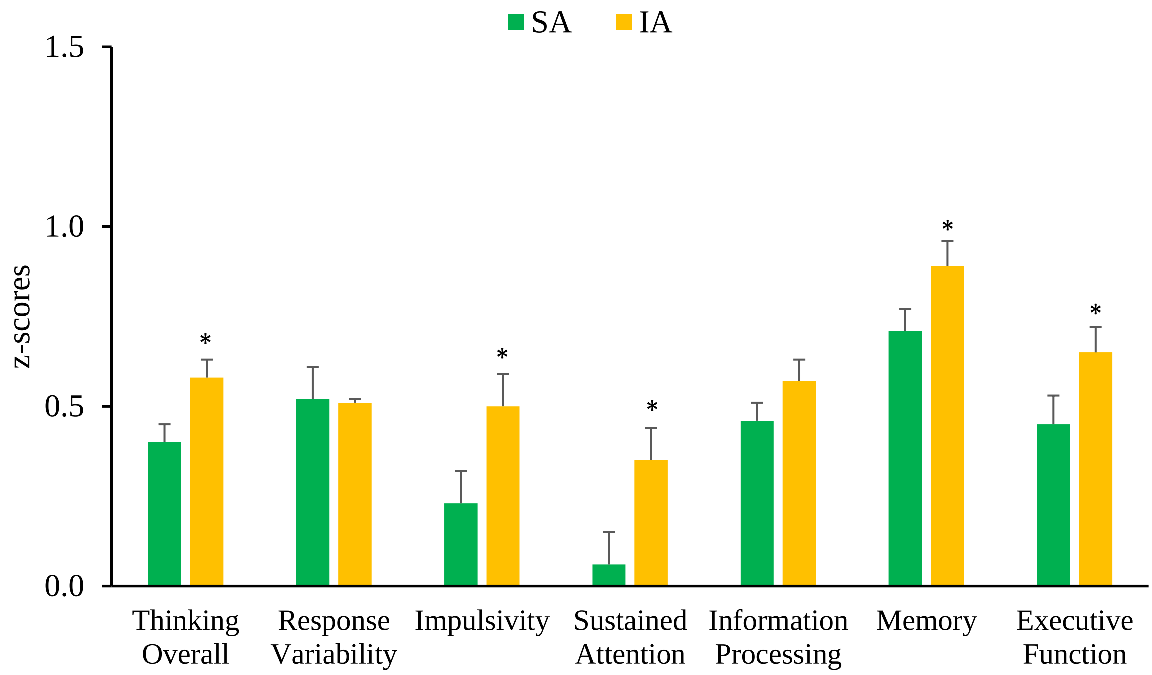


Figure 13: Mean (±SE) z-scores for Thinking domains in the physical activity groups. * indicates significant group differences on univariate tests.

The Feeling domain scores were similar in both physical activity groups (Figure 14), contrary to the study hypothesis, with no significant overall difference between groups ($F_{1,241} = 2.33$, $p = 0.13$, $\eta_p^2 = 0.01$), nor any interaction between groups and domains ($F_{3,723} = 1.40$, $p = 0.24$, $\eta_p^2 = 0.006$). Feeling scores were all negative, at -0.5 or less.

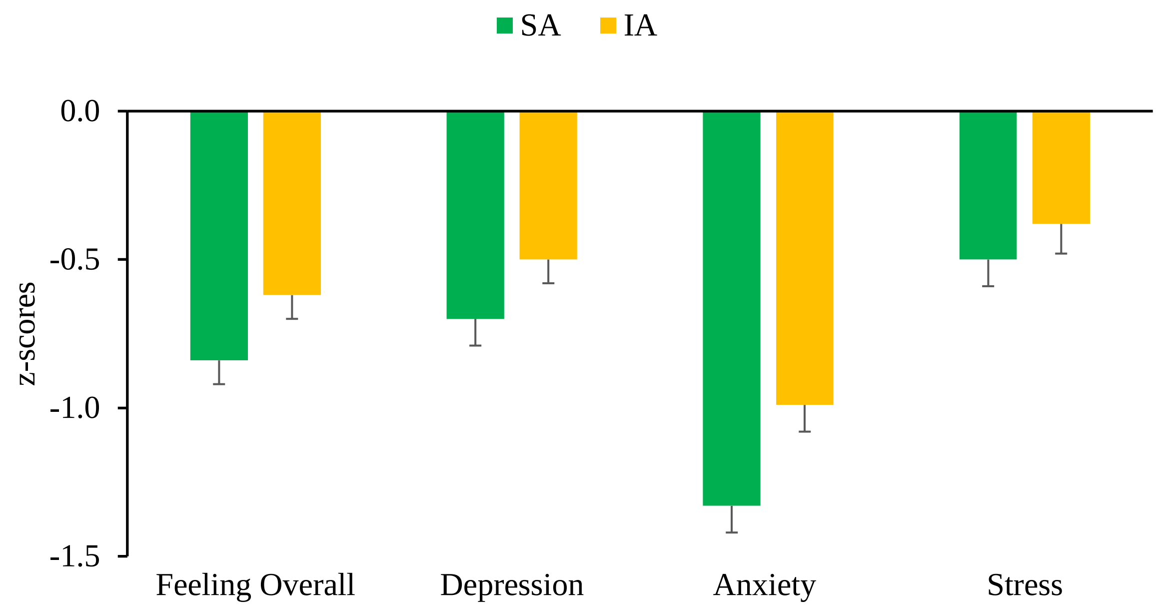


Figure 14: Mean (±SE) z-scores for Feeling domains in the physical activity groups.

The Self-regulation domain scores also were very similar in both physical activity groups (Figure 15), contrary to the study hypothesis, with no significant overall difference between groups ($F_{1,241} = 0.13$, $p = 0.72$, $\eta_p^2 = 0.0005$), nor any interaction between groups and domains ($F_{3,723} = 2.01$, $p = 0.11$, $\eta_p^2 = 0.008$).

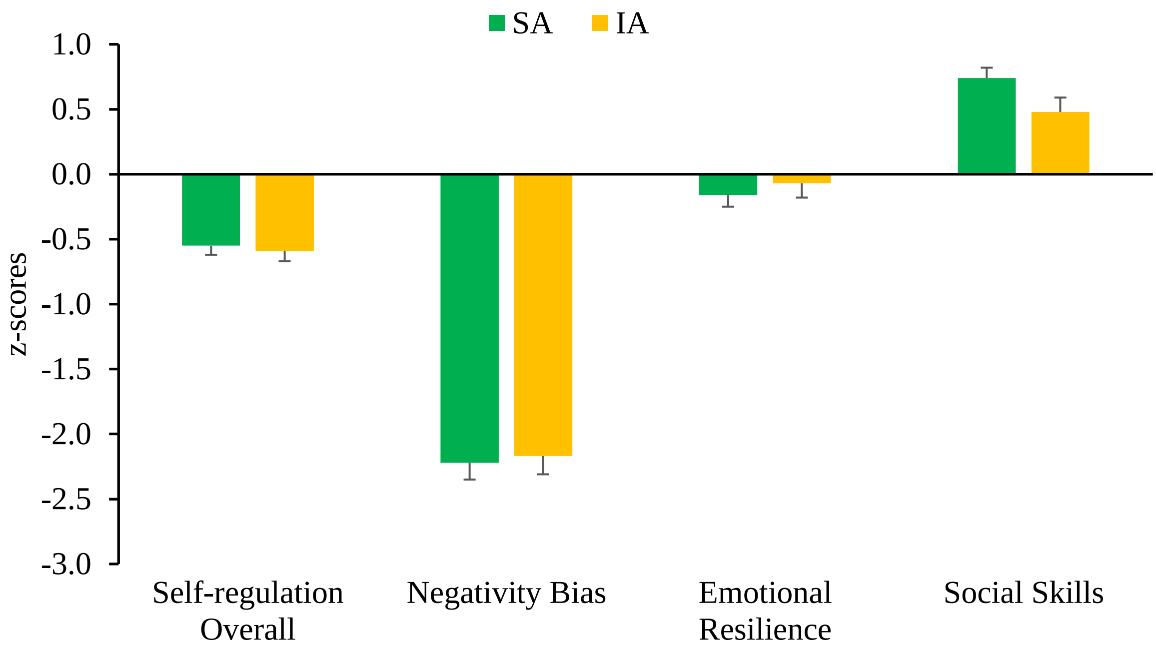


Figure 15: Mean (±SE) z-scores for Self-regulation domains in the fitness groups.

Both physical activity groups scored highly on the AGAT, with closely similar domain scores and low within- and between-group variability (Figure 16). There was no significant overall difference between groups ($F_{1,241} = 2.64$, $p = 0.11$, $\eta_p^2 = 0.01$) and no interaction between groups and domains ($F_{3,723} = 1.23$, $p = 0.30$, $\eta_p^2 = 0.005$).

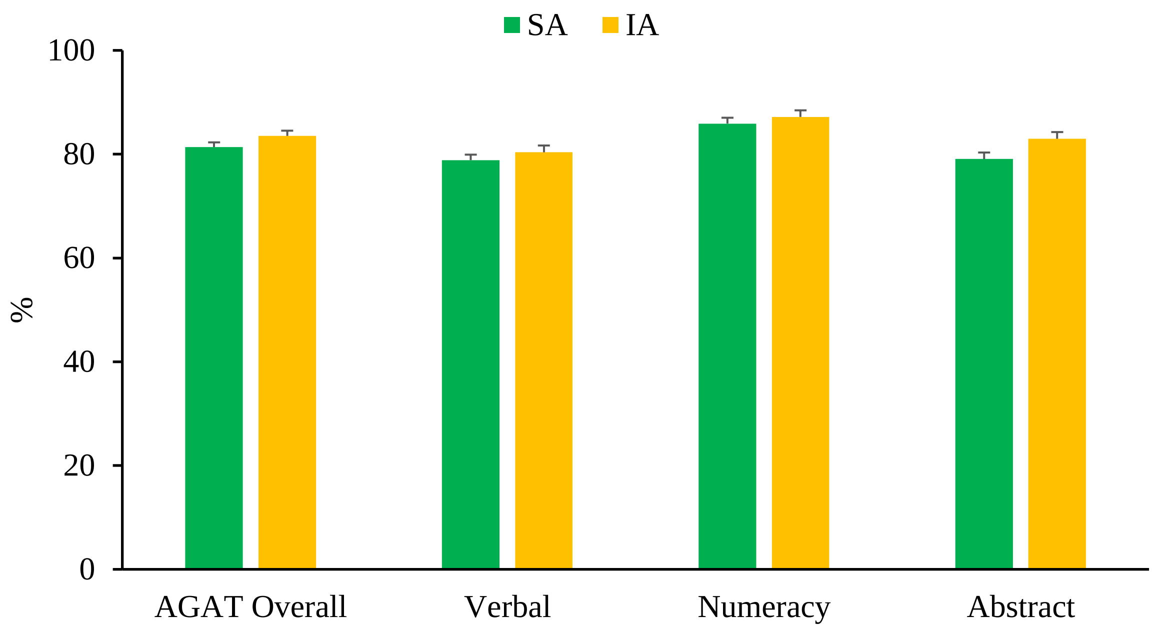


Figure 16: Mean (±SE) AGAT scores in the physical activity groups.

DISCUSSION

In this study, cognitive (Thinking, Feeling, Self-regulation) and academic (AGAT) performance were investigated in a cohort of 250 adolescent male participants divided into sub-groups based on body composition, aerobic fitness and physical activity levels (BMI, WtHR, $\dot{V}O_{2peak}$, PA). The entire cohort performed strongly on Thinking, with all scores positive and within the normal range (± 1). However, participants performed poorly on Feeling, (scores -0.5 or less). For Self-regulation, participant scores were negative for Self-regulation overall, negativity bias and emotional resilience, though positive for social skills. For negativity bias in particular, the cohort were, significantly below the normal range (scores below -2). Academic performance of the participants was consistently high (~80-85%), with low within- and between-group variability across all academic domains (verbal, numeracy, abstract) and almost identical for all sub-groups, regardless of grouping parameter.

Similarities in cognitive performance were observed within the two sub-groups based on body composition (BMI, WtHR). Contrary to the hypotheses, there were no significant differences between groups in Thinking performance. The hypotheses were supported in the Feeling and Self-regulation domains, whereby participants with normal BMI and WtHR performed better than those who were overweight/obese and had ECA, respectively. Small to moderate ES favouring participants with normal weight and healthy WtHR were observed. Contrary to the hypotheses, there were no significant differences between groups in Thinking performance or academic performance. Cognitive performance within the two sub-groups based on aerobic fitness ($\dot{V}O_{2peak}$) and habitual physical activity (METs/week) were also comparable. Contrary to the hypotheses, however, participants with higher fitness and PA performed more poorly across Thinking domains, while there were no group differences in the Feeling or Self-regulation domains.

Contrary to the hypotheses, body composition had no effect on the Thinking domain of cognition or on academic performance. This finding is also contrary to current literature whereby obese and overweight adolescents aged 12 to 18 years compared to healthy-weight peers were found to have poorer cognitive function,[63-65,67-69] demonstrated by poorer outcomes in planning and organising, problem solving,[63] sustained attention, and shifting and decision-making functions.[64] Moreover, a recent systematic review[65] found in three studies in adolescents,[67-69] that there was a negative association between body composition (BMI and waist circumference) and CF (verbal and spatial working memory,[67] inhibitory control,[68] working memory, cognitive flexibility and processing speed[69]). Only one study[70] showed no association between cognition and body weight. One plausible explanation of the discrepant findings may be that the participants in this study attended elite selective elite schools which highly prioritise academic performance, making it more difficult to observe significant changes in CF and AP. This was underscored by the positive Thinking z-scores and AGAT scores close to or above 80% in all domains.

Feeling and Self-regulation, were in line with our hypotheses with respect to body composition. Overweight and obese boys had poorer Feeling (depression, stress and anxiety) and Self-regulation (negativity bias, emotional resilience) scores. These findings add to current literature that overweight and obese adolescent males fare significantly poorer on the DASS than their healthy-body mass counterparts. Studies suggest that the association between body composition and depression is bidirectional,[71,72] and childhood and adolescent obesity identified as a predictor in 7/10 studies in another review.[73] This bidirectional association differs between the sexes, in that females show a stronger relationship.[73,74] This study's finding contributes to the evidence for a relationship in males also.

To the researchers' knowledge, no study thus far has investigated the impact of body composition or fitness on negativity bias. Previous studies have suggested that genetic variation and environmental stressors contribute to enhanced negativity bias. As there is some evidence that the genotype associated with poorer negativity bias scores is also associated with significantly higher BMI and depressive symptoms in Caucasian adults,[75] the finding in this study, that negativity bias was significantly poorer than normal in the overweight and obese boys (more than 2 SDs below the normal mean) could indicate that they also had such a genetic predisposition. Negativity bias represents a hypersensitivity to stress, poorer regulation of emotions and the expectation of negative outcomes, which elevates the risk for poor brain health.[76-78] This is congruent with the findings that overweight and obese boys felt significantly more stressed than normal weight boys. Although this study did not investigate the effect of stress on cognition, the finding is concerning because chronic stress has been found to cause structural changes in the brain associated with learning, memory and executive function,[79-82] and also to affect emotional functioning[83] in the form of poorer negativity bias. Although the participants had positive mean Thinking scores, chronic depression of their cognitive functioning in the subdomains of Feelings and Self-regulation could have an enduring negative impact on their cognition later on in life.

The finding that aerobically fitter and more physically active boys had poorer Thinking scores than less fit and less active boys was contrary to current literature. Adolescents with higher fitness had shorter reaction times and higher accuracy in a modified Eriksen Flanker task,[84-86] indicating better inhibitory control. Higher accuracy was also observed in a colour-shape switching task in adolescents of higher fitness, indicating higher competency in cognitive flexibility[84]. The nine cognitive tasks used in this study included tasks that assessed inhibitory control and switching of attention, putting these results at odds with previous findings. To my knowledge, no studies to date have shown a negative association between fitness and thinking in adolescents, although one study found no association between fitness and cognition.[87] Since the participants were from schools that prioritised academic rigour, they may have spent more time on academic studies at the expense of physical activities.

Singaporean students have consistently ranked amongst the top three nations in assessments of mathematics, reading and science in past Programme for International Student Assessment (PISA) surveys,[88] which cover more than 70 nations. The high AGAT results confirm this report. However, the PISA survey also showed that school-related anxiety levels in Singaporean students were significantly higher than the Organisation for Economic Cooperation and Development (OECD) average, with 86% of surveyed Singaporean students indicating being worried and anxious over school tests and grades, compared to the OECD average of 66%.[89] Additionally, the Institute of Mental Health in Singapore has seen an increasing trend of students (aged 6 to 18 years) seeking treatment for school-related stress, anxiety and depression disorders.[90] Additionally, the results for Feeling and Self-regulation are in line with these reports. Compared with normal-weight adolescents, obese adolescents have been reported to have a higher prevalence of school and mental health problems, including poorer academic performance and self-esteem, anxiety, and depressive disorders.[91] However, the results of this study report that although obese and overweight boys had significantly poorer depression, anxiety and stress outcomes compared to normal-weight boys, they showed had no difference in academic performance or thinking scores. These results may be explained by the study participants coming from a selective high school in an academically-driven nation, so that academic performance was high regardless of fitness, activity levels or body composition.

A key strength of this study is the comprehensive and holistic battery of cognitive assessments used to investigate the association between physical fitness, activity, body composition and cognition. To the researchers' knowledge this is the first study examining the relationship between physical fitness, activity, body composition and cognitive function and academic performance in a Singaporean population. Additionally, no study thus far has examined the association between body composition and aerobic fitness on negativity bias in any population demographic. A key limitation of this study is the sampling bias (from convenience sampling) of participants being recruited only from two academically-selective high schools, resulting in the participants' characteristic being skewed towards high-achieving students, not representative of a general adolescent population. Other limitations included the recruitment of only one gender as well as the use of VO_{2peak} to quantify aerobic performance and fitness instead of total laps completed in the Beep Test.

Conclusion

This study has found that amongst high-achieving adolescent schoolboys, the hypothesised relationships between body composition, aerobic fitness and physical activity levels on the one hand, and cognitive function and academic performance on the other, were not supported by the findings. Most importantly, despite a majority of the participants having normal body composition and healthy fitness, and just over half being sufficiently active, it highlighted a concerning possibility that these Singaporean schoolboys may have prioritised academic performance over overall mental well-being, which may contribute to further physical and mental health issues as they progress into adulthood. Future studies in this unique participant demographic are warranted to give further insights into the impact of body composition and aerobic fitness on cognitive function and academic performance in adolescents.

REFERENCES

1 Luppino, F. S., de Wit, L. M., Bouvy, P. F., Stijnen, T., Cuijpers, P., Penninx, B. W., & Zitman, F. G. (2010). Overweight, obesity, and depression: a systematic review and meta-analysis of longitudinal studies. *Archives of General Psychiatry, 67*(3), 220-229.

2 Vidoni, E. D., Johnson, D. K., Morris, J. K., Van Sciver, A., Greer, C. S., Billinger, S. A., Donnelly, J. E., & Burns, J. M. (2015). Dose-response of aerobic exercise on cognition: a community-based, pilot randomized controlled trial. *PLOS One, 10*(7), e0131647.

3 Phillips, C., Baktir, M. A., Srivatsan, M., & Salehi, A. (2014). Neuroprotective effects of physical activity on the brain: a closer look at trophic factor signaling. *Frontiers in Cellular Neuroscience, 8*, 170.

4 Kim, S., Choi, J.-Y., Moon, S., Park, D.-H., Kwak, H.-B., & Kang, J.-H. (2019). Roles of myokines in exercise-induced improvement of neuropsychiatric function. *Pflügers Archiv-European Journal of Physiology*, *471*(3), 491-505.

5 Arcoverde, C., Deslandes, A., Rangel, A., Rangel, A., Pavão, R., Nigri, F., Engelhardt, E., & Laks, J. (2008). Role of physical activity on the maintenance of cognition and activities of daily living in elderly with Alzheimer's disease. *Arquivos de Neuro-Psiquiatria*, *66*(2B), 323-327.

6 Hoffmann, K., Frederiksen, K. S., Sobol, N. A., Beyer, N., Vogel, A., Andersen, B. B., Lolk, A., Gottrupp, H., Waldemar, G., & Hasselbalch, S. G. (2014). Impact of physical activity and cognition on Activities of Daily Living in home-dwelling patients with mild to moderate Alzheimer's disease. *Alzheimer's & Dementia, 10*(4), 761-762.

7 Davis, C. L., Tomporowski, P. D., Boyle, C. A., Waller, J. L., Miller, P. H., Naglieri, J. A., & Gregoski, M. (2007). Effects of aerobic exercise on overweight children's cognitive functioning: a randomized controlled trial. *Research Quarterly for Exercise and Sport*, *78*(5), 510-519.

8 Oertel-Knöchel, V., Mehler, P., Thiel, C., Steinbrecher, K., Malchow, B., Tesky, V., Ademmer, K., Prvulovic, D., Banzer, W., & Zopf, Y. (2014). Effects of aerobic exercise on cognitive performance and individual psychopathology in depressive and schizophrenia patients. *European Archives of Psychiatry and Clinical Neuroscience*, *264*(7), 589-604.

9 Lee, Y. S. C., Ashman, T., Shang, A., & Suzuki, W. (2014). Brief report: Effects of exercise and self-affirmation intervention after traumatic brain injury. *NeuroRehabilitation, 35*(1), 57-65.

10 Hopkins, R. O., Suchyta, M. R., Farrer, T. J., & Needham, D. (2012). Improving post–intensive care unit neuropsychiatric outcomes: understanding cognitive effects of physical activity. *American Journal of Respiratory and Critical Care Medicine*, *186*(12), 1220-1228.

11 Sibley, B. A., & Etnier, J. L. (2002). The effects of physical activity on cognition in children: A meta-analysis. *Medicine & Science in Sports & Exercise*, *34*(5), S214.

12 Etnier, J. L., Salazar, W., Landers, D. M., Petruzzello, S. J., Han, M., & Nowell, P. (1997). The influence of physical fitness and exercise upon cognitive functioning: A meta-analysis. *Journal of Sport and Exercise Psychology*, *19*(3), 249-277.

13 Voss, M. W., Nagamatsu, L. S., Liu-Ambrose, T., & Kramer, A. F. (2011). Exercise, brain, and cognition across the life span. *Journal of Applied Physiology, 111*(5), 1505-1513.

14 Etnier, J. L., & Chang, Y.-K. (2019). Exercise, cognitive function, and the brain: Advancing our understanding of complex relationships. *Journal of Sport and Health Science, 8*(4), 299.

15 Hillman, C. H., Erickson, K. I., & Kramer, A. F. (2008). Be smart, exercise your heart: exercise effects on brain and cognition. *Nature Reviews Neuroscience*, *9*(1), 58-65.

16 McMorris, T. (2009). Exercise and cognitive function: a neuroendocrinological explanation. *Exercise and Cognitive Function*, 41-68.

17 World Health Organization (2019). *New WHO-led study says majority of adolescents worldwide are not sufficiently physically active, putting their current and future health at risk*. https://www.who.int/news/item/22-11-2019-new-who-led-study-says-majority-of-adolescents-worldwide-are-not-sufficiently-physically-active-putting-their-current-and-future-health-at-risk.

18 Abarca-Gómez, L., Abdeen, Z. A., Hamid, Z. A., Abu-Rmeileh, N. M., Acosta-Cazares, B., Acuin, C., Adams, R. J., Aekplakorn, W., Afsana, K., & Aguilar-Salinas, C. A. (2017). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128· 9 million children, adolescents, and adults. *The Lancet, 390*(10113), 2627-2642.

19 Twig, G., Ben-Ami Shor, D., Furer, A., Levine, H., Derazne, E., Goldberger, N., Haklai, Z., Levy, M., Afek, A., & Leiba, A. (2017). Adolescent body mass index and cardiovascular disease–specific mortality by midlife. *The Journal of Clinical Endocrinology & Metabolism, 102*(8), 3011-3020.

20 Ross, N., Yau, P. L., & Convit, A. (2015). Obesity, fitness, and brain integrity in adolescence. *Appetite*, *93*, 44-50.

21 Verstynen, T. D., Weinstein, A., Erickson, K. I., Sheu, L. K., Marsland, A. L., & Gianaros, P. J. (2013). Competing physiological pathways link individual differences in weight and abdominal adiposity to white matter microstructure. *Neuroimage, 79*, 129-137.

22 Davis, C. L., Tkacz, J. P., Tomporowski, P. D., & Bustamante, E. E. (2015). Independent associations of organized physical activity and weight status with children's cognitive functioning: a matched-pairs design. *Pediatric Exercise Science*, *27*(4), 477-487.

23 Li, Y., Dai, Q., Jackson, J. C., & Zhang, J. (2008). Overweight is associated with decreased cognitive functioning among school-age children and adolescents. *Obesity*, *16*(8), 1809-1815.

24 Tandon, P., Thompson, S., Moran, L., & Lengua, L. (2015). Body mass index mediates the effects of low income on preschool children's executive control, with implications for behavior and academics. *Childhood Obesity*, *11*(5), 569-576.

25 Wirt, T., Schreiber, A., Kesztyüs, D., & Steinacker, J. M. (2015). Early life cognitive abilities and body weight: cross-sectional study of the association of inhibitory control, cognitive flexibility, and sustained attention with BMI percentiles in primary school children. *Journal of Obesity, 2015*.

26 Pontifex, M. B., Kamijo, K., Scudder, M. R., Raine, L. B., Khan, N. A., Hemrick, B., Evans, E. M., Castelli, D. M., Frank, K. A., & Hillman, C. H. (2014). V. The differential association of adiposity and fitness with cognitive control in preadolescent children. *Monographs of the Society for Research in Child Development, 79*(4), 72-92.

27 Datar, A., Sturm, R., & Magnabosco, J. L. (2004). Childhood overweight and academic performance: national study of kindergartners and first-graders. *Obesity Research, 12*(1), 58-68.

28 Sardinha, L. B., Marques, A., Martins, S., Palmeira, A., & Minderico, C. (2014). Fitness, fatness, and academic performance in seventh-grade elementary school students. *BMC Pediatrics, 14*(1), 1-9.

29 Torrijos-Niño, C., Martínez-Vizcaíno, V., Pardo-Guijarro, M. J., García-Prieto, J. C., Arias-Palencia, N. M., & Sánchez-López, M. (2014). Physical fitness, obesity, and academic achievement in schoolchildren. *The Journal of Pediatrics*, *165*(1), 104-109.

30 Berchtold, N., Chinn, G., Chou, M., Kesslak, J., & Cotman, C. (2005). Exercise primes a molecular memory for brain-derived neurotrophic factor protein induction in the rat hippocampus. *Neuroscience, 133*(3), 853-861.

31 Cotman, C. W., Berchtold, N. C., & Christie, L.-A. (2007). Exercise builds brain health: key roles of growth factor cascades and inflammation. *Trends in Neurosciences*, *30*(9), 464-472.

32 Intlekofer, K. A., Berchtold, N. C., Malvaez, M., Carlos, A. J., McQuown, S. C., Cunningham, M. J., Wood, M. A., & Cotman, C. W. (2013). Exercise and sodium butyrate transform a subthreshold learning event into long-term memory via a brain-derived neurotrophic factor-dependent mechanism. *Neuropsychopharmacology*, *38*(10), 2027-2034.

33 Erickson, K. I., Voss, M. W., Prakash, R. S., Basak, C., Szabo, A., Chaddock, L., Kim, J. S., Heo, S., Alves, H., & White, S. M. (2011). Exercise training increases size of hippocampus and improves memory. *Proceedings of the National Academy of Sciences, 108*(7), 3017-3022.

34 Erickson, K., Weinstein, A. M., Verstynen, T. D., Voss, M. W., Prakash, R. S., Woods, J., McAuley, E., & Kramer, A. F. (2012). F1-03-01: The influence of an aerobic exercise intervention on brain volume in late adulthood. *Alzheimer's & Dementia*, *8*(4S_Part_2), 81-81.

35 Scharfman, H., Goodman, J., Macleod, A., Phani, S., Antonelli, C., & Croll, S. (2005). Increased neurogenesis and the ectopic granule cells after intrahippocampal BDNF infusion in adult rats. *Experimental Neurology, 192*(2), 348-356.
36 Tolwani, R., Buckmaster, P., Varma, S., Cosgaya, J., Wu, Y., Suri, C., & Shooter, E. (2002). BDNF overexpression increases dendrite complexity in hippocampal dentate gyrus. *Neuroscience, 114*(3), 795-805.
37 Arancibia, S., Silhol, M., Mouliere, F., Meffre, J., Höllinger, I., Maurice, T., & Tapia-Arancibia, L. (2008). Protective effect of BDNF against beta-amyloid induced neurotoxicity in vitro and in vivo in rats. *Neurobiology of Disease, 31*(3), 316-326.
38 Ma, Q. (2008). Beneficial effects of moderate voluntary physical exercise and its biological mechanisms on brain health. *Neuroscience Bulletin, 24*(4), 265-270.
39 Park, C.-H., Kim, J., Namgung, E., Lee, D.-W., Kim, G. H., Kim, M., Kim, N., Kim, T. D., Kim, S., & Lyoo, I. K. (2017). The BDNF Val66Met polymorphism affects the vulnerability of the brain structural network. *Frontiers in Human Neuroscience, 11*, 400.
40 Egan, M. F., Kojima, M., Callicott, J. H., Goldberg, T. E., Kolachana, B. S., Bertolino, A., Zaitsev, E., Gold, B., Goldman, D., & Dean, M. (2003). The BDNF val66met polymorphism affects activity-dependent secretion of BDNF and human memory and hippocampal function. *Cell, 112*(2), 257-269.
41 Schofield, P. R., Williams, L. M., Paul, R. H., Gatt, J. M., Brown, K., Luty, A., Cooper, N., Grieve, S., Dobson-Stone, C., & Morris, C. (2009). Disturbances in selective information processing associated with the BDNF Val66Met polymorphism: evidence from cognition, the P300 and fronto-hippocampal systems. *Biological Psychology, 80*(2), 176-188.
42 Knaepen, K., Goekint, M., Heyman, E. M., & Meeusen, R. (2010). Neuroplasticity—exercise-induced response of peripheral brain-derived neurotrophic factor. *Sports Medicine, 40*(9), 765-801.
43 Pilc, J. (2010). The effect of physical activity on the brain derived neurotrophic factor: from animal to human studies. *Journal of Physiology and Pharmacology, 61*(5), 533-541.
44 Huang, T., Larsen, K., Ried-Larsen, M., Møller, N., & Andersen, L. B. (2014). The effects of physical activity and exercise on brain-derived neurotrophic factor in healthy humans: A review. *Scandinavian Journal of Medicine & Science in Sports, 24*(1), 1-10.
45 Azevedo, K. P. M. d., de Oliveira, V. H., Medeiros, G. C. B. S. D., Mata, Á. N. D. S., García, D. Á., Martínez, D. G., Leitão, J. C., Knackfuss, M. I., & Piuvezam, G. (2020). The effects of exercise on BDNF levels in adolescents: a systematic review with meta-analysis. *International Journal of Environmental Research and Public Health, 17*(17), 6056.
46 Li, J. W., O'Connor, H., O'Dwyer, N., & Orr, R. (2017). The effect of acute and chronic exercise on cognitive function and academic performance in adolescents: A systematic review. *Journal of Science and Medicine in Sport, 20*(9), 841-848.
47 Steinberg, L. (2005). Cognitive and affective development in adolescence. *Trends in Cognitive Sciences, 9*(2), 69-74.
48 Blakemore, S. J., & Choudhury, S. (2006). Development of the adolescent brain: implications for executive function and social cognition. *Journal of Child Psychology and Psychiatry, 47*(3-4), 296-312.
49 Williams, R. (1990). The nature of adolescence (2nd edn). By JC Coleman and LB Hendry London: Routledge. *The British Journal of Psychiatry, 157*(6), 952-953.
50 Feldman, S. S., Elliott, G. R., & Elliott, G. R. (1990). *At the threshold: The developing adolescent*. Harvard University Press.
51 Williams, L. M., Gatt, J. M., Hatch, A., Palmer, D. M., Nagy, M., Rennie, C., Cooper, N. J., Morris, C., Grieve, S., & Dobson-Stone, C. (2008). The integrate model of emotion, thinking and self regulation: An application to the" paradox of aging". *Journal of Integrative Neuroscience, 7*(03), 367-404.
52 Education, C. (2020). *Top 10 secondary schools with the most offers to Cambridge*. https://www.crimsoneducation.org/sg/blog/admissions-news/cambridge-acceptance-rates-schools/.

53 Cole, T. J., Bellizzi, M. C., Flegal, K. M., & Dietz, W. H. (2000). Establishing a standard definition for child overweight and obesity worldwide: international survey. *Bmj, 320*(7244), 1240.

54 Cole, T. J., Flegal, K. M., Nicholls, D., & Jackson, A. A. (2007). Body mass index cut offs to define thinness in children and adolescents: international survey. The *BMJ, 335*(7612), 194.

55 Mirwald, R. L., Baxter-Jones, A. D., Bailey, D. A., & Beunen, G. P. (2002). An assessment of maturity from anthropometric measurements. *Medicine and Science in Sports and Exercise, 34*(4), 689-694.

56 Garnett, S., Baur, L., & Cowell, C. (2008). Waist-to-height ratio: a simple option for determining excess central adiposity in young people. *International Journal of Obesity, 32*(6), 1028-1030.

57 Leger, L. A., & Lambert, J. (1982). A maximal multistage 20-m shuttle run test to predict VO_{2max}. *European Journal of Applied Physiology and Occupational Physiology, 49*(1), 1-12.

58 Welk, G. J., Maduro, P. F. D. S.-M., Laurson, K. R., & Brown, D. D. (2011). Field evaluation of the new FITNESSGRAM® criterion-referenced standards. *American Journal of Preventive Medicine, 41*(4), S131-S142.

59 Booth, M. L., Okely, A. D., Chey, T., & Bauman, A. (2002). The reliability and validity of the adolescent physical activity recall questionnaire. *Medicine & Science in Sports & Exercise, 34*(12), 1986-1995.

60 Lovibond, S. H., & Lovibond, P. F. (1996). *Manual for the depression anxiety stress scales*. Psychology Foundation of Australia.

61 Williams, L. M., Cooper, N. J., Wisniewski, S. R., Gatt, J. M., Koslow, S. H., Kulkarni, J., DeVarney, S., Gordon, E., & John Rush, A. (2012). Sensitivity, specificity, and predictive power of the "Brief Risk-resilience Index for SCreening," a brief pan-diagnostic web screen for emotional health. *Brain and Behavior, 2*(5), 576-589.

62 Hopkins, W., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise, 41*(1), 3.

63 Qavam, S. E., Anisan, A., Fathi, M., & Pourabbasi, A. (2015). Study of relationship between obesity and executive functions among high school students in Bushehr, Iran. *Journal of Diabetes & Metabolic Disorders, 14*(1), 1-5.

64 Verdejo-García, A., Pérez-Expósito, M., Schmidt-Río-Valle, J., Fernández-Serrano, M. J., Cruz, F., Pérez-García, M., López-Belmonte, G., Martín-Matillas, M., Martín-Lagos, J. A., & Marcos, A. (2010). Selective alterations within executive functions in adolescents with excess weight. *Obesity, 18*(8), 1572-1578.

65 Mamrot, P., & Hanć, T. (2019). The association of the executive functions with overweight and obesity indicators in children and adolescents: A literature review. *Neuroscience & Biobehavioral Reviews, 107*, 59-68.

66 Cohen, J. (2013). *Statistical power analysis for the behavioral sciences*. Academic Press.

67 Alarcón, G., Ray, S., & Nagel, B. J. (2016). Lower working memory performance in overweight and obese adolescents is mediated by white matter microstructure. *Journal of the International Neuropsychological Society, 22*(3), 281-292.

68 Huang, T., Tarp, J., Domazet, S. L., Thorsen, A. K., Froberg, K., Andersen, L. B., & Bugge, A. (2015). Associations of adiposity and aerobic fitness with executive function and math performance in danish adolescents. *The Journal of Pediatrics, 167*(4), 810-815.

69 Schwartz, D. H., Leonard, G., Perron, M., Richer, L., Syme, C., Veillette, S., Pausova, Z., & Paus, T. (2013). Visceral fat is associated with lower executive functioning in adolescents. *International Journal of Obesity, 37*(10), 1336-1343.

70 Hughes, S. O., Power, T. G., O'Connor, T. M., & Fisher, J. O. (2015). Executive functioning, emotion regulation, eating self-regulation, and weight status in low-income preschool children: How do they relate? *Appetite, 89*, 1-9.

71 Russell-Mayhew, S., McVey, G., Bardick, A., & Ireland, A. (2012). Mental health, wellness, and childhood overweight/obesity. *Journal of Obesity, 2012*.

72 Roberts, R. E., & Duong, H. T. (2016). Do anxiety disorders play a role in adolescent obesity? *Annals of Behavioral Medicine, 50*(4), 613-621.

73 Mühlig, Y., Antel, J., Föcker, M., & Hebebrand, J. (2016). Are bidirectional associations of obesity and depression already apparent in childhood and adolescence as based on high-quality studies? A systematic review. *Obesity Reviews, 17*(3), 235-249.

74 Korczak, D. J., Lipman, E., Morrison, K., & Szatmari, P. (2013). Are children and adolescents with psychiatric illness at risk for increased future body weight? A systematic review. *Developmental Medicine & Child Neurology, 55*(11), 980-987.

75 Borkowska, A., Bieliński, M., Szczęsny, W., Szwed, K., Tomaszewska, M., Kaława, A., Lesiewska, N., Junik, R., Gołębiewski, M., & Sikora, M. (2015). Effect of the 5-HTTLPR polymorphism on affective temperament, depression and body mass index in obesity. *Journal of Affective Disorders, 184*, 193-197.

76 Wichers, M., Myin-Germeys, I., Jacobs, N., Peeters, F., Kenis, G., Derom, C., Vlietinck, R., Delespaul, P., & Van Os, J. (2007). Genetic risk of depression and stress-induced negative affect in daily life. *The British Journal of Psychiatry, 191*(3), 218-223.

77 Williams, L. M., Gatt, J. M., Schofield, P. R., Olivieri, G., Peduto, A., & Gordon, E. (2009). 'Negativity bias' in risk for depression and anxiety: Brain–body fear circuitry correlates, 5-HTT-LPR and early life stress. *Neuroimage, 47*(3), 804-814.

78 Williams, L. M., Gatt, J. M., Grieve, S. M., Dobson-Stone, C., Paul, R. H., Gordon, E., & Schofield, P. R. (2010). COMT Val108/158Met polymorphism effects on emotional brain function and negativity bias. *Neuroimage, 53*(3), 918-925.

79 Arnsten, A. F. (2009). Stress signalling pathways that impair prefrontal cortex structure and function. *Nature Reviews Neuroscience, 10*(6), 410-422.

80 Jonsdottir, I. H., Nordlund, A., Ellbin, S., Ljung, T., Glise, K., Währborg, P., & Wallin, A. (2013). Cognitive impairment in patients with stress-related exhaustion. *Stress, 16*(2), 181-190.

81 Lupien, S. J., & Lepage, M. (2001). Stress, memory, and the hippocampus: can't live with it, can't live without it. *Behavioural Brain Research, 127*(1-2), 137-158.

82 Sandi, C. (2013). Stress and cognition. *Wiley Interdisciplinary Reviews: Cognitive Science, 4*(3), 245-261.

83 Sandi, C., & Haller, J. (2015). Stress and the social brain: behavioural effects and neurobiological mechanisms. *Nature Reviews Neuroscience, 16*(5), 290-304.

84 Westfall, D. R., Gejl, A. K., Tarp, J., Wedderkopp, N., Kramer, A. F., Hillman, C. H., & Bugge, A. (2018). Associations between aerobic fitness and cognitive control in adolescents. *Frontiers in Psychology, 9*, 1298.

85 Stroth, S., Kubesch, S., Dieterle, K., Ruchsow, M., Heim, R., & Kiefer, M. (2009). Physical fitness, but not acute exercise modulates event-related potential indices for executive control in healthy adolescents. *Brain Research, 1269*, 114-124.

86 Hogan, M., Kiefer, M., Kubesch, S., Collins, P., Kilmartin, L., & Brosnan, M. (2013). The interactive effects of physical fitness and acute aerobic exercise on electrophysiological coherence and cognitive performance in adolescents. *Experimental Brain Research, 229*(1), 85-96.

87 Ruiz, J. R., Ortega, F. B., Castillo, R., Martín-Matillas, M., Kwak, L., Vicente-Rodríguez, G., Noriega, J., Tercedor, P., Sjöström, M., & Moreno, L. A. (2010). Physical activity, fitness, weight status, and cognitive performance in adolescents. *The Journal of Pediatrics, 157*(6), 917-922. e915.

88 Gurria, A. (2016). PISA 2015 results in focus. *PISA in Focus*, (67), 1.

89 Jones, C. (2021). *Young singaporeans are stressed and anxious: Singapore's strategies to protect the mental health of students*. https://www.theearthawards.org/young-singaporeans-are-stressed-and-anxious-singapores-strategies-to-protect-the-mental-health-of-students/.

90 Cheow, S. A. (2019). *More teens in Singapore seeking help at IMH for school stress*. https://www.straitstimes.com/singapore/education/more-teens-in-singapore-seeking-help-for-school-stress-at-imh.

91 Nemiary, D., Shim, R., Mattox, G., & Holden, K. (2012). The relationship between obesity and depression among adolescents. *Psychiatric Annals, 42*(8), 305-308.

APPENDICES

Table A1. BMI group mean values (±SE) for cognitive function and academic performance and effect sizes of group differences

Cognitive and Academic Assessment	Mean ± SD				p-value	ES (95% CI)
	Overall (n = 250)	Normal (n = 175)	Overweight[a] (n = 39)	Obese[b] (n = 10)		
Feeling Overall	-0.76 ± 1.12	-0.61 ± 0.97	-1.26 ± 1.33	-1.42 ± 1.29	**<0.001[a]**	-0.62 (0.23 to 0.93)[a]
					0.013[b]	-0.82 (-1.46 to -0.17)[b]
Depression	-0.63 ± 1.23	-0.47 ± -1.31	-1.31 ± 1.58	-0.84 ± 1.12	**<0.001[a]**	0.72 (0.36 to 1.07)[a]
Anxiety	-1.20 ± 1.46	-1.04 ± 1.29	-1.66 ± 1.69	-2.18 ± 1.78	**0.01[a]**	0.42 (0.07 to 0.77)[a]
					0.009[b]	-0.86 (-1.50 to -0.22)[b]
Stress	-0.46 ± 1.06	-0.32 ± 0.97	-0.81 ± 1.11	-1.23 ± 1.38	<**0.01[a]**	-0.49 (-0.84 to -0.14)[a]
					0.006[b]	-0.91 (-1.56 to -0.27)[b]
Self-Regulation Overall	-0.58 ± 0.84	-0.49 ± 0.79	-0.99 ± 0.97	-0.77 ± 0.82	**<0.001[a]**	-0.60 (-0.96 to -0.25)[a]
Negativity Bias	-2.23 ± 1.49	-2.05 ± 1.35	-2.84 ± 1.71	-2.88 ± 1.70	**0.002[a]**	-0.55 (-0.90 to -0.20)[a]
Emotional Resilience	-0.13 ± 1.08	-0.03 ± 1.03	-0.62 ± 1.24	-0.60 ± 1.18	**0.002[a]**	-0.55 (-0.90 to -0.20)[a]

**ES (Effect size, Hedge's g) were categorised as trivial (<0.02), small (0.02-0.6), moderate (0.6-1.2), large (1.2-2.0) and very large (>2.0).[66]
Positive ES favoured the overweight[a] or obese[b] group, while negative ES favoured the normal weight group

Table A2: Physical fitness group mean values (±SE) for cognitive function and academic performance and effect sizes of significant group differences

Cognitive and Academic Assessment	**Mean ± SD**			**p-value**	**ES Hedges' g (95% CI)**
	Overall (n = 250)	**HFZ (n = 173)**	**NIZ (n = 77)**		
Thinking Overall	0.48 ± 0.57	0.43 ± 0.58	0.60 ± 0.53	**0.03***	0.30 (0.03 to 0.57)
Information Processing	0.52 ± 0.61	0.43 ± 0.65	0.71 ± 0.46	**0.0006***	0.47 (0.19 to 0.74)
Memory	0.79 ± 0.72	0.72 ± 0.68	0.94 ± 0.78	**0.03***	0.31 (0.04 to 0.58)

**Effect sizes (ES) were categorised as trivial (<0.02), small (0.02-0.6), moderate (0.6-1.2), large (1.2-2.0) and very large (>2.0).[87] Positive ES favoured the needs improvement (NIZ) zone while negative ES favoured the healthy fitness zone (HFZ) .

Table A3: Waist to height ratio group mean values (±SE) for cognitive and academic performance and effect sizes of significant group differences

Cognitive and Academic Assessment	Mean ± SE Overall (n = 250)	Normal (n = 212)	ECA (n = 38)	p-value	ES Hedges' g (95% CI)
Feeling Overall	-0.76 ± 1.12	-0.61 ± 1.01	-1.61 ± 1.31	**<0.0001***	-0.94 (-1.30 to -0.59)
Depression	-0.63 ± 1.23	-0.48 ± 1.10	-1.45 ± 1.56	**<0.0001***	-0.82 (-1.17 to -0.47)
Anxiety	-1.20 ± 1.46	-1.03 ± 1.33	-2.17 ± 1.72	**<0.0001***	-0.81 (-1.17 to -0.46)
Stress	-0.46 ± 1.06	-0.33 ± 0.99	-1.22 ± 1.12	**<0.0001***	-0.88 (-1.23 to -0.52)
Self-Regulation Overall	-0.58 ± 0.84	-0.51 ± 0.79	-0.99 ± 1.00	**< 0.01***	-0.58 (-0.93 to -0.23)
Negativity Bias	-2.23 ± 1.49	-2.06 ± 1.38	-3.17 ± 1.76	**0.0001***	-0.77 (-1.12 to -0.42)
Emotional Resilience	-0.13 ± 1.08	-0.06 ± 1.03	-0.54 ± 1.25	**0.01***	-0.45 (-0.80 to -0.10)

**Effect sizes (ES) were categorised as trivial (<0.02), small (0.02-0.6), moderate (0.6-1.2), large (1.2-2.0) and very large (>2.0).[87]
Positive ES favoured the Excess Central Adiposity (ECA) group while negative ES favoured the normal WtHR group.

Table A4: Physical activity level group mean values (±SE) for cognitive and academic performance and effect sizes of significant group differences

Cognitive and Academic Assessment	Mean ± SD Overall (n = 243)	Sufficiently Active (n = 135)	Insufficiently Active (n = 108)	p-value	ES Hedges' g (95% CI)
Thinking Overall	0.48 ± 0.57	0.40 ± 0.59	0.58 ± 0.54	**0.02***	0.32 (0.06 to 0.57)
Impulsivity	0.35 ± 1.00	0.23 ± 1.03	0.50 ± 0.94	**0.04***	0.27 (0.02 to 0.53)
Memory	0.79 ± 0.72	0.71 ± 0.69	0.89 ± 0.74	**0.05***	0.25 (0.00 to 0.51)
Executive Function	0.54 ± 0.82	0.45 ± 0.88	0.65 ± 0.72	**0.06***	0.25 (-0.01 to 0.50)

**Effect sizes (ES) were categorised as trivial (<0.02), small (0.02-0.6), moderate (0.6-1.2), large (1.2-2.0) and very large (>2.0).[87] Positive ES favoured the Insufficiently Active (IA) group while negative ES favoured the Sufficiently Active (SA) group

CHAPTER 5

Effect of eight-week body versus brain training interventions on cognitive function and academic performance in high-achieving Singaporean male adolescents: A randomised controlled trial

FOREWARD

A key finding from the systematic review (Chapter 3) was that not only are there limited exercise-cognition studies in the adolescent population, but these studies were also lacking in quality. Often, exercise dose (frequency, intensity, type and duration) were not clearly reported, with different studies using different outcome measures to quantify exercise intensity. Additionally, some studies were found to be of poor study design with no control/rest group. As such, this thesis seeks to add research of high quality to the current limited database of adolescent exercise-cognition studies. A randomised-controlled trial with three groups (one control and two intervention (Body training and Brain training)) was thus designed to examine the effects of chronic exercise dose of high intensity on cognitive function (CF) and academic performance (AP) in adolescent males. Due to the plasticity of the adolescent brain making it an opportune phase to study the effects of environmental factors on cognitive functioning, Brain training was also included as an intervention protocol to examine the possible effect of neuroplasticity on CF and AP.

ABSTRACT

Objectives: To investigate the effect of eight weeks of body or brain training t on the cognitive function (CF) and academic performance (AP) of Singaporean male adolescents.

Design: Randomised controlled trial evaluating the effectiveness compared to control of two interventions, body or brain training, on CF and AP.

Methods: Male participants (body: n=43, brain: n= 45, control: n=45) with a mean age of 15.7 ± 0.4 years (range 13-18 years) were recruited from an elite high school in Singapore. Anthropometric measurements were taken to obtain body mass index (BMI), waist circumference and waist/height ratio (WtHR). Maximal aerobic capacity ($\dot{V}O_{2peak}$) was estimated using the 20m Shuttle Run Test. Participants were block randomised according to school classes to three groups. The intervention was conducted, twice per week across eight weeks, during scheduled hour-long physical education lessons. Body training consisted of high-intensity exercises and team sports, with heart rate monitors used to track exercise intensity (maintained at 75 to 90% of maximum heart rate). Brain training was conducted using web-based activities on the MyBrainSolutions© platform which targeted the cognitive domains of thinking, feeling and self-regulation. Participants in the Control group continued their usual daily activities which comprised a theory-based physical education class where physical activities were minimal. Three domains of CF were assessed using the WebNeuro™ platform: thinking (subdomains: response variability, impulsivity, sustained attention, information processing, memory, executive function); feeling (subdomains: depression, anxiety, stress); and self-regulation (subdomains: negativity bias, emotional resilience, social skills). Academic performance (subdomains: verbal, numeracy, abstract reasoning) was assessed using the Australian Council for Educational Research (ACER) General Ability Test (AGAT). Effect size (ES, Hedges g) was calculated where possible. Pre- and post-intervention testing of CF and AP was carried out. Results were presented as z-scores for CF and percentage for AP.

Results: The cohort scored well on thinking independently of the interventions, with z-scores above zero in all sub-domains. Similarly, their academic performance was good, with most sub-domain scores ≥75%. In contrast, performance in all feeling domains was poor (z-scores = -

1.51 to -3.42) and for self-regulation, performance on negativity bias was particularly low (z-scores = -1.82 to -2.49). The Body training resulted in an increase in aerobic fitness (from 45 ± 0.89 to 47.7 ± 0.79 $ml.kg^{-1}min^{-1}$; $p < 0.001$) and a slight decrease in BMI (from 21.9 ± 4.69 to: 21.6 ± 0.67 $kg.m^{-2}$; $p = 0.04$), but no change in CF or AP. The Brain training did not produce any significant effects on any cognitive or academic outcome measures

Conclusion: The aerobic exercise protocol in the Body training group was effective in increasing aerobic fitness in these adolescent males but neither Body nor Brain training produced improvements in cognitive or academic performance. All participants were also found to have negative Feeling and Self-regulation scores which indicates high levels of anxiety, stress as well as sensitivity to stress, and depression. This incidental but concerning finding highlights the need for an intervention in these students to prevent the worsening of their mental health which in turn adversely impact cognition.

Keywords: Exercise, cognition, students, fitness, Body Mass Index

INTRODUCTION

The second decade of life is marked by major cerebral cortical and cognitive reorganisation. In particular, the pre-frontal cortex has been shown to continue to myelinate through to the early adult years.[1] Neuroimaging studies show that the pre-frontal cortex is the last brain area to mature in the course of development.[2] This region is responsible for highly integrative cognitive functions such as executive control, which continue to develop throughout early adulthood.[3] Given this protracted development in the frontal lobe compared to other regions of the brain, the impact of environmental factors is hypothesised to be greater during this period of plasticity than after brain maturation is complete.[3] Two such environmental factors that have received recent attention in the literature are aerobic exercise and brain training.

Regular physical activity is known to confer a variety of brain health benefits. Exercise increases brain-derived neurotrophic factor (BDNF) and nerve-growth factor which mediate short- and long-term enhancement of synaptic strength and reduce cell death in the hippocampus.[4] Aerobic exercise has been shown to enhance blood flow, as well as the number of capillaries and capillary density in the brain of animals.[5] These neurotrophic, angiogenic and neurogenic effects of exercise on the brain may play a role as both enhancers and protectors of cognitive function and central nervous system integrity. Along with structural and functional changes within the brain, exercise has been shown to improve cognitive function and protect against age-related cognitive decline.[6] Exercise training in adults, for example, has been reported to improve executive control mediated by the frontal lobe.[6] However, recent critical reviews[7,8] have identified that there is limited research investigating the effects of exercise and physical activity on cognition in the adolescent population, with inconclusive evidence to support the beneficial effect of exercise on cognition in this age group. Furthermore, of 11 studies identified in one systematic review[9], only two[10,11] investigated the impact of chronic exercise on CF, while the majority[11-19] used an acute exercise intervention protocol. The present study therefore adds to the limited literature on adolescents.

In addition to physical activity and exercise, body composition is an important consideration in regard to cognition and academic performance in adolescents. Current literature reports a global trend in adolescents having inadequate physically activity (less than 1h a day of moderate-to-vigorous)[20], as well as the prevalence of increasing body mass index (BMI) in both children and adolescents.[21] In the previous chapter, boys with unhealthy body composition were found to have poorer scores in the cognitive domain of Feeling and Self-regulation. Additionally, studies have found that overweight and/or obese students have differing prefrontal cortex structures[22] and reduced white matter integrity[23] as well as poorer cognitive[24-28] and academic[29-31] outcomes, compared with their normal-weight counterparts.

Brain or cognitive training consists of practising and learning skills and techniques (e.g. use of mnemonics to aid recall) to manage cognitively demanding situations.[32] Just as running can improve cycling performance by improving cardiovascular fitness, brain training has been reported to result in the transfer of practised skills to what has been termed 'fluid intelligence',[33] the ability to reason abstractly and solve novel problems. Fluid intelligence is predictive of academic and professional success.[34] Brain training is emerging as an alternative approach to improve academic success.[35] More research is required in healthy populations, particularly adolescents, to evaluate its effectiveness and the transfer to academic improvement. Although brain or cognitive training has been reported as effective in some studies in adults and the elderly,[36,37] there are few studies in healthy children or adolescents, where most studies have targeted clinical populations, particularly those with attention deficit hyperactivity disorder.[38] Evidence for the effectiveness of brain training in typically developing children has only recently been reported.[34,39,40] Although such training can be effective, it is unclear which training tasks and processes contribute most to improvements in CF, or what duration of training may be required for optimum improvements.[34] The one study in typically developing adolescent populations,[38] showed little support for any benefit.

The lack of evidence about body or brain training in adolescents should be addressed because executive control processes are more critical to academic performance in high school than in the primary years[41,42] and continue to develop well into early adulthood.[43] Exercise has been found to enhance executive function in children and this is postulated to be the result of physiological changes (often hypothesised to be related to BDNF)[44-46] that lead to overall improvements in brain health.[47-52] Brain training has been found to have modest effects on executive function only in older adults[53,54] and pre-school children,[55] and these effects are generally restricted to the trained function and do not easily transfer to non-trained tasks.[56-58] Thus, the present study aimed to compare the effects of aerobic exercise with those of brain training for improvement in cognitive function and academic performance in male adolescents. The following hypotheses were tested: (1) Aerobic exercise and brain training will result in measurable improvement in cognitive function and academic achievement. (2) An eight weeks chronic aerobic exercise intervention protocol training of high intensity will improve cardiorespiratory fitness and body composition status.

METHODS

Participants

Adolescent males (n =146) aged 15.0 to 17.4 years (15.7 ± 0.5 years), recruited from an elite high school in Singapore, participated in this study. The protocol was approved by the Human Research Ethics Committee of The University of Sydney (Ethics reference number: 2012/629). Before taking part, both the school and the parents and participants were fully informed of the experimental protocol and gave written informed consent. Inclusion criteria were healthy male adolescents aged 13 to 18 (± 0.5 years). Exclusion criteria were any medical condition which put participants at increased risk of injury or illness after submaximal physical exertion, any mental or physical impairment/injury, colour blindness, and consumption of psychoactive substances. Two participants were excluded due to these criteria, while another two were excluded due to non-study related injuries. A further nine participants were excluded due to continued non-compliance during testing or intervention sessions.

Procedure

The experimental protocol was conducted in groups of 24-28 participants, in 20 sessions of one-hour, twice per week, across 10 weeks. After recruitment, participants from six classes were block randomised according to their classes into three groups of two classes each; two intervention groups ('Body' and 'Brain') and one control group. Randomisation was done before baseline measures were taken. All participants took part in pre- and post-testing.

Pre- and post-testing were conducted in Week 1 and 10 respectively, with the order of testing as follows: cognitive and academic testing, anthropometry measurements, 20m shuttle run test. The intervention programme was carried out from Weeks two to nine. Neither the participants nor the experimenters were blinded to the intervention. Participants in the 'Body' group completed eight weeks of mainly aerobic exercises specially designed for adolescent males at an intensity of 75-90% of maximum heart rate (HR_{max}). Each 'Body' training session consisted of a dynamic warm-up session, interval training with predominantly aerobic exercises, team sports, and ending with cooling down session of stretching. Participants in the 'Brain' training group completed eight weeks of training using computer-based software, MyBrainSolutions©,(Brain Resource Company™). These 'Brain' training sessions involved completing web-based activities on the MyBrainSolutions© platform, which trained the cognitive domains of Thinking, Feeling, Self-regulation and Emotion. Participants in the control group were instructed to go about their usual daily activities, which was a theory-based physical education class where physical activities were minimal. The interventions were carried out during the physical education period of each class involved in the study. The study took place within the premises of the high school, with a teacher assigned to each class to help with supervision and compliance during experimental activities.

Anthropometry and aerobic fitness testing

The height (cm) and body mass (kg) of participants were measured to calculate body mass index (BMI). Sitting height (torso length, cm) was used to calculate leg length (total height minus sitting height, cm), which in turn was used to compute age of peak height velocity (APHV),[59] a measurement used to identify the approximate age of peak pubertal growth in participants, an indicator of biological maturation. Waist circumference (cm) was measured at the mid-point between the lowest rib and the iliac crest in accordance with International Diabetes Federation guidelines, to provide an indication of body fat composition using waist/height ratio (WtHR). All measurements were carried out in duplicate by the same researcher to ensure consistency. A third measurement was taken if the difference between the two measurements exceeded 1%.

The 20m shuttle-run test[60] was used to determine the peak aerobic capacity ($\dot{V}O_2$ peak) of participants using the equation: VO2peak = 31.025 + 3.238(speed at attained level) – 3.248 (decimal age) + 0.1536 (speed at attained level × decimal age)[61]. The test was carried out in the indoor sports gymnasium within the high school. Participants were classified into two aerobic fitness groups, “Healthy Fitness Zone” (HFZ) and “Needs Improvement Zone” (NIZ), based on the age and sex-specific cut-offs provided in a cross-sectional study in participants 8-18 years.[62]

Cognitive testing

Cognitive function was assessed using WebNeuro™ (Brain Resource Company), a web-based platform, throughout all three studies. Refer to Methods Chapter (Page 24) for details of the cognitive testing.

Academic testing

Academic performance was assessed using the Australian Council for Educational Research General Ability Test (AGAT), a web-based test of three reasoning skill components: verbal, numeracy and abstract (visual). Refer to Methods Chapter (Pg 27) for more details.

Intervention protocol

For Body training, the protocol consisted of eight weeks of specially designed exercises and games for adolescent males. Each 1h session consisted of five minutes of dynamic warmup, 30 minutes of structured high-intensity exercise, 20 minutes of team games (e.g. soccer, floorball, touch rugby) and five minutes of cooling down with stretching (refer to appendix 4 of manual of procedures). Due to the limited availability of heart rate monitors, only 10 participants were fitted with heart rate monitors in each session, with different groups of 10 participants wearing the monitors across the sessions. All participants wore the heart rate monitors at least six times throughout the eight weeks of intervention. They were prompted to adjust their level of physical exertion according to the targeted heart rate zone (75-90% of HRmax), regardless of the activity designed. Participants not wearing HR monitors were instructed to adjust their efforts to a score of 8 to 10 according to the Borg rating of perceived exertion (RPE) scale (0 to 10 scale).[63] Make up sessions were conducted after school for participants who were not able to attend their allocated training session.

The Brain training protocol consisted of eight weeks of training using the MyBrainSolutions© interface. Due to the web-based and electronic nature of this training programme, these sessions were conducted in the school's computer room. Each session was 1h in duration and involved participants doing various activities on the online platform designed to train the four cognitive domains of Thinking, Feeling, Self-regulation and Emotion. Make-up sessions were also conducted after school. Control group participants' physical activity was kept to a minimum because the curriculum in their physical education lessons during the 10 weeks of the study was focused on the "theory of games design".

Neither participants nor the experimenters were blinded in this randomised controlled trial. There were no dropouts but nine participants' data had to be excluded at the end of 10 weeks due to behavioural and discipline issues during the intervention and testing sessions leading to poor compliance of experimental instructions. Percentage of participants that had their data analysed was 93.7% (n=133).

Statistical analyses

Statistical analyses were carried out using IBM® SPSS® Statistics (v.22) and TIBCO Statistica (v.13). One-way analyses of variance (ANOVAs) were used to compare the baseline characteristics of the three groups (Control, Brain training, Body training) in terms of age, maturation, anthropometry (body mass, BMI, waist circumference, waist/height ratio) and aerobic fitness. Two- and three-factor ANOVAs were used to examine the effects of the training interventions on the groups. In these analyses, there was one independent groups factor (Control, Brain training, Body training) and two repeated measures factors (the pre- and post-training measurements, and the various outcome variables). The outcome variables were cognitive function, Self-regulation, Feeling or academic performance, as well as the anthropometry measures and aerobic fitness. These ANOVAs were extended to analyses of covariance (ANCOVAs) in order to control for the effect of a difference in baseline BMI that was observed between the Control and Brain groups. Tukey *post hoc* tests were employed to determine the locus of any significant effects observed.

Data extracted were reported as mean ± standard deviation (SD) in the tables and mean ± standard error (SE) in the figures. Comprehensive Meta-Analysis (CMA) Software (Biostat Inc. Englewood, New Jersey, USA) was used to calculate effect size (ES) and reported as standardised mean differences (SMD). ES was based on post-pre intervention changes in each group and was determined by subtracting the mean change score in the intervention groups from the mean change score in the Control group and dividing the difference by the pooled SD of the change scores in each group. ES was then corrected for small-sample bias using Hedges' g and reported with 95% confidence intervals (CIs). ES was categorised as trivial (<0.02), small (0.02-0.6), moderate (0.6-1.2), large (1.2-2.0) or very large (>2.0).[7] Positive ES favoured Brain or Body training while negative favoured Control.

RESULTS

Participant characteristics

The participant characteristics at baseline are summarised in Table 1. The three groups were similar with respect to age ($F_{2,130} = 3.0$, $p = 0.054$, $\eta^2=0.04$) and predicted age of puberty ($F_{2,130} = 1.8$, $p = 0.17$, $\eta^2=0.03$). The age and maturation data indicated that, as a group, the participants had passed the age of peak pubertal growth, but there was a group difference in years after APHV ($F_{2,130} = 4.6$, $p = 0.01$, $\eta^2=0.07$) which, on *post hoc* testing, showed that the Body group was more advanced in pubertal growth than the Control group ($p = 0.008$), though not the Brain group.

The participants' mean body mass and BMI were all within the healthy range and their mean cardiorespiratory fitness was within the Healthy Fitness Zone.[62] There were no differences in height at baseline ($F_{2,130} = 2.4$, $p = 0.10$, $\eta^2=0.04$) but there was a group difference in body mass ($F_{2,130} = 5.1$, $p < 0.01$, $\eta^2=0.08$), where *post hoc* tests showed that the Body group was heavier than the Control group ($p = 0.004$), though not the Brain group. This in turn was reflected in a group difference in BMI ($F_{2,130} = 3.7$, $p < 0.05$, $\eta^2=0.05$), where *post hoc* tests showed that the Body group was higher than the Control group ($p = 0.02$), though not the Brain group. There were no significant group differences in waist circumference ($F_{2,130} = 2.9$, $p = 0.06$, $\eta^2=0.04$), waist/height ratio ($F_{2,130} =1.6$, $p = 0.20$, $\eta^2=0.02$) or aerobic fitness ($F_{2,130} = 2.5$, $p = 0.09$, $\eta^2=0.04$) at baseline.

Table 1: Participants characteristics at baseline.

	Total (n = 133)	Control (n=45)	Body (n=43)	Brain (n=45)
		Age and maturation		
Age	15.7 ± 0.4	15.6 ± 0.4	15.8 ± 0.5	15.7 ± 0.5
APHV (yrs)	14.0 ± 0.5	14.1 ± 0.6	13.9 ± 0.5	13.9 ± 0.5
Years after APHV	1.7 ± 0.7	1.5 ± 0.7	*1.9 ± 0.6	1.8 ± 0.6
		Anthropometric variables		
Height (m)	1.72 ± 0.06	1.70 ± 0.07	1.73 ± 0.05	1.71 ± 0.07
Body mass (kg)	61.5 ± 12.6	57.7±8.2	*66.0 ± 16.0	61.0 ± 11.2
BMI (kg.m^{-2})	20.8 ± 3.6	19.8 ± 2.3	*21.9 ± 4.5	20.8 ± 3.5
Waist circumference (cm)	74.4 ± 10.3	72.3±6.7	77.3±13.0	73.9±10.1
Waist to height ratio	0.43 ± 0.06	0.42 ± 0.04	0.45 ± 0.07	0.43 ± 0.06
		Aerobic fitness		
$\dot{V}O_{2peak}$ (ml.kg^{-1}.min^{-1})	45.0 ± 5.3	46.1 ± 5.0	45.0 ± 5.8	43.9 ± 4.8

Data presented as mean ± SD; (APHV): Age of Peak Height Velocity, indicative of age of peak pubertal growth; (BMI): Body Mass Index; (cm): Centimetres; (kg): Kilogram; (m): Metres; (ml): Millilitres; (min): Minute; ($\dot{V}O_{2peak}$): Peak rate of Oxygen Consumption.; (yrs): Years. *: significantly different from Control group; $p < 0.05$.

Over the nine weeks from baseline to post-testing, there was a small increase in height across the three groups (from 1.716 ± 0.063 to 1.720 ± 0.064 m; $F_{1,130} = 11.0$, $p < 0.01$, $\eta^2=0.08$), with no difference between groups in this respect ($F_{2,130} = 2.5$, $p = 0.09$, $\eta^2=0.04$). There were two significant changes in group characteristics as a result of the training intervention, as reflected in significant interactions between the training groups and the pre/post testing of fitness ($F_{2,130} = 9.3$, $p < 0.001$, $\eta^2=0.12$) and BMI ($F_{2,130} = 3.9$, $p < 0.05$, $\eta^2=0.06$). *Post hoc* tests showed that fitness (Figure 1) increased ($p < 0.001$; ES = 0.49 [0.06 to 0.91]) and BMI (Figure 2) decreased ($p = 0.04$; ES = 0.16 [-0.27 to 0.58]) with training in the Body group, with no significant changes in the other two groups. 'Body' group participants' heart rate and RPE were maintained within the targeted zone (75-90% of HR_{max}) and a score of 8 to 10 respectively regardless of the exercise prescribed throughout the intervention.

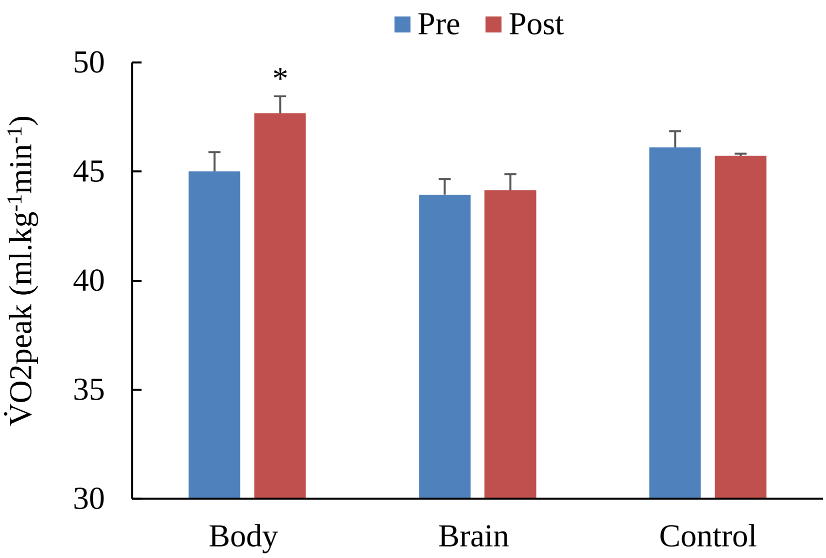


Figure 1: Group mean (± SE) aerobic fitness before and after the interventions. *significantly different to before intervention, $p < 0.05$.

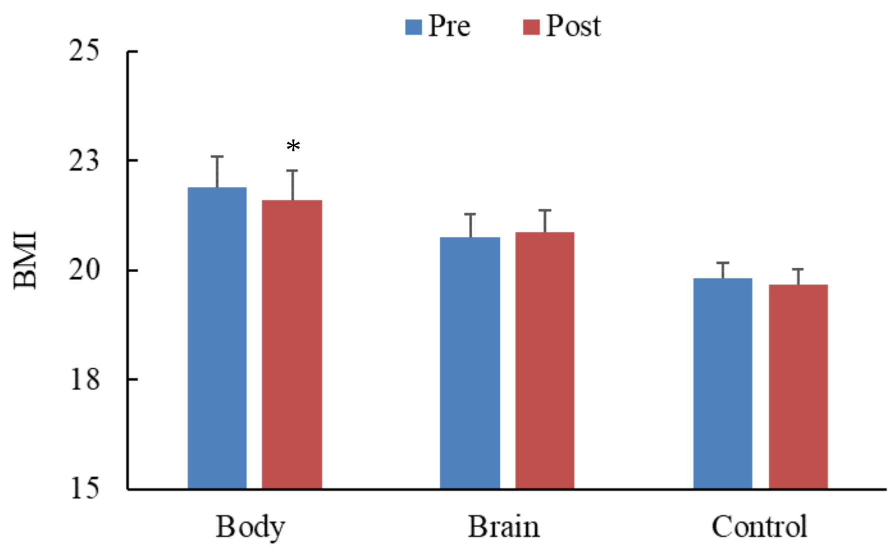


Figure 2: Group mean (± SE) BMI before and after the interventions. *significantly different to before intervention, $p < 0.05$.

Thinking

The three groups performed well on the thinking tests, with mean z-scores all above zero both before and after the training interventions, with one minor exception (Figure 3). There was no significant beneficial effect on thinking scores from any training intervention ($F_{2,130} = 0.59$, $p = 0.55$, $\eta^2=0.009$). There was a significant overall difference between the groups independent of training ($F_{2,130} = 3.3$, $p < 0.05$, $\eta^2=0.05$), which *post hoc* tests showed was attributable to an overall difference between the Control and Brain groups ($p = 0.028$). The Brain group had higher scores than the Control group across all domains, both before and after the interventions, with the exception of executive function post-training (Figure 3). The effect size in favour of the Brain group was moderate for thinking overall (ES = 0.70 [0.28 to 1.13]).

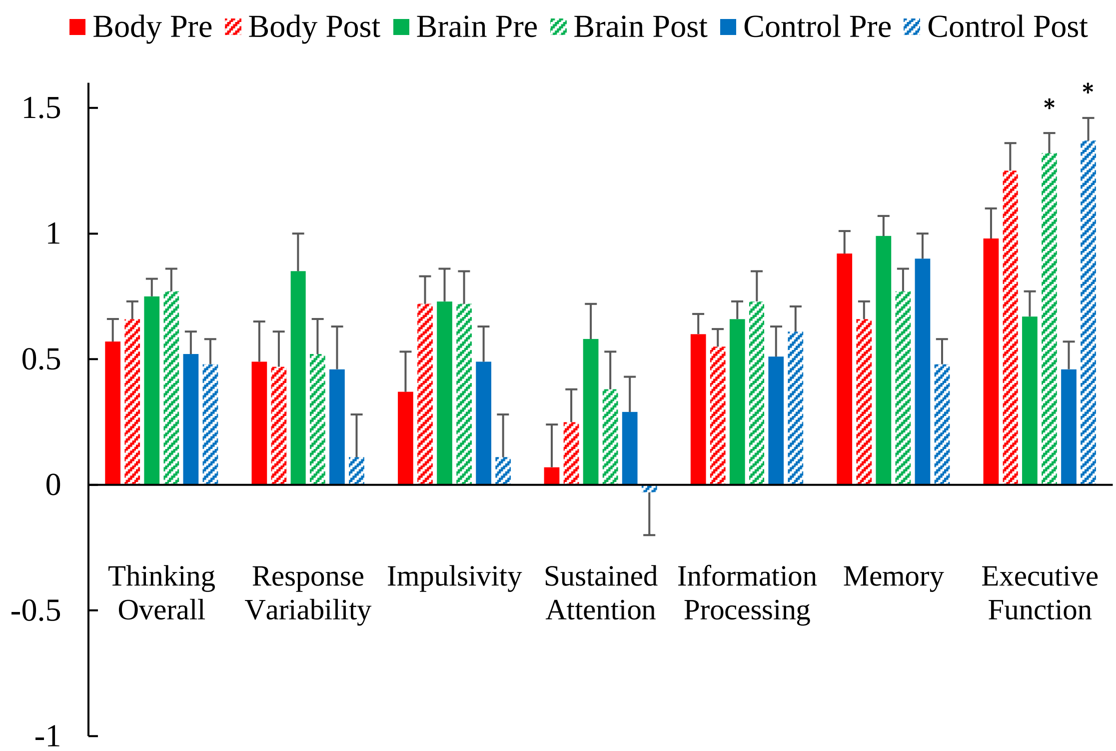


Figure 3: Group mean (± SE) BMI before and after the interventions. * significantly different to pre-intervention score, $p < 0.05$.

The only other significant effect detected was a three-way interaction between group, training and thinking sub-domains ($F_{12,780} = 4.8$, $p < 0.001$, $\eta^2=0.07$). *Post hoc* tests showed that this effect was due to significant post-intervention increases in executive function scores in the

Control (ES = 1.33 [0.87 to 1.78], p < 0.0001) and Brain training groups (ES = 1.02 [0.58 to 1.46], p < 0.0001). Indeed, all three groups showed high performance (z-score > 1) for executive function after the interventions, with little difference between the three groups in their post-test scores. Both the Control vs Brain overall group difference and the three-way interaction remained when BMI was included as a covariate in the analyses.

Feeling

The mean z-scores for feeling across the three groups were notable for being all below zero, both before and after the training interventions (Figure 4). The ANOVA detected no significant differences between training groups (p = 0.19), no significant changes as a result of the interventions (p = 0.22), nor any significant two- or three-way interactions (p ≥ 0.1). Univariate tests indicated a post-intervention group difference (p = 0.03), on which *post hoc* tests showed that the scores for the Control group decreased after the intervention (feeling overall: p = 0.014, ES = -0.26 [-0.68 to 0.15]; depression: p = 0.005, ES = -0.25 [-0.66 to 0.17]; anxiety: p = 0.006, ES = -1.64 [-2.12 to -1.16]; stress: p = 0.07, ES = -0.25 [-0.67 to 0.16]). These results were unaltered when BMI was included as a covariate in the analyses.

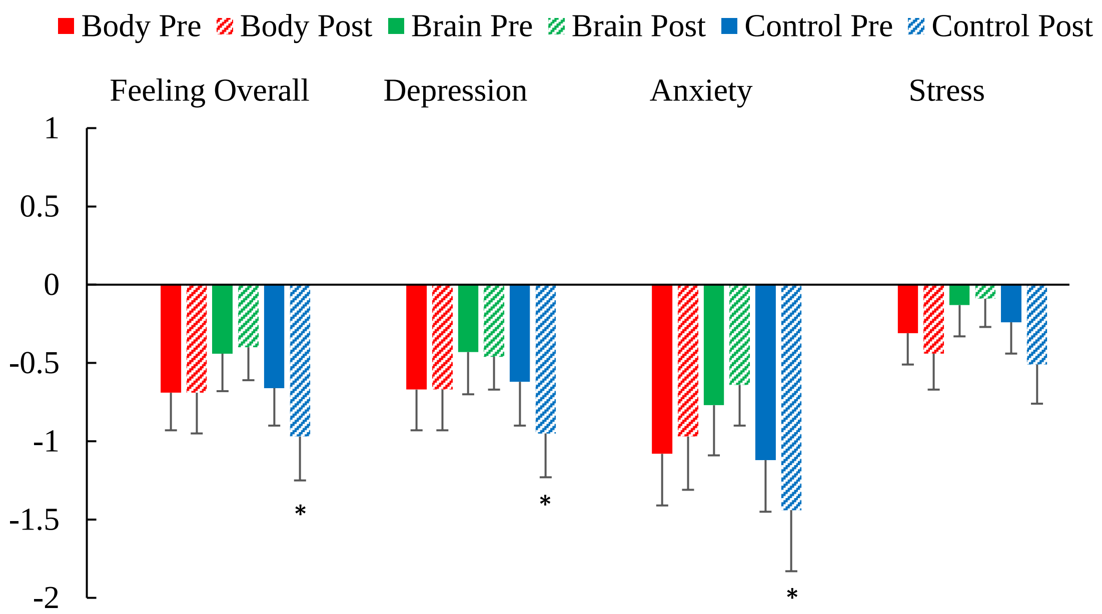


Figure 4: Group mean (± SE) feeling scores before and after the interventions. *significantly different to pre-intervention score, p < 0.05.

Self-regulation

The most notable feature of the self-regulation assessment was that the z-scores for negativity bias were all below -1.5 (Figure 5). The ANOVA detected no significant differences between training groups nor any significant changes as a result of the interventions. This result was unaltered when BMI was included as a covariate in the analyses.

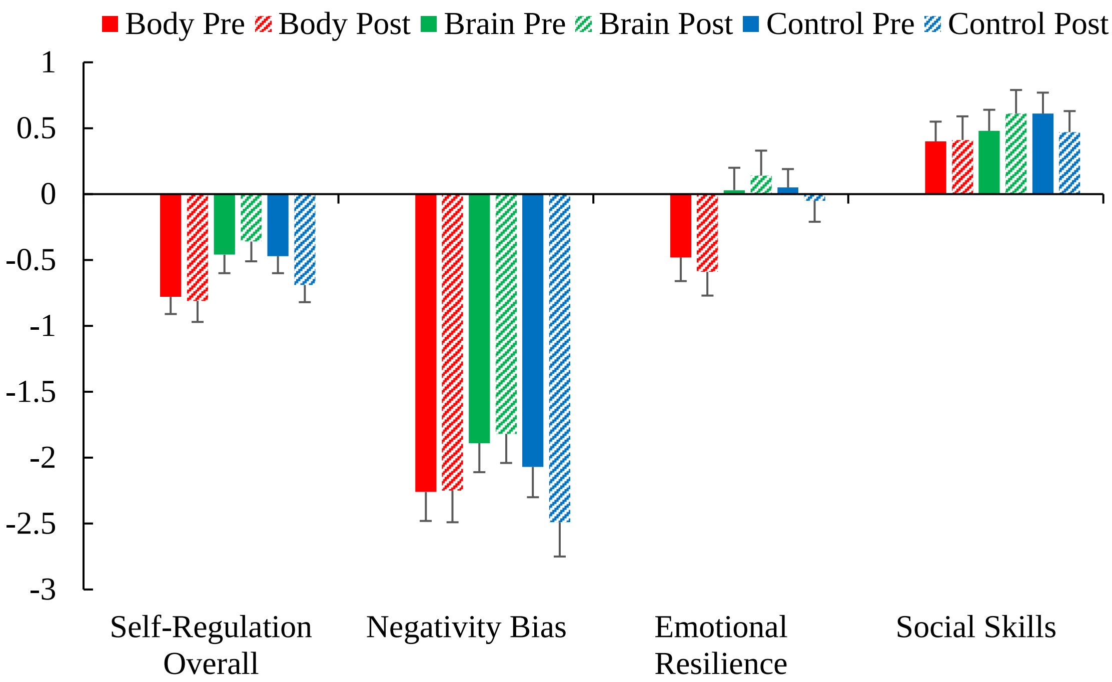


Figure 5: Group mean (± SE) self-regulation scores before and after the interventions.

Academic performance

The scores on the AGAT were all above 65% (Figure 6). An overall group difference ($F_{2,130}$ = 14.1, p < 0.0001, η^2=0.18) was observed where *post hoc* tests showed that the Brain group scored higher than both the Control (p < 0.0001) and Body (p < 0.01) groups across all sub-domains, both before and after the intervention. For the AGAT overall scores, the effect size was large for the comparison against the Body group (ES = 1.71 [1.22 to 2.19]) and small for the comparison against the Control group (ES = 0.48 [0.05 to 0.90]). In addition, an interaction between the groups and the interventions ($F_{2,130}$ = 3.9, p < 0.05, η^2=0.06) was shown on *post hoc* tests to reflect that fact that the Control group score was lower after the intervention across all domains (p = 0.005). For the AGAT overall scores, the effect size was small (ES = 0.16 [-0.05 to 0.37]).

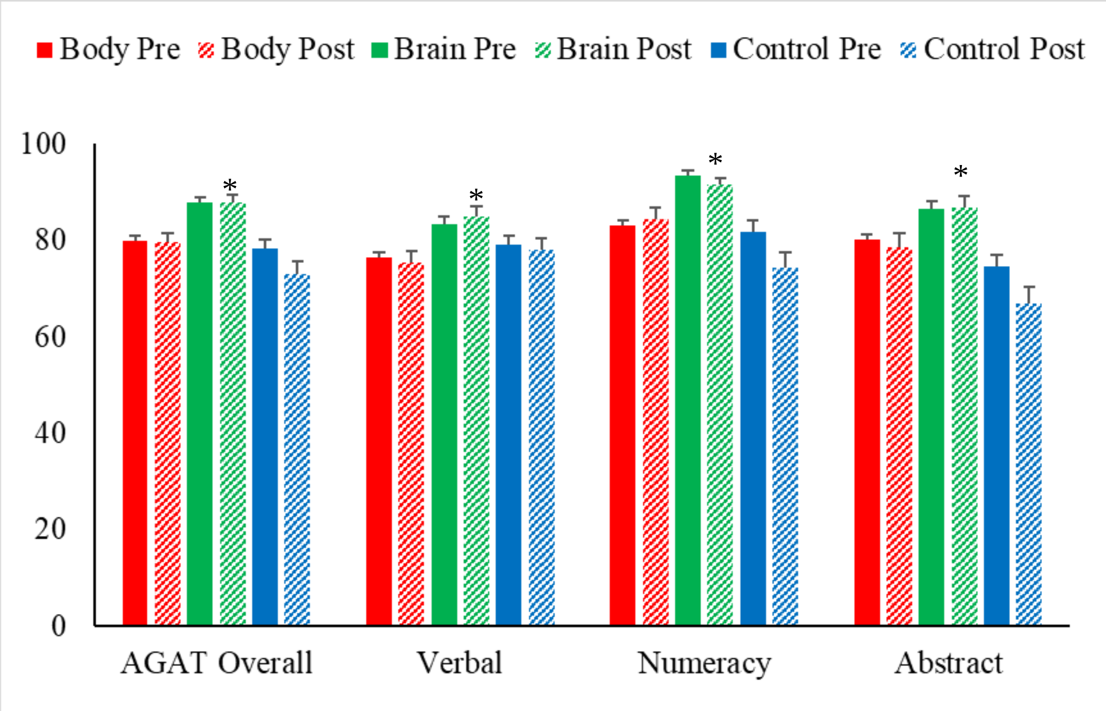


Figure 6: Group mean (± SE) AGAT scores before and after the interventions. * significantly different to pre- and post-intervention scores of Control and Body groups, p < 0.05.

DISCUSSION

This study aimed to investigate the effects of both aerobic and brain exercise on cognitive function and academic achievement and to examine if aerobic exercise improved academic performance to a greater extent than brain exercise. Contrary to the hypothesis tested, the results showed that neither aerobic nor brain exercise demonstrated any significant benefit to measures of cognitive function or academic performance. Aerobic exercise, however, did improve participants' fitness but not body composition. The cohort overall displayed a high level of Thinking independently and academic competence but poor cognitive functioning in feelings and self-regulation, negativity bias, in particular.

Cognitive performance

The findings that Body training did not lead to any other beneficial effects on thinking, feeling, self-regulation is at odds with the findings of a recent review[64] on high intensity interval training which showed improvements in cognition in children and adolescents (5 to 18 years). The exercise intensity involved in high intensity interval training typically ranges from 85% of maximum heart rate to exercising at a maximal effort.[65] This is higher than our prescribed Body training exercise intensity of 75% to 90% HR_{max} and could possibly indicate that a higher exercise intensity is required in healthy adolescent males to elicit any exercise-induced cognitive enhancements.

A plethora of studies in recent years have demonstrated the beneficial effects of exercise and physical activity on cognitive function in children with ADHD,[66-73] and older adults with Alzheimer's disease and dementia[47,67,74] but not in healthy populations. However there also have been evidence indicating that exercise did not improve cognition. This view is supported by an 8-week aerobic exercise intervention in young adults (aged 21±1.27 years) did not improve cognitive function or change plasma biochemical marker concentrations.[75] Collectively, these studies suggest that cognitive function may not be as susceptible to change after exercise in healthy brains or that longer study duration may be required to endorse improved cognitive function.

Brain training showed no significant effects on any measure of cognition contrary to previous studies, predominantly in adults. Training in tasks designed to improve reasoning, memory, planning, visuospatial skills and attention, for a minimum of 10 minutes, three times per week, over six weeks in adults (n = 11,430 aged 18 to 60 years) showed significant improvements across all cognitive assessments.[76] The current study (one hour, twice per week, over 8 weeks) differed from the aforementioned trial, mainly in the longer duration of the training sessions and younger participants, so it is possible that a protocol higher in frequency but shorter in duration could produce better outcomes in this population. However, it may very well be that the cognitive function is difficult to influence.

Academic performance: AGAT

Contrary to the hypothesis that both intervention protocols would result in measurable changes in both CF and AP, neither aerobic nor brain training improved academic performance measured by AGAT. This finding adds to the current literature that the relationship between physical activity interventions and AP is inconsistent amongst children (6 to 12 years).[77] In a recent systematic review, 60% of analyses (25 constructs) across six high quality studies[78-83] were found to favour the beneficial effect of exercise on AP.[77] Across the entire cohort, irrespective of group allocation, academic performance was good, with most scores above 75%. An overall group difference was observed where the Brain group scored significantly higher across all sub-domains compared with the Control and Body groups, before and after the intervention. The Control group did display slight decrements across all domains in AP. Brain and Control group results cannot be attributed to a training stimulus, suggesting that some unknown factor(s) may have impacted the groups.

The entire cohort, irrespective of group allocation, performed well in thinking, with scores in all sub-domains above zero. As participants were from an academic selective top-tiered high schools[84], this finding is consistent with literature supporting cognitive function as a predictor of academic success and performance.[85] All three groups showed higher scores for executive function on the post-training assessments. In particular, the Brain and Control groups showed significantly large improvements with moderate (1.02) and large (1.33) effect sizes. These changes cannot be attributed to the training interventions and suggest that some unknown factor affected all three groups. In contrast, performance in all feeling domains was poor, with participants scoring negatively, especially for depression and anxiety. Being highly anxious and depressed can have serious negative implications not only for one's mental health, but can also suppress cognitive development and brain function when the stress is prolonged.[86] Additionally, a major concern from our results was that participants in all groups scored poorly on the self-regulation; the sub-domain of negativity bias being particularly low. This reflects hypersensitivity to stress and as a result, poor brain health.[87-89] These results in feeling and self-regulation are consistent with a national trend in Singapore where academic performance is highly prioritised but students report lower life satisfaction.[90] In the 2015 triennial Programme for International Student Assessment (PISA) survey that covered more than 70 nations, Singaporean students ranked consistently in the top three globally in terms of academic performance. However they had significantly higher school-related anxiety and stress, with 86% of Singaporean students surveyed indicating being worried and anxious about school tests and grades, compared with the Organisation for Economic Cooperation and Development average of 66%.[91] This situation might be the unintended cost of high performance[92] but it could also be due to Singapore's deeply rooted competitive culture where people are driven hard due to the fear of losing out.[93] Thus, it is imperative that the respective student governing bodies in both the schools and the nation to actively implement interventions and measure that can be taken, to prevent the worsening of students' mental health which in turn has been shown to adversely[94] impact cognition.[95-97] It has been suggested that the key to improving students' wellbeing in Singapore is to create appropriate learning challenges while providing necessary and adequate support for students to foster grit and resilience.[98]

Aerobic fitness and BMI

In line with the hypothesis, the Body training group significantly increased its aerobic fitness from 45 to 47.7 ml.kg^{-1}min^{-1}.The improved fitness confirms the efficacy of this exercise program for male adolescents in a school setting, based on one-hour sessions at a HRmax of 75-90%, running twice a week for eight weeks. The findings support the conclusion of a recent meta-analysis[99] that improved cardiorespiratory fitness can be obtained with a minimum exercise protocol of 20 minutes of moderate intensity twice a week for 11 days in children and adolescents. Body training significantly improved body mass index but not the waist to height ratio of participants.

A key limitation of this study is the participant selection bias whereby only males from one elite high school were recruited. The limitation of sampling to an academic-selective high school as well as participants coming from only one high school is recognised as a key contributor to the null findings. A further number of limitations in this study are recognised. The study was carried out during term in a high school setting allowing only an 8-week study duration. Because recruitment of participants was limited by the students' availability during term time, as well as by their fixed class schedule, the intervention protocol was also limited in its frequency and duration, being restricted to the two hours per week of physical education lessons. To minimise disruptions to class and maximise intervention participation time, participants were block randomised according to their classes. This limitation likely resulted in these differences in group anthropometric characteristics, simply by chance. Further investigation examining the effects of frequency and exercise duration on improvement of both cognition and aerobic fitness in adolescents, in a completely randomised trial is warranted.

CONCLUSION

The results of this study do not support the hypothesis that a body or brain training protocol over eight weeks can elicit positive cognitive and academic change in adolescent males. This could perhaps be attributed to the insufficient duration of the intervention protocols, with future studies examining the frequency and duration of brain and body training in adolescents warranted A key finding of this study is that all participants were found to have negative Feeling and Self-regulation scores which indicates high levels of anxiety, stress as well as sensitivity to stress, and depression. Perhaps the implementation of regular annual screening of the cognitive domains of Feeling and Self-regulation, through a platform similar to Brief Risk-Resilience Index for Screening (BRISC) and the Depression Anxiety Stress Scale (DASS) could serve as a means to monitoring the brain health of adolescent-aged students.

REFERENCES

1 Giedd, J. N., Blumenthal, J., Jeffries, N. O., Castellanos, F. X., Liu, H., Zijdenbos, A., Paus, T., Evans, A. C., & Rapoport, J. L. (1999). Brain development during childhood and adolescence: a longitudinal MRI study. *Nature Neuroscience, 2*(10), 861-863.

2 Sowell, E. R., Thompson, P. M., Welcome, S. E., Henkenius, A. L., Toga, A. W., & Peterson, B. S. (2003). Cortical abnormalities in children and adolescents with attention-deficit hyperactivity disorder. *The Lancet*, *362*(9397), 1699-1707.

3 Fuster, J. (2015). *The prefrontal cortex*. Academic Press.

4 Cotman, C. W., & Berchtold, N. C. (2002). Exercise: a behavioral intervention to enhance brain health and plasticity. *Trends in Neurosciences, 25*(6), 295-301.

5 Swain, R. A., Harris, A. B., Wiener, E. C., Dutka, M. V., Morris, H. D., Theien, B. E., Konda, S., Engberg, K., Lauterbur, P. C., & Greenough, W. T. (2003). Prolonged exercise induces angiogenesis and increases cerebral blood volume in primary motor cortex of the rat. *Neuroscience*, *117*(4), 1037-1046.

6 Colcombe, S. J., Erickson, K. I., Raz, N., Webb, A. G., Cohen, N. J., McAuley, E., & Kramer, A. F. (2003). Aerobic fitness reduces brain tissue loss in aging humans. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 58*(2), M176-M180.

7 Li, J. W., O'Connor, H., O'Dwyer, N., & Orr, R. (2017). The effect of acute and chronic exercise on cognitive function and academic performance in adolescents: A systematic review. *Journal of Science and Medicine in Sport*, *20*(9), 841-848.

8 Esteban-Cornejo, I., Tejero-Gonzalez, C. M., Sallis, J. F., & Veiga, O. L. (2015). Physical activity and cognition in adolescents: A systematic review. *Journal of Science and Medicine in Sport*, *18*(5), 534-539.

9 Ruiz-Ariza, A., Grao-Cruces, A., de Loureiro, N. E. M., & Martinez-Lopez, E. J. (2017). Influence of physical fitness on cognitive and academic performance in adolescents: A systematic review from 2005–2015. *International Review of Sport and Exercise Psychology*, *10*(1), 108-133.

10 Ardoy, D. N., Fernández-Rodríguez, J., Jiménez-Pavón, D., Castillo, R., Ruiz, J., & Ortega, F. (2014). A physical education trial improves adolescents' cognitive performance and academic achievement: the EDUFIT study. *Scandinavian Journal of Medicine & Science in Sports, 24*(1), e52-e61.

11 Zervas, Y., Danis, A., & Klissouras, V. (1991). Influence of physical exertion on mental performance with reference to training. *Perceptual and Motor Skills, 72*(3_suppl), 1215-1221.

12 Budde, H., Voelcker-Rehage, C., Pietrassyk-Kendziorra, S., Machado, S., Ribeiro, P., & Arafat, A. M. (2010). Steroid hormones in the saliva of adolescents after different exercise intensities and their influence on working memory in a school setting. *Psychoneuroendocrinology, 35*(3), 382-391.

13 Budde, H., Voelcker-Rehage, C., Pietraßyk-Kendziorra, S., Ribeiro, P., & Tidow, G. (2008). Acute coordinative exercise improves attentional performance in adolescents. *Neuroscience Letters, 441*(2), 219-223.

14 Stroth, S., Kubesch, S., Dieterle, K., Ruchsow, M., Heim, R., & Kiefer, M. (2009). Physical fitness, but not acute exercise modulates event-related potential indices for executive control in healthy adolescents. *Brain Research*, *1269*, 114-124.

15 Travlos, A. K. (2010). High intensity physical education classes and cognitive performance in eighth-grade students: An applied study. *International Journal of Sport and Exercise Psychology*, *8*(3), 302-311.

16 Soga, K., Shishido, T., & Nagatomi, R. (2015). Executive function during and after acute moderate aerobic exercise in adolescents. *Psychology of Sport and Exercise, 16*, 7-17.

17 Hogan, M., Kiefer, M., Kubesch, S., Collins, P., Kilmartin, L., & Brosnan, M. (2013). The interactive effects of physical fitness and acute aerobic exercise on

electrophysiological coherence and cognitive performance in adolescents. *Experimental Brain Research*, *229*(1), 85-96.

18 Cooper, S. B., Bandelow, S., Nute, M. L., Morris, J. G., & Nevill, M. E. (2012). The effects of a mid-morning bout of exercise on adolescents' cognitive function. *Mental Health and Physical Activity, 5*(2), 183-190.

19 Gu, H. M., Shin, D. S., Lee, K. H., Choi, J. S., & Yu, J. (1992). The relationship between physical exercise and cognitive ability (II). *Korean Journal of Sports Science, 4*, 70-78.

20 World Health Organization. (2019). *New WHO-led study says majority of adolescents worldwide are not sufficiently physically active, putting their current and future health at risk.* https://www.who.int/news/item/22-11-2019-new-who-led-study-says-majority-of-adolescents-worldwide-are-not-sufficiently-https://www.who.int/news/item/22-11-2019-new-who-led-study-says-majority-of-adolescents-worldwide-are-not-sufficiently-physically-active-putting-their-current-and-future-health-at-risk.

21 Abarca-Gómez, L., Abdeen, Z. A., Hamid, Z. A., Abu-Rmeileh, N. M., Acosta-Cazares, B., Acuin, C., Adams, R. J., Aekplakorn, W., Afsana, K., & Aguilar-Salinas, C. A. (2017). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128· 9 million children, adolescents, and adults. *The Lancet, 390*(10113), 2627-2642.

22 Ross, N., Yau, P. L., & Convit, A. (2015). Obesity, fitness, and brain integrity in adolescence. *Appetite, 93*, 44-50.

23 Verstynen, T. D., Weinstein, A., Erickson, K. I., Sheu, L. K., Marsland, A. L., & Gianaros, P. J. (2013). Competing physiological pathways link individual differences in weight and abdominal adiposity to white matter microstructure. *Neuroimage, 79*, 129-137.

24 Davis, C. L., Tkacz, J. P., Tomporowski, P. D., & Bustamante, E. E. (2015). Independent associations of organized physical activity and weight status with children's cognitive functioning: a matched-pairs design. *Pediatric Exercise Science, 27*(4), 477-487.

25 Li, Y., Dai, Q., Jackson, J. C., & Zhang, J. (2008). Overweight is associated with decreased cognitive functioning among school-age children and adolescents. *Obesity, 16*(8), 1809-1815.

26 Tandon, P., Thompson, S., Moran, L., & Lengua, L. (2015). Body mass index mediates the effects of low income on preschool children's executive control, with implications for behavior and academics. *Childhood Obesity, 11*(5), 569-576.

27 Wirt, T., Schreiber, A., Kesztyüs, D., & Steinacker, J. M. (2015). Early life cognitive abilities and body weight: cross-sectional study of the association of inhibitory control, cognitive flexibility, and sustained attention with BMI percentiles in primary school children. *Journal of Obesity, 2015*.

28 Pontifex, M. B., Kamijo, K., Scudder, M. R., Raine, L. B., Khan, N. A., Hemrick, B., Evans, E. M., Castelli, D. M., Frank, K. A., & Hillman, C. H. (2014). V. The differential association of adiposity and fitness with cognitive control in preadolescent children. *Monographs of the Society for Research in Child Development, 79*(4), 72-92.

29 Datar, A., Sturm, R., & Magnabosco, J. L. (2004). Childhood overweight and academic performance: national study of kindergartners and first-graders. *Obesity Research, 12*(1), 58-68.

30 Sardinha, L. B., Marques, A., Martins, S., Palmeira, A., & Minderico, C. (2014). Fitness, fatness, and academic performance in seventh-grade elementary school students. *BMC Pediatrics, 14*(1), 1-9.

31 Torrijos-Niño, C., Martínez-Vizcaíno, V., Pardo-Guijarro, M. J., García-Prieto, J. C., Arias-Palencia, N. M., & Sánchez-López, M. (2014). Physical fitness, obesity, and academic achievement in schoolchildren. *The Journal of Pediatrics, 165*(1), 104-109.

32 O'Connor, A. R., Han, S., & Dobbins, I. G. (2010). The inferior parietal lobule and recognition memory: expectancy violation or successful retrieval? *Journal of Neuroscience, 30*(8), 2924-2934.

33 Shipstead, Z., Harrison, T. L., & Engle, R. W. (2016). Working memory capacity and fluid intelligence: Maintenance and disengagement. *Perspectives on Psychological Science*, *11*(6), 771-799.

34 Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Shah, P. (2012). Cogmed and working memory training—Current challenges and the search for underlying mechanisms. *Journal of Applied Research in Memory and Cognition, 1*.

35 Harveson, A. T., Hannon, J. C., Brusseau, T. A., Podlog, L., Papadopoulos, C., Hall, M. S., & Celeste, E. (2019). Acute exercise and academic achievement in middle school students. *International Journal of Environmental Research and Public Health, 16*(19), 3527.

36 Rebok, G. W., Ball, K., Guey, L. T., Jones, R. N., Kim, H. Y., King, J. W., Marsiske, M., Morris, J. N., Tennstedt, S. L., & Unverzagt, F. W. (2014). Ten-year effects of the advanced cognitive training for independent and vital elderly cognitive training trial on cognition and everyday functioning in older adults. *Journal of the American Geriatrics Society, 62*(1), 16-24.

37 Bauer, A. C. M., & Andringa, G. (2020). The potential of immersive virtual reality for cognitive training in elderly. *Gerontology, 66*(6), 614-623.

38 Zinke, K., Einert, M., Pfennig, L., & Kliegel, M. (2012). Plasticity of executive control through task switching training in adolescents. *Frontiers in Human Neuroscience, 6*, 41.

39 Karbach, J., & Kray, J. (2009). How useful is executive control training? Age differences in near and far transfer of task-switching training. *Developmental Science, 12*(6), 978-990.

40 Loosli, S. V., Buschkuehl, M., Perrig, W. J., & Jaeggi, S. M. (2012). Working memory training improves reading processes in typically developing children. *Child Neuropsychology, 18*(1), 62-78.

41 Zorza, J. P., Marino, J., & Acosta Mesas, A. (2019). Predictive influence of executive functions, effortful control, empathy, and social behavior on the academic performance in early adolescents. *The Journal of Early Adolescence, 39*(2), 253-279.

42 Ludyga, S., Gerber, M., Brand, S., Holsboer-Trachsler, E., & Pühse, U. (2016). Acute effects of moderate aerobic exercise on specific aspects of executive function in different age and fitness groups: A meta-analysis. *Psychophysiology, 53*(11), 1611-1626.

43 Kremen, W. S., Beck, A., Elman, J. A., Gustavson, D. E., Reynolds, C. A., Tu, X. M., Sanderson-Cimino, M. E., Panizzon, M. S., Vuoksimaa, E., & Toomey, R. (2019). Influence of young adult cognitive ability and additional education on later-life cognition. *Proceedings of the National Academy of Sciences, 116*(6), 2021-2026.

44 Berchtold, N., Chinn, G., Chou, M., Kesslak, J., & Cotman, C. (2005). Exercise primes a molecular memory for brain-derived neurotrophic factor protein induction in the rat hippocampus. *Neuroscience, 133*(3), 853-861.

45 Cotman, C. W., Berchtold, N. C., & Christie, L.-A. (2007). Exercise builds brain health: key roles of growth factor cascades and inflammation. *Trends in Neurosciences, 30*(9), 464-472.

46 Intlekofer, K. A., Berchtold, N. C., Malvaez, M., Carlos, A. J., McQuown, S. C., Cunningham, M. J., Wood, M. A., & Cotman, C. W. (2013). Exercise and sodium butyrate transform a subthreshold learning event into long-term memory via a brain-derived neurotrophic factor-dependent mechanism. *Neuropsychopharmacology, 38*(10), 2027-2034.

47 Erickson, K. I., Voss, M. W., Prakash, R. S., Basak, C., Szabo, A., Chaddock, L., Kim, J. S., Heo, S., Alves, H., & White, S. M. (2011). Exercise training increases size of hippocampus and improves memory. *Proceedings of the National Academy of Sciences, 108*(7), 3017-3022.

48 Erickson, K., Weinstein, A. M., Verstynen, T. D., Voss, M. W., Prakash, R. S., Woods, J., McAuley, E., & Kramer, A. F. (2012). F1-03-01: The influence of an aerobic exercise intervention on brain volume in late adulthood. *Alzheimer's & Dementia, 8*(4s_Part_2), 81.

49 Scharfman, H., Goodman, J., Macleod, A., Phani, S., Antonelli, C., & Croll, S. (2005). Increased neurogenesis and the ectopic granule cells after intrahippocampal BDNF infusion in adult rats. *Experimental Neurology, 192*(2), 348-356.

50 Tolwani, R., Buckmaster, P., Varma, S., Cosgaya, J., Wu, Y., Suri, C., & Shooter, E. (2002). BDNF overexpression increases dendrite complexity in hippocampal dentate gyrus. *Neuroscience, 114*(3), 795-805.

51 Arancibia, S., Silhol, M., Mouliere, F., Meffre, J., Höllinger, I., Maurice, T., & Tapia-Arancibia, L. (2008). Protective effect of BDNF against beta-amyloid induced neurotoxicity in vitro and in vivo in rats. *Neurobiology of Disease, 31*(3), 316-326.

52 Ma, Q. (2008). Beneficial effects of moderate voluntary physical exercise and its biological mechanisms on brain health. *Neuroscience Bulletin, 24*(4), 265-270.

53 Papp, K. V., Walsh, S. J., & Snyder, P. J. (2009). Immediate and delayed effects of cognitive interventions in healthy elderly: a review of current literature and future directions. *Alzheimer's & Dementia, 5*(1), 50-60.

54 Smith, G. E., Housen, P., Yaffe, K., Ruff, R., Kennison, R. F., Mahncke, H. W., & Zelinski, E. M. (2009). A cognitive training program based on principles of brain plasticity: results from the Improvement in Memory with Plasticity-based Adaptive Cognitive Training (IMPACT) Study. *Journal of the American Geriatrics Society, 57*(4), 594-603.

55 Thorell, L. B., Lindqvist, S., Bergman Nutley, S., Bohlin, G., & Klingberg, T. (2009). Training and transfer effects of executive functions in preschool children. *Developmental Science, 12*(1), 106-113.

56 Green, C. S., & Bavelier, D. (2008). Exercising your brain: a review of human brain plasticity and training-induced learning. *Psychology and Aging, 23*(4), 692.

57 Hertzog, C., Kramer, A. F., Wilson, R. S., & Lindenberger, U. (2008). Enrichment effects on adult cognitive development: can the functional capacity of older adults be preserved and enhanced? *Psychological Science in the Public Interest, 9*(1), 1-65.

58 Ackerman, P. L., Kanfer, R., & Calderwood, C. (2010). Use it or lose it? Wii brain exercise practice and reading for domain knowledge. *Psychology and Aging, 25*(4), 753.

59 Mirwald, R. L., Baxter-Jones, A. D., Bailey, D. A., & Beunen, G. P. (2002). An assessment of maturity from anthropometric measurements. *Medicine and Science in Sports and Exercise, 34*(4), 689-694.

60 Leger, L. A., & Lambert, J. (1982). A maximal multistage 20-m shuttle run test to predict VO_2 max. *European Journal of Applied Physiology and Occupational Physiology, 49*(1), 1-12.

61 Leger, L. A., Mercier, D., Gadoury, C., & Lambert, J. (1988). The multistage 20 metre shuttle run test for aerobic fitness. *Journal ofsports sciences, 6*(2), 93-101.

62 Welk, G. J., Maduro, P. F. D. S.-M., Laurson, K. R., & Brown, D. D. (2011). Field evaluation of the new FITNESSGRAM® criterion-referenced standards. *American Journal of Preventive Medicine, 41*(4), S131-S142.

63 Borg, G. (1998). *Borg's perceived exertion and pain scales*. Human Kinetics.

64 Leahy, A. A., Mavilidi, M. F., Smith, J. J., Hillman, C. H., Eather, N., Barker, D., & Lubans, D. R. (2020). Review of high-intensity interval training for cognitive and mental health in youth. *Medicine & Science in Sports & Exercise, 52*(10), 2224-2234.

65 Costigan, S. A., Eather, N., Plotnikoff, R. C., Taaffe, D. R., & Lubans, D. R. (2015). High-intensity interval training for improving health-related fitness in

adolescents: a systematic review and meta-analysis. *British Journal of Sports Medicine, 49*(19), 1253-1261.
66 Choi, J. W., Han, D. H., Kang, K. D., Jung, H. Y., & Renshaw, P. F. (2015). Aerobic exercise and attention deficit hyperactivity disorder: brain research. *Medicine and Science in Sports and Exercise, 47*(1), 33.
67 Colcombe, S. J., Erickson, K. I., Scalf, P. E., Kim, J. S., Prakash, R., McAuley, E., Elavsky, S., Marquez, D. X., Hu, L., & Kramer, A. F. (2006). Aerobic exercise training increases brain volume in aging humans. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 61*(11), 1166-1170.
68 Seifert, T., Rasmussen, P., Brassard, P., Homann, P. H., Wissenberg, M., Nordby, P., Stallknecht, B., Secher, N. H., & Nielsen, H. B. (2009). Cerebral oxygenation and metabolism during exercise following three months of endurance training in healthy overweight males. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 297*(3), R867-R876.
69 Cerrillo-Urbina, A. J., García-Hermoso, A., Sánchez-López, M., Pardo-Guijarro, M. J., Santos Gómez, J., & Martínez-Vizcaíno, V. (2015). The effects of physical exercise in children with attention deficit hyperactivity disorder: A systematic review and meta-analysis of randomized control trials. *Child: Care, Health and Development, 41*(6), 779-788.
70 Hoza, B., Smith, A. L., Shoulberg, E. K., Linnea, K. S., Dorsch, T. E., Blazo, J. A., Alerding, C. M., & McCabe, G. P. (2015). A randomized trial examining the effects of aerobic physical activity on attention-deficit/hyperactivity disorder symptoms in young children. *Journal of Abnormal Child Psychology, 43*(4), 655-667.
71 Huang, C.-J., Huang, C.-W., Tsai, Y.-J., Tsai, C.-L., Chang, Y.-K., & Hung, T.-M. (2017). A preliminary examination of aerobic exercise effects on resting EEG in children with ADHD. *Journal of Attention Disorders, 21*(11), 898-903.
72 Williams, L. M., Gatt, J. M., Hatch, A., Palmer, D. M., Nagy, M., Rennie, C., Cooper, N. J., Morris, C., Grieve, S., & Dobson-Stone, C. (2008). The integrate model of emotion, thinking and self regulation: An application to the" paradox of aging". *Journal of Integrative Neuroscience, 7*(03), 367-404.
73 Benzing, V., Chang, Y.-K., & Schmidt, M. (2018). Acute physical activity enhances executive functions in children with ADHD. *Scientific Reports, 8*(1), 1-10.
74 Erickson, K. I., Prakash, R. S., Voss, M. W., Chaddock, L., Hu, L., Morris, K. S., White, S. M., Wójcicki, T. R., McAuley, E., & Kramer, A. F. (2009). Aerobic fitness is associated with hippocampal volume in elderly humans. *Hippocampus, 19*(10), 1030-1039.
75 Gourgouvelis, J., Yielder, P., Clarke, S. T., Behbahani, H., & Murphy, B. (2018). You can't fix what isn't broken: eight weeks of exercise do not substantially change cognitive function and biochemical markers in young and healthy adults. *PeerJ, 6*, e4675.
76 Owen, A. M., Hampshire, A., Grahn, J. A., Stenton, R., Dajani, S., Burns, A. S., Howard, R. J., & Ballard, C. G. (2010). Putting brain training to the test. *Nature, 465*(7299), 775-778.
77 Singh, A. S., Saliasi, E., van den Berg, V., Uijtdewilligen, L., de Groot, R. H. M., Jolles, J., Andersen, L. B., Bailey, R., Chang, Y. K., Diamond, A., Ericsson, I., Etnier, J. L., Fedewa, A. L., Hillman, C. H., McMorris, T., Pesce, C., Pühse,

U., Tomporowski, P. D., & Chinapaw, M. J. M. (2019). 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. *British Journal of Sports Medicine*, *53*(10), 640-647.

78 Ahamed, Y., Macdonald, H., Reed, K., Naylor, P. J., Liu-Ambrose, T., & McKay, H. (2007). School-based physical activity does not compromise children's academic performance. *Medicine & Science in Sports & Exercise*, *39*(2), 371-376.

79 Gao, Z., Hannan, P., Xiang, P., Stodden, D. F., & Valdez, V. E. (2013). Video game-based exercise, Latino children's physical health, and academic achievement. *American Journal of Preventive Medicine*, *44*(3 Suppl 3), S240-246.

80 Telford, R. D., Cunningham, R. B., Fitzgerald, R., Olive, L. S., Prosser, L., Jiang, X., & Telford, R. M. (2012). Physical education, obesity, and academic achievement: a 2-year longitudinal investigation of Australian elementary school children. *American Journal of Public Health*, *102*(2), 368-374.

81 Donnelly, J. E., Greene, J. L., Gibson, C. A., Smith, B. K., Washburn, R. A., Sullivan, D. K., DuBose, K., Mayo, M. S., Schmelzle, K. H., Ryan, J. J., Jacobsen, D. J., & Williams, S. L. (2009). Physical Activity Across the Curriculum (PAAC): a randomized controlled trial to promote physical activity and diminish overweight and obesity in elementary school children. *Preventive Medicine*, *49*(4), 336-341.

82 Kirk, S. M., Vizcarra, C. R., Looney, E. C., & Kirk, E. P. (2014). Using physical activity to teach academic content: A study of the effects on literacy in head start preschoolers. *Early Childhood Education Journal*, *42*, 181-189.

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

84 Education, C. (2020). *Top 10 secondary schools with the most offers to Cambridge*. https://www.crimsoneducation.org/sg/blog/admissions-news/cambridge-acceptance-rates-schools/

85 Nesayan, A., Amani, M., & Gandomani, R. A. (2019). Cognitive profile of children and its relationship with academic performance. *Basic and Clinical Neuroscience*, *10*(2), 165-174.

86 Williams, L., Simms, E., Clark, C., Paul, R., Rowe, D., & Gordon, E. (2005). The test-retest reliability of a standardized neurocognitive and neurophysiological test battery:"neuromarker". *International Journal of Neuroscience*, *115*(12), 1605-1630.

87 Gordon, E. (2000). *Integrative neuroscience: Bringing together biological, psychological and clinical models of the human brain*. CRC Press.

88 Gordon, E. (2003). Integrative neuroscience. *Neuropsychopharmacology*, *28*(1), S2-S8.

89 Silverstein, S. M., Berten, S., Olson, P., Paul, R., Williams, L. M., Cooper, N., & Gordon, E. (2007). Development and validation of a World-Wide-Web-based neurocognitive assessment battery: WebNeuro. *Behavior Research Methods*, *39*(4), 940-949.

90 Gurria, A. (2016). PISA 2015 results in focus. *PISA in Focus*, (67), 1.

91 Jones, C. (2021). *Young singaporeans are stressed and anxious: Singapore's strategies to protect the mental health of students*. https://www.theearthawards.org/young-singaporeans-are-stressed-and-anxious-singapores-strategies-to-protect-the-mental-health-of-students/.
92 Zhao, Y. (2017). What works may hurt: Side effects in education. *Journal of Educational Change*, *18*(1), 1-19.
93 Ng, P. T. (2017). *Learning from Singapore: The power of paradoxes*. Routledge.
94 Mamrot, P., & Hanć, T. (2019). The association of the executive functions with overweight and obesity indicators in children and adolescents: A literature review. *Neuroscience & Biobehavioral Reviews, 107*, 59-68.
95 Alarcón, G., Ray, S., & Nagel, B. J. (2016). Lower working memory performance in overweight and obese adolescents is mediated by white matter microstructure. *Journal of the International Neuropsychological Society, 22*(3), 281-292.
96 Huang, T., Tarp, J., Domazet, S. L., Thorsen, A. K., Froberg, K., Andersen, L. B., & Bugge, A. (2015). Associations of adiposity and aerobic fitness with executive function and math performance in danish adolescents. *The Journal of Pediatrics*, *167*(4), 810-815.
97 Schwartz, D. H., Leonard, G., Perron, M., Richer, L., Syme, C., Veillette, S., Pausova, Z., & Paus, T. (2013). Visceral fat is associated with lower executive functioning in adolescents. *International Journal of Obesity, 37*(10), 1336-1343.
98 Ng, P. T. (2020). The Paradoxes of student well-being in Singapore. *ECNU Review of Education*, *3*(3), 437-451.
99 Carazo-Vargas, P., & Moncada-Jiménez, J. (2015). A meta-analysis on the effects of exercise training on the VO_{2max} in children and adolescents. *Retos. Nuevas tendencias en Educación Física, Deporte y Recreación*, (27), 184-187.

APPENDIX

Table A1: Group mean (±SD) cognitive function (z-scores) and academic performance (%) pre- and post-intervention

	Overall (n=133)		Body (n=43)		Brain (n=45)		Control (n=45)	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Thinking Overall	0.61 ± 0.54	0.64 ± 0.59	0.57 ± 0.57	0.66 ± 0.46	0.75 ± 0.47	0.77 ± 0.59	0.52 ± 0.57	0.48 ± 0.66
Response Variability	0.60 ± 1.07	0.36 ± 1.02	0.49 ± 1.07	0.47 ± 0.93	0.85 ± 1.00	0.52 ± 0.97	0.46 ± 1.11	0.11 ± 1.12
Impulsivity	0.53 ± 0.96	0.51 ± 0.96	0.37 ± 1.06	0.72 ± 0.72	0.73 ± 0.87	0.72 ± 0.86	0.49 ± 0.95	0.11 ± 1.13
Sustained Attention	0.32 ± 1.01	0.20 ± 1.02	0.07 ± 1.10	0.25 ± 0.84	0.58 ± 0.95	0.38 ± 1.02	0.29 ± 0.93	-0.03 ± 1.15
Information Processing	0.59 ± 0.61	0.63 ± 0.66	0.60 ± 0.52	0.55 ± 0.46	0.66 ± 0.44	0.73 ± 0.81	0.51 ± 0.80	0.61 ± 0.65
Memory	0.94 ± 0.59	0.79 ± 0.85	0.92 ± 0.59	0.74 ± 0.77	0.99 ± 0.52	0.95 ± 0.82	0.90 ± 0.66	0.69 ± 0.93
Executive Function	0.70 ± 0.77	1.32 ± 0.62	0.98 ± 0.78	1.25 ± 0.71	0.67 ± 0.70	1.32 ± 0.55	0.46 ± 0.75	1.37 ± 0.60
Feeling Overall	-0.60 ± 1.09	-0.69 ± 1.16	-0.69 ± 1.09	-0.69 ± 1.21	-0.44 ± 1.10	-0.40 ± 0.96	-0.66 ± 1.07	-0.97 ± 1.25
Depression	-0.57 ± 1.28	-0.69 ± 1.29	-0.67 ± 1.22	-0.67 ± 1.35	-0.43 ± 1.29	-0.46 ± 1.15	-0.62 ± 1.34	-0.95 ± 1.33
Anxiety	-0.99 ± 1.40	-1.02 ± 1.46	-1.08 ± 1.39	-0.97 ± 1.44	-0.77 ± 1.38	-0.64 ± 1.14	-1.12 ± 1.42	-1.44 ± 1.66
Stress	-0.23 ± 0.96	-0.35 ± 1.05	-0.31 ± 0.96	-0.44 ± 1.09	-0.13 ± 0.97	-0.09 ± 0.86	-0.24 ± 0.95	-0.51 ± 1.16
Self-Regulation Overall	-0.57 ± 0.88	-0.61 ± 1.01	-0.78 ± 0.86	-0.81 ± 1.05	-0.46 ± 0.92	-0.36 ± 1.04	-0.47 ± 0.85	-0.69 ± 0.90
Negativity Bias	-2.07 ± 0.47	-2.18 ± 1.60	-2.26 ± 1.45	-2.25 ± 1.54	-1.89 ± 1.45	-1.82 ± 1.45	-2.07 ± 1.53	-2.49 ± 1.76
Emotional Resilience	-0.13 ± 1.11	-0.16 ± 1.18	-0.48 ± 1.16	0.59 ± 1.15	0.03 ± 1.13	0.14 ±1.24	0.05 ± 0.96	-0.05 ± 1.04
Social Skills	0.50 ± 1.04	0.50 ± 1.13	0.40 ± 1.02	0.41 ± 1.15	0.48 ± 1.05	0.61 ± 1.19	0.61 ± 1.05	0.47 ± 1.05
AGAT Overall (%)	82.0 ± 11.0	80.2 ± 15.0	80.0 ± 10.8	89.5 ± 13.1	87.8 ± 7.0	87.9 ± 9.5	78.2 ± 12.3	73.0 ± 17.5
Verbal	79.7 ± 13.1	79.5 ± 15.9	76.4 ± 15.1	75.5 ± 15.6	83.3 ± 11.4	84.9 ± 13.6	79.1 ± 11.9	77.9 ± 17.1
Numeracy	86.1 ± 13.4	83.4 ± 17.1	83.1 ± 12.4	84.5 ± 14.3	93.3 ± 8.2	91.4 ± 10.1	81.8 ± 15.7	74.4 ± 20.7
Abstract	80.4 ± 14.5	77.4 ± 21.4	80.2 ± 13.5	78.6 ± 18.8	86.5 ± 10.9	86.8 ± 16.1	74.5 ± 16.3	66.8 ± 23.9

CHAPTER 6

The effect of acute exercise on cognitive function and academic performance in high-fit male adolescents: An acute dose-response study

FOREWORD

After the examination of the effects of chronic exercise on cognitive function and academic performance in adolescent in Chapter 5, this thesis sought to further broaden the scope of the investigation by examining the effect of single bouts of various exercise types have on CF and AP. Furthermore, the mechanisms of exercise-induced cognitive enhancement in chronic versus acute exercise are thought to be different (Chapter 1), with the former working through various persistent signal cascade over time to upregulate brain-derived neurotrophic factor (BDNF) leading to structural and physiological changes to the brain, while the latter transiently upregulates serum BDNF. BDNF is a protein found to promote neuron and synaptic growth, important in the development and maintenance of neural circuitry and brain function. Exercise intensity is thought to be a determining factor in eliciting various physiological response in the human body such as the upregulation of BDNF. Exercise intensity for this following chapter was guided by findings in the systematic review (Chapter 3) where positive cognitive changes required at least 75% of maximum heart rate. The study design in this chapter includes three different exercise types - steady state aerobic exercise, resistance exercise and stretching (acting as an active control protocol). This acute dose response study adopts a controlled cross-over model with intervention order randomised.

ABSTRACT

Objectives: To investigate the effect of acute exercise on cognitive function (CF) and academic performance (AP) in Australian male adolescents.

Design: Acute dose-response study evaluating the effectiveness of three acute exercise modalities (aerobic, resistance and stretching) on the CF and AP in male adolescents (13-18 years).

Methods: Male participants (n = 38, mean age 14.4 ±1 years) were recruited from an Australian independent high school. Participants underwent five consecutive weeks of acute intervention (all three modalities) and CF testing, including pre- and post-testing. Anthropometric measurements were taken to obtain body mass index (BMI), waist circumference and waist/height ratio (WtHR). Aerobic fitness ($\dot{V}O_2$ peak) was estimated using the 20m Shuttle Run Test. Thinking, feeling and self-regulation domains of CF were assessed using the WebNeuro™ platform. Academic performance (verbal, numeracy and abstract reasoning) was assessed using the Australian Council for Educational Research General Ability Test. Effect size (ES, Hedges g) was calculated where possible.

Results: A majority of the participants of this study had healthy BMI (86.8%) and WtHR (97.4%), and a majority (97.4%) were found to be in the high-fitness zone (Welks cut-off). Academic performance was good (70 - 78%) but did not improve after the five weeks of the acute interventions. Similarly, performance across the thinking, feeling and self-regulation domains of cognitive function was generally positive but did not improve following any intervention.

Conclusion: Acute aerobic, resistance and stretching exercise programs provided no beneficial impact on cognitive function or academic performance likely due to the transient effect of acute exercise.

Keywords: Working memory, executive function, students, fitness, depression

INTRODUCTION

In addition to the well-established benefits that exercise and physical activity confer to cardiovascular health, exercise is also a positively associated with brain health and function.[1] In the past two decades an emerging body of research has associated exercise, a subset of physical activity, to improvements in cognitive function.[2] Often, exercise-induced cognitive enhancement is linked to significant changes in the neural circuitry involved in learning and memory, such as the hippocampus and prefrontal cortex.[3,4] However, it is likely that the mechanism(s) underpinning these cognitive enhancements are impacted differentially for chronic and acute exercise.

Chronic exercise has been hypothesised to upregulate specific metabolic pathways such as the signal cascades of mitogen-activated protein/extracellular signal-regulated kinase (MAP/ERK) and calmodulin-dependent protein kinase 2 (CAMKII), which increase the production of brain-derived neurotrophic factor (BDNF) in the hippocampus and cortical region of the brain.[5,6] BDNF has been found to promote brain health via neurogenesis and synaptogenesis[7-11] and is thought to be associated with the cognitive functions of memory[12] and information processing.[13] Acute exercise, in single bouts, has been found to increase peripheral BDNF[14] that also contributes to enhanced neural circuitry and synaptic plasticity.[15] Exercise-induced cognitive enhancement elicited by acute exercise may be the result of generalised physiological arousal and to impact neural mechanisms via the upregulation of central and peripheral catecholamine pathways.[16]

Compared to other cognitive processes, those that require greater executive control seem to benefit from acute exercise to the greatest extent.[6] One such process is inhibitory control, a factor of executive function that is involved in the control over response inhibition.[17] Several studies have demonstrated acute effects of moderate and vigorus intensity aerobic exercise on inhibitory control.[18-20] Working memory, which involves the temporary maintenance of a limited amount of information online in an accessible state,[21] also has been demonstrated to show transient improvements following a 30 minute-bout of acute moderate- intensity aerobic exercise.[22]

Literature pertaining to the relationship between acute physical exercise and cognitive function have found some positive association between acute exercise and cognition.[23,24] However, some studies on this topic provide contradictory findings.[25]Such discrepancies in findings may be attributable to differences in intensity and duration of exercise between studies, since dose has shown to play a crucial role in the effect of exercise on cognitive performance.[5,6,26] Immediately after an exercise session of sub-maximal intensity (i.e. heart rate of 110-130 beats per minute, duration of 20-40 mins), there was an improvement in sensorimotor and cognitive performance.[25,27-30] However, studies investigating the mechanisms of exercise-induced cognitive enhancement in adolescent participants remains limited, where the plasticity of the brain and neuronal connectivity provide an opportune developmental phase to examine the potential cognitive and impact of exercise.[26,31]

Although there have been numerous health benefits associated with resistance training in both the young[1] and elderly,[32,33] research pertaining to resistance exercise and cognition be it acute or chronic have been rather limited,[27,34] but with a general consensus in findings that resistance exercise is beneficial to cognition.[35-37] It has been suggested in elderly population with mild cognitive impairments that long term resistance exercise upregulates hippocampal volume.[38] A recent study in adolescents (mean age 13.7 ± 0.5 years) found that participants performed significantly better in the cognitive assessment of the Stroop Test (a test of selective attention) after a bout of resistance exercise compared to a bout of aerobic exercise.[39]

Evidence supporting the beneficial effects of acute exercise on academic performance in adolescents is limited.[40] Studies investigating the effect of physical activity on academic performance in adolescents have however demonstrated a positive association between increased physical activity levels and better academic outcomes.[41,42]

To further develop the acute exercise-cognition understanding and better describe the cognitive mechanisms that are impacted by exercise and physical activity, it would be meaningful to examine the impact of different exercise modalities (aerobic, resistance or low-intensity stretching) on cognition. Given that the literature on acute exercise and cognition in adolescents is limited,[40] high-quality evidence is needed to better examine potential links between acute exercise and cognition. This study therefore aimed to investigate the relationship between acute exercise and both cognitive function (CF) and academic performance (AP) in adolescent schoolboys. It is hypothesised that aerobic and resistance exercise, but not stretching, would have a beneficial impact on CF, while AP would not be impacted because the effects of acute exercise, if any, were expected to be transient.

Participants

Adolescent males (n=38) aged 12.6 to 15.8 years (14.4 ± 1.0 years) from an elite independent high school in Australia participated in this study. At the point of testing, participants were undergoing their mandatory outdoor education curriculum which saw the test being conducted in the high school's satellite campus three hours south of Sydney, New South Wales, in Kangaroo Valley. The study was approved by the Human Research Ethics Committee of The University of Sydney (project number: 2014/166). Before taking part, the school, parents and participants were fully informed of the experimental protocol and gave written informed consent. Inclusion criteria were healthy adolescent boys aged 13-18 years or within one standard deviation of these age limits. Exclusion criteria were any medical condition which put participants at increased risk of injury or illness after submaximal physical exertion, colour blindness, any mental or physical impairment/injury and consumption of psychoactive substances. No participant was excluded due to these criteria.

Procedure

The experimental procedure was conducted in groups of four to six participants over five consecutive weeks. The entire cohort was completed across five months. Each session was carried out at the same time and day of the week. Each participant underwent five consecutive sessions starting with baseline testing, where the order of the events was standardised: anthropometric measurements, cognitive and academic testing, 20m shuttle run test. This was followed by three weeks of interventions, comprising the three exercise modalities: steady-state aerobic exercise, resistance exercise and stretching. The order of the exercise interventions was randomised across participants. Each session duration was 1.5 hours and consisted of 30 minutes of exercise, followed immediately by the cognitive testing. Participants were allowed a brief recess of two minutes to hydrate and cool down before taking the cognitive tests.

Participants underwent post-testing in the fifth week, repeating the procedures of the baseline-testing. Additional sessions were scheduled within the same week if participants missed a session. One participant incurred a shoulder injury unrelated to the intervention and had a month of medical leave before completing weeks two to five of the experiment. The study took place in the indoor sports hall as well as a classroom of the high school.

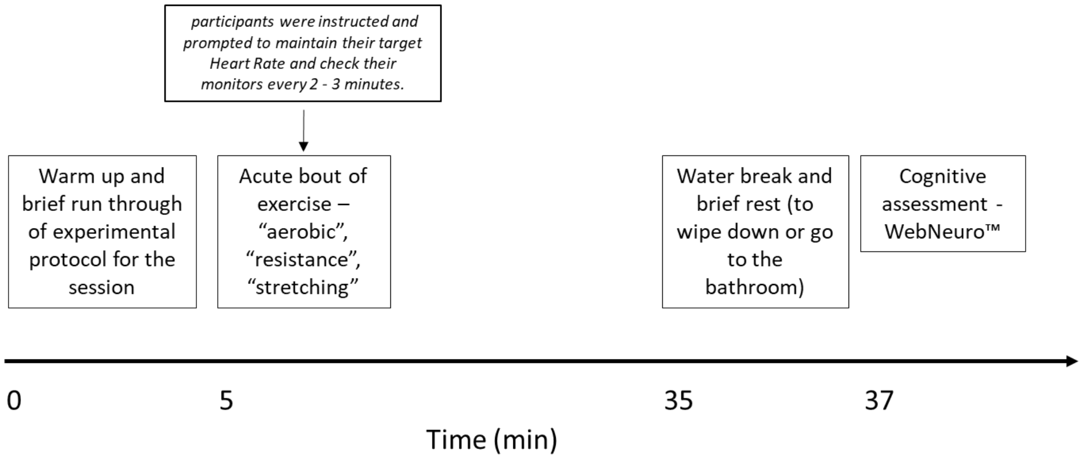


Figure 1: Experimental protocol

Intervention Protocols

All participants wore heart rate monitors before each session. They were instructed to regulate their level of physical exertion according to the targeted heart rate for each intervention. During each exercise intervention, participants were instructed to maintain their target HR and check their monitor every 2 - 3 minutes.

Steady-state aerobic exercise: This session was conducted on a cycle ergometer and consisted of five minutes of warm-up and 30 minutes of steady-state cycling at 65-75 revolutions per minute (rpm) at a power output of 180-220 Watts, whilst maintaining a constant heart rate kept of 75-80% of maximum heart rate (HRmax).

Resistance training: This session was conducted at the gym and consisted of five minutes of warm up and 30 minutes of body-weight resistance exercise. Participants completed three sets of exercises in a circuit style. Each set consisted of alternate lunges, push-ups, crunches, squats, incline pull-ups, plank, BOSU[43] half-ball single leg half-squats and Russian twist exercises. Participants were given rest at fixed intervals to ensure that their heart rate was maintained within the targeted zone (75-80% HRmax).

Stretching: Participants were given stretching exercises with a foam roller for the first 15 minutes, while the second 15 minutes consisted of stretching exercise without the roller. The stretching exercises involved mainly the muscles of the back and lower limbs. Exercise intensity was kept below 60% HRmax. The stretching intervention was designed as the control activity for the non-specific effects of intervention *per se*, while keeping the heart rate low.

Anthropometry and aerobic fitness testing

The height and body mass of participants were measured to calculate body mass index (BMI). Sitting height (torso length) was used to calculate leg length, which in turn was used to compute age of peak height velocity (APHV),[44] a measurement used to identify the approximate age of peak pubertal growth in participants, as an indicator of maturation. Waist circumference was measured at the mid-point between the lowest rib and the iliac crest in accordance with International Diabetes Federation guidelines, to provide an indication of body fat composition using waist/height ratio (WtHR). All measurements were carried out in duplicate by the same researcher to ensure consistency. A third measurement was taken if the difference between the two measurements exceeded 1%. The 20m shuttle-run test[45] was used to estimate peak aerobic capacity ($\dot{V}O_2$ peak). The test was carried out in the indoor sports gymnasium within the high school.

Cognitive testing

Cognitive function was assessed using WebNeuro™ (Brain Resource Company), a web-based platform, throughout all three studies. Refer to Methods Chapter (Page 24) for details of the cognitive testing.

Academic testing

Academic performance was assessed using the Australian Council for Educational Research General Ability Test (AGAT), a web-based test of three reasoning skill components: verbal, numeracy and abstract (visual). This assessment tool was also used across all three studies, only at baseline and final testing. Refer to Methods Chapter (Page 27) for more details.

Statistical analyses

Repeated measures factorial analyses of variance (ANOVAs) were used to compare outcome measures of CF and AP across the three interventions. In the analyses of CF, there was one group factor comprising the intervention conditions (baseline, stretching, resistance, aerobic, final test) and a second factor comprising the subdomains for the cognitive testing (thinking overall, response variability, impulsivity, sustained attention, information processing, memory, executive function). Both factors were fully repeated measures, since the same participants were tested across all subdomains in each intervention condition. ANOVAs were also carried out to compare the change from baseline for each of the three exercise interventions (aerobic, resistance, stretching). Tukey *post hoc* tests were carried to identify the locus of any significant effects observed in the omnibus tests.

In order to test for temporal effects due to repeated testing, CF was also analysed according to the chronological sequence of testing (baseline, post-intervention 1, post-intervention 2, post-intervention 3, final test). The four change scores from the previous test were also analysed chronologically (intervention 1-baseline, intervention 2-intervention 1, intervention 3-intervention 2, final test-intervention 3). In these tests, both factors (time, cognition subdomain) again were fully repeated measures. AP factors used in the repeated measures ANOVA were time (baseline, final test) and the subdomains of AP (verbal, numeracy, abstract). Data extracted were reported as mean ± standard deviation (SD). Statistical analyses were carried out using IBM® SPSS® Statistics (v.22) and Statistica (v.13, TIBCO Software Inc.). Comprehensive Meta-Analysis (CMA) Software (Biostat Inc. Englewood, New Jersey, USA) was used to calculate effect sizes (ESs) and reported as standardised mean differences (SMDs). Statistical analyses were carried out using IBM® SPSS® Statistics (v.22) and Statistica (v.13, TIBCO Software Inc.). Effect sizes were determined by subtracting the mean change score in the intervention groups from the mean change score in the baseline group and dividing the difference by the pooled SD of the change scores in each group. ES was then corrected for small-sample bias using Hedges' g and reported with 95% confidence intervals (CI). ES was categorised as trivial (<0.02), small (0.02-0.6), moderate (0.6-1.2), large (1.2-2.0) or very large (>2.0). [46]

RESULTS

Participant characteristics

Participant characteristics are presented in Table 1. The age and maturation data indicated that, as a group, the participants had passed the age of peak pubertal growth. The majority of participants had a normal BMI (86.8%) and WtHR (97.4%), and aerobic fitness in the "high-fitness zone"(97.4%) based on the age and sex-specific aerobic fitness cut-offs provided in a cross-sectional study of participants 8-18 years.[47]

Table 1. Participant characteristics (n=38)

	Mean ± SD
Age and maturation	
Decimal age (years)	14.4 ± 1.0
Years from peak height velocity	0.8 ± 1.2
Predicted age of puberty	13.6 ± 0.6
Anthropometric variables	
Height (m)	1.7 ± 0.1
Body mass (kg)	57.3 ± 13.1
Body mass index ($kg.m^{-2}$)	19.9 ± 2.6
Waist circumference (cm)	74.1 ± 10.3
Waist/height ratio (WtHR)	0.44 ± 0.0
Aerobic Fitness	
$\dot{V}O_2$peak ($ml.kg^{-1}min^{-1}$)	53.3 ± 4.5

Data are presented as mean ± standard deviation: (cm): centimetre; (kg): kilograms; (m): meter; (min): minutes; (ml): mililitre; (SD): standard deviation; ($\dot{V}O_{2peak}$):peak rate of oxygen consumption

Academic performance

The AGAT scores for the participants averaged 70 - 78% across the three sub-domains (Figure 1). As hypothesised, academic performance did not improve after the five weeks of the acute interventions. There was no overall pre- to post-testing difference ($F_{3,105} = 0.21$, $p = 0.89$, $\eta^2 = 0.01$) nor any interaction between academic subdomains and the pre-post testing ($F_{1,35} = 0.00$, $p = 0.98$, $\eta^2 = 0.00$).

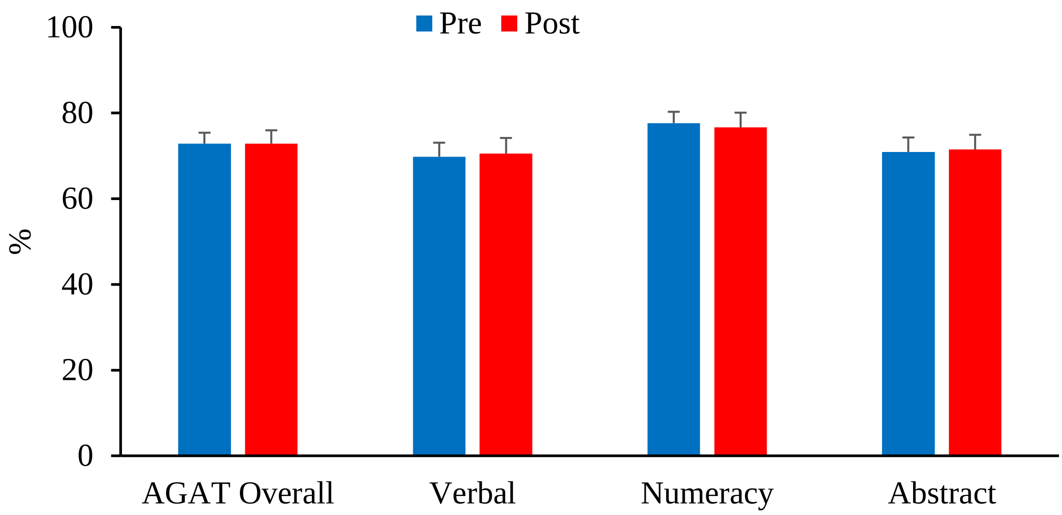


Figure 2: AGAT scores (mean ± standard error [SE]) pre- and post-testing.

Cognitive performance

Thinking domain

The mean z-scores across the subdomains of thinking were predominantly within the normal range of ±1, with only the score for executive function following resistance training exceeding 1 (Figure 2). No significant overall differences were observed between baseline scores, the scores following the three interventions and the final scores ($F_{4,128} = 1.48$, $p = 0.21$, $\eta^2 = 0.04$). There was some variation in the scores for the sub-domains across the five testing times, as shown by a significant interaction between sub-domain scores and the testing times ($F_{24,768} = 3.48$, $p < 0.001$, $\eta^2 = 0.10$). On *post hoc* analyses, executive function scores were significantly lower after aerobic training compared to stretching ($p = 0.02$), resistance training ($p < 0.001$) and final testing ($p = 0.002$). These results were contrary to our hypothesis that the subdomains of thinking would benefit only from acute aerobic and resistance training interventions. Effect sizes [with 95%CI] were moderate for the subdomain of executive function, favouring resistance (ES = 1.10 [0.61 to 1.59]), stretching (ES = 0.79 [0.27 to 1.21]), and post testing (ES = 0.81 [0.34 to 1.29]), over aerobic training.

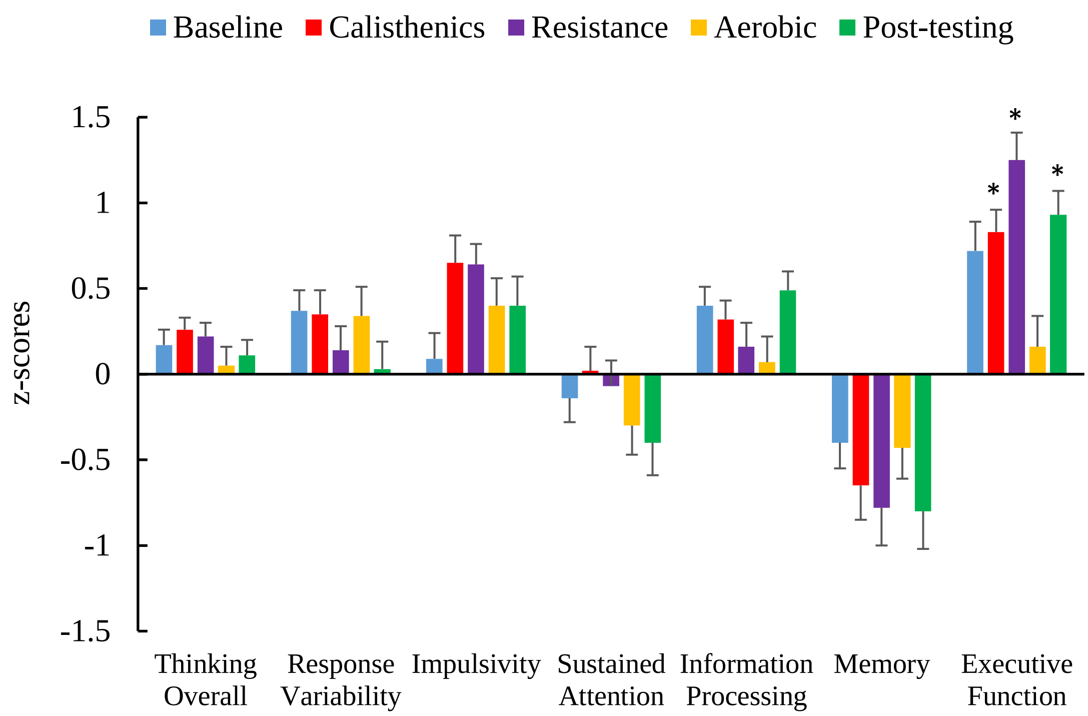


Figure 3: Thinking subdomain z-scores (mean ± SE) for baseline, the three training interventions and final testing. * significantly different from aerobic training, $p < 0.05$.

The effect of the three acute interventions on the domain of thinking was further analysed by examining change in scores compared to baseline. The three interventions did not differ overall ($F_{2,74} = 2.99$, $p = 0.06$, $\eta^2 = 0.07$) but there was a significant interaction between subdomains and the interventions ($F_{12,444} = 4.56$, $p < 0.001$, $\eta^2 = 0.11$). *Post hoc* analyses showed, similarly to the raw scores, that in the subdomain of executive function, the change scores for aerobic training were significantly lower than those for stretching ($p = 0.02$) and resistance ($p < 0.001$) interventions. The effect size for resistance training was moderate, favouring resistance training over aerobic training (ES = 0.74 [0.27 to 1.21]). Effect size for stretching was small favouring stretching over aerobic training. (ES = 0.46 [0.00 to 0.92]).

Analyses of the scores according to the chronological sequence of testing showed no significant differences in either the absolute scores across the weeks of testing ($F_{4,144} = 2.07$, $p = 0.09$, $\eta^2 = 0.05$) or in the change scores from the previous week of testing ($F_{3,111} = 2.30$, $p = 0.08$, $\eta^2 = 0.06$).

Self-regulation domain

The scores for self-regulation were within the normal range, although the scores for negativity bias were all negative and its baseline score was -1.02 (Figure 3). There was a significant difference between the grand mean scores across the interventions ($F_{4,144} = 2.87$, $p = 0.03$, $\eta^2 = 0.07$) but more importantly, this difference varied significantly across domains, as shown by an interaction between interventions and domains ($F_{12,432} = 7.22$, $p < 0.001$, $\eta^2 = 0.17$). *Post hoc* analyses of the interaction showed that the score for negativity bias at baseline was significantly lower than for all the interventions (all $p < 0.001$), while the baseline score for emotional resilience was significantly lower than that following resistance training ($p < 0.01$). In addition, the final testing score for social skills was significantly lower than the baseline score ($p < 0.01$). Effect sizes ranged from small to moderate for the subdomain of negativity bias, favouring all the interventions over baseline (ES = 0.44 to 0.61 [-0.03 to 1.08]). Effect size for emotional resilience was small, favouring resistance training over baseline (ES = 0.38 [in line with the findings for the raw scores, -0.08 to 0.84]). Effect size for social skills was also small favouring baseline over post-testing (ES = -0.47 [-0.93 to -0.01]).

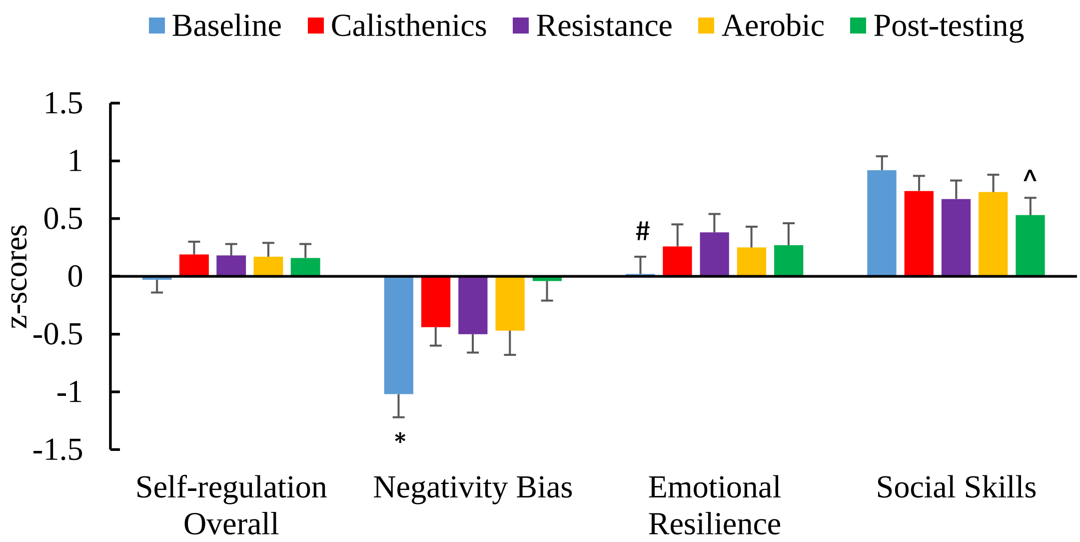


Figure 4: Self-regulation subdomain z-scores (mean ± SE) for baseline, the three training interventions and final testing. * significantly different from stretching, resistance and aerobic training and post-testing, $p < 0.05$; # significantly different from resistance training, $p < 0.05$; ^ significantly different from baseline, $p < 0.01$.

There was no significant difference between the three training interventions in the change in self-regulation scores from baseline ($F_{2,74} = 0.65$, $p = 0.52$, $\eta^2 = 0.02$). When the scores were analysed according to the chronological sequence of testing, however, there was a significant domain by time interaction ($F_{12,432} = 8.09$, $p < 0.001$, $\eta^2 = 0.19$). *Post hoc* analyses showed, in line with the findings for the raw scores, that the baseline score for negativity bias was significantly poorer than the subsequent three bouts of testing and the final test (all $p < 0.001$). These analyses also showed that baseline score for social skills was significantly higher than the scores for the subsequent three bouts of testing and the final test (all $p < 0.001$). Effect sizes for negativity bias ranged from small to moderate favouring Week 2 to 5 of testing over Week 1 (ES = 0.33 to 0.64 [-0.13 to 1.10]). Effect sizes for social skills were small favouring Week 1 of testing over all other subsequent weeks of testing (ES = -0.47 to -0.18 [-0.93 to 0.28]). There were no significant differences in the changes in the self-regulation scores compared to each preceding week of testing ($F_{3,111} = 1.92$, $p = 0.13$, $\eta^2 = 0.05$).

Feeling domain

The z-scores for feeling were within the normal range and all positive except for the baseline score for Feeling overall and anxiety (Figure 4). There was a significant difference between the interventions ($F_{4,144} = 16.65$, $p < 0.001$, $\eta^2 = 0.32$) but no interaction between interventions and domains ($F_{12,432} = 0.90$, $p = 0.54$, $\eta^2 = 0.02$). *Post hoc* tests on the intervention difference showed that the baseline scores were significantly lower than all the other scores (all $p < 0.001$). Effect sizes for feeling overall ranged from small to moderate where the effect favoured all the other interventions and the post-test over baseline testing (ES = 0.47 to 0.71 [0.01 to 1.18]). There was no significant difference between the three training interventions in their change scores compared to baseline ($F_{2,74} = 0.80$, $p = 0.45$, $\eta^2 = 0.02$).

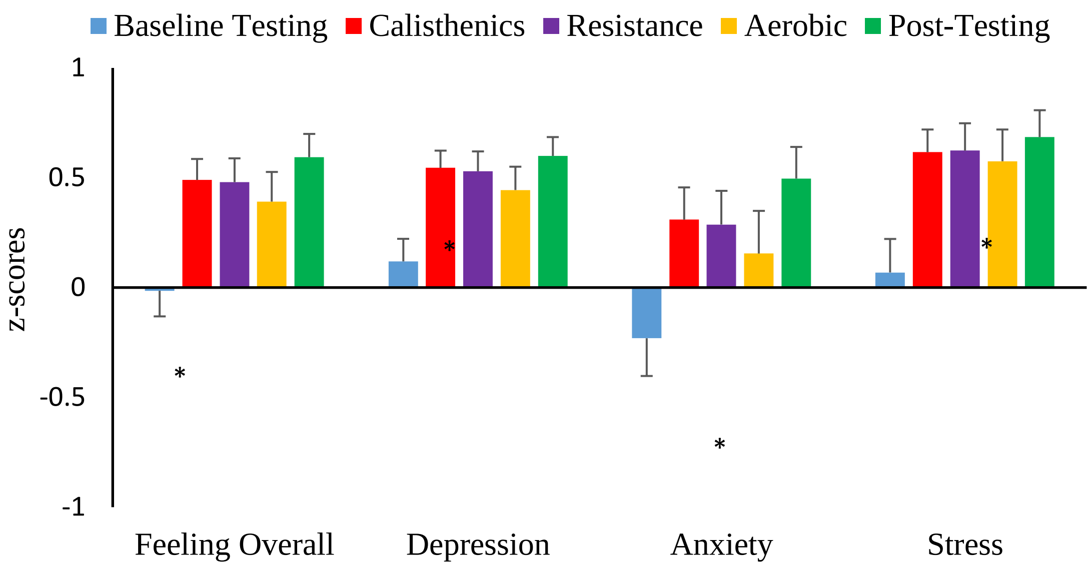


Figure 5: Feeling subdomain z-scores (mean ± SE) for baseline, the three training interventions and final testing. * significantly different from stretching, resistance, aerobic and post-testing

When the scores were analysed according to the chronological sequence of testing, the domain of feeling showed a significant time effect ($F_{4,144} = 19.69$, $p < 0.001$, $\eta^2 = 0.35$). *Post hoc* analyses showed, in line with the findings for the raw scores, that Week 1 baseline scores were significantly lower than the Week 2, 3, 4 and 5 scores across all subdomains (all $p < 0.001$), while the Week 2 scores were significantly lower than Week 4 ($p = 0.013$) and 5 ($p = 0.006$) scores across all subdomains. Effect sizes for feeling overall ranged from small to moderate favouring Week 2 to 5 of testing over Week 1 (ES = 0.33 to 0.71 [-0.13 to 1.18]). Effect sizes for feeling overall were also small favouring Week 4 and 5 of testing over Week 2 (ES = 0.37 to 0.51 [-0.09 to 0.97]). Consistent with these findings, the feeling change scores compared to each preceding week showed significant time differences ($F_{3,108} = 4.25$, $p < 0.01$, $\eta^2 = 0.11$). *Post hoc* analyses here showed that the change in scores from Week 1 to 2 was significantly larger than the change from Week 4 to 5 ($p = 0.004$). Effect size was moderate favouring the change from Week 1 to 2 (ES = -0.91 [-1.39 to -0.43]).

DISCUSSION

This study aimed to investigate the effect of three modalities of acute exercise (aerobic, resistance and stretching) on cognitive function and academic performance in adolescent schoolboys. The findings indicated that although participants' academic performance was good, acute exercise provided no significant benefit to cognitive function and academic performance. Participants' cognitive profile generally displayed positive thinking, self-regulation and feeling domains, however, some concerning negative scores were observed in the subdomains of sustained attention, memory (thinking) and negativity bias (self-regulation).

The cohort of this study was found to have a normal BMI and WtHR, to be aerobically fit (in the high-fitness zone according to Welk's cut-off). Contrary to the hypothesis cognitive function did not gain benefit from an acute bout of either aerobic or resistance exercise. If acute exercise elicits cognitive enhancement by generalised physiological arousal[48], it is possible that the aerobic exercise intensity (75-80%HRmax) and duration (30 minutes) was not sufficient to stimulate sufficient upregulation of the catecholamine pathways supporting neural activation in these aerobically fit participants who were already accustomed to the rigours of exercise. However, in older adults with mild cognitive impairments, six months of high-intensity progressive resistance training produced significant improvements in cognitive function[49] likely through hippocampal plasticity[38]. The acute effect of resistance exercise in adolescents is yet to be fully elucidated with one recent study reporting participants performed significantly better in the cognitive domain of selective attention after a bout of resistance exercise compared to a bout of aerobic exercise.[39]

This study showed that thinking scores in any sub-domain did not change significantly after each intervention. However, executive function (EF) scores were relatively high (> 0.5) at baseline and significantly higher after resistance and stretching exercise when compared to aerobic exercise. Most cognition research focuses on EF in the form of inhibitory control, using either the Stroop test or the Eriksen Flanker test (Go/NoGo test) as an assessment tool.[27] However, other facets[50-52] of EF such as planning and problem solving, also essential parts of daily life, have seen very limited investigation.[53] In our study, EF was accessed based on the Austin Maze test, which in part involves planning and problem solving as well.[54] Mastery of this test requires simultaneous monitoring of performance and comparison of the correct and incorrect choices made on the current as well as previous trials.[54] As such, test participants need to keep the maze objective in mind, know the rules, recall previous errors in order to avoid them in future, and remember the correct coordinates of the hidden path from previous trials.[54] This involves the use of visuospatial memory as well as working memory to plan and problem solve to reach the maze objective.[54] The study results, thus expand the current literature on type of assessment tools use, showing that apart from inhibition, working memory could potentially also benefit from short bouts of acute resistance and stretching exercise.

In addition to improvements in EF, self-regulation, specifically negativity bias, improved significantly after all three exercise interventions of aerobic, resistance and stretching from a low baseline score (-1.02). Negativity bias is defined as the tendency to see oneself and one's world as negative (lower z scores) or positive (higher z scores), and is thought to be associated with an individual's sensitivity versus hardiness to daily stresses.[55] These results highlight that a 30-minute bout of acute exercise, regardless of exercise type, may help to improve negativity bias and aid an individual to better adjust to daily stressors. Studies have suggested that systematic cognitive negativity bias produces a hyper-reactivity to negative emotions and can be used as a marker of depression.[56] As such, the results of this study lend support to the growing literature that an acute bout of exercise may help to alleviate symptoms of depression.[57,58]

In the feeling domain, the scores increased across all sub-domains from small negative or low positive baseline scores to all positive post-intervention scores. The size of these effects was small to moderate. These results are consistent with previous findings[59,60] that both children and adults who are classified as having lower aerobic fitness tend to be more susceptible to the feelings of depression, anxiety and stress, whereas aerobically fit participants in this study scored largely positive scores in this domain.

The positive results observed from the self-regulation and feeling domain are consistent with research on the relationship between exercise and mood state where positive changes in mood were observed as a consequence of aerobic exercise[61]. It has been demonstrated in anxiety disorders, that the positive effects of exercise on mood states were visible even with short bursts of exercise regardless of the type of exercise[62]. Improvements in depressive mood post exercise has been associated with changes in peripheral BDNF[63].

Participants scored well on academic performance (≥ 70% on the AGAT). Overall, the results are consistent with the hypothesis that academic performance would not be impacted because the effects of acute exercise, if any, were expected to be transient.

Limitations

A major limitation of this study is its small sample size, where a majority (97.4%) of the participants have healthy cardiovascular fitness and is not representative of the general population. As such this group of participants may require a higher exercise intensity for a significant change in cognition to be observed. Another limitation was that participants were undergoing their outdoor education semester where students boarded at the school's satellite campus for six months, as such participants were relatively restless and found it difficult to focus on the instructions given during the cognitive and academic testing. Many participants had to be told repeatedly to remain in their seats to complete the assessments. This may have affected their cognitive and academic performance. Lastly, due to the experiment only being carried out by one researcher, participant's' mean heart rate was not collected. Thus no further analysis between exercise intensity and cognition could be done.

CONCLUSION

Contrary to the hypothesis that acute exercise may enhance cognition in adolescents, findings from this study showed no improvements in cognition after an acute bout of aerobic, resistance and stretching exercise. The study results may be limited by the small sample size and non-homogenous fitness status of participants. Future studies with a larger sample size and examining various degree of exercise intensity is warranted to establish a more conclusive association between acute exercise and cognition in the adolescent population

References

1 Hillman, C. H., Erickson, K. I., & Kramer, A. F. (2008). Be smart, exercise your heart: exercise effects on brain and cognition. *Nature Reviews Neuroscience, 9*(1), 58-65.

2 Garber, C. E., Blissmer, B., Deschenes, M. R., Franklin, B. A., Lamonte, M. J., Lee, I.-M., Nieman, D. C., & Swain, D. P. (2011). American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Medicine and Science in Sports and Exercise*, *43*(7), 1334-1359.

3 Brockett, A. T., LaMarca, E. A., & Gould, E. (2015). Physical exercise enhances cognitive flexibility as well as astrocytic and synaptic markers in the medial prefrontal cortex. *PlOS One, 10*(5), e0124859.

4 Creer, D. J., Romberg, C., Saksida, L. M., van Praag, H., & Bussey, T. J. (2010). Running enhances spatial pattern separation in mice. *Proceedings of the National Academy of Sciences*, *107*(5), 2367-2372.

5 Kamijo, K., Nishihira, Y., Higashiura, T., & Kuroiwa, K. (2007). The interactive effect of exercise intensity and task difficulty on human cognitive processing. *International Journal of Psychophysiology*, *65*(2), 114-121.

6 Tomporowski, P. D. (2003). Effects of acute bouts of exercise on cognition. *Acta psychologica*, *112*(3), 297-324.

7 Erickson, K. I., Voss, M. W., Prakash, R. S., Basak, C., Szabo, A., Chaddock, L., Kim, J. S., Heo, S., Alves, H., & White, S. M. (2011). Exercise training increases size of hippocampus and improves memory. *Proceedings of the National Academy of Sciences*, *108*(7), 3017-3022.

8 Scharfman, H., Goodman, J., Macleod, A., Phani, S., Antonelli, C., & Croll, S. (2005). Increased neurogenesis and the ectopic granule cells after intrahippocampal BDNF infusion in adult rats. *Experimental Neurology*, *192*(2), 348-356.

9 Tolwani, R., Buckmaster, P., Varma, S., Cosgaya, J., Wu, Y., Suri, C., & Shooter, E. (2002). BDNF overexpression increases dendrite complexity in hippocampal dentate gyrus. *Neuroscience*, *114*(3), 795-805.

10 Arancibia, S., Silhol, M., Mouliere, F., Meffre, J., Höllinger, I., Maurice, T., & Tapia-Arancibia, L. (2008). Protective effect of BDNF against beta-amyloid induced neurotoxicity in vitro and in vivo in rats. *Neurobiology of Disease*, *31*(3), 316-326.

11 Erickson, K., Weinstein, A. M., Verstynen, T. D., Voss, M. W., Prakash, R. S., Woods, J., McAuley, E., & Kramer, A. F. (2012). F1-03-01: The influence of an aerobic exercise intervention on brain volume in late adulthood. *Alzheimer's & Dementia*, *8*(4s_Part_2), 81.

12 Egan, M. F., Kojima, M., Callicott, J. H., Goldberg, T. E., Kolachana, B. S., Bertolino, A., Zaitsev, E., Gold, B., Goldman, D., & Dean, M. (2003). The BDNF val66met polymorphism affects activity-dependent secretion of BDNF and human memory and hippocampal function. *Cell*, *112*(2), 257-269.

13 Schofield, P. R., Williams, L. M., Paul, R. H., Gatt, J. M., Brown, K., Luty, A., Cooper, N., Grieve, S., Dobson-Stone, C., & Morris, C. (2009). Disturbances in selective information processing associated with the BDNF Val66Met polymorphism: evidence from cognition, the P300 and fronto-hippocampal systems. *Biological Psychology*, *80*(2), 176-188.

14 Piepmeier, A. T., & Etnier, J. L. (2015). Brain-derived neurotrophic factor (BDNF) as a potential mechanism of the effects of acute exercise on cognitive performance. *Journal of Sport and Health Science*, *4*(1), 14-23.

15 Knaepen, K., Goekint, M., Heyman, E. M., & Meeusen, R. (2010). Neuroplasticity—exercise-induced response of peripheral brain-derived neurotrophic factor. *Sports Medicine*, *40*(9), 765-801.

16 Audiffren, M. (2009). Acute exercise and psychological functions: A cognitive-energetic approach. In *Exercise and Cognitive Function.* (pp. 3-39). Wiley-Blackwell.

17 Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: a latent-variable analysis. *Journal of Experimental Psychology: General*, *133*(1), 101.

18 Kao, S.-C., Drollette, E. S., Ritondale, J. P., Khan, N., & Hillman, C. H. (2018). The acute effects of high-intensity interval training and moderate-intensity continuous exercise on declarative memory and inhibitory control. *Psychology of Sport and Exercise, 38*, 90-99.

19 Peruyero, F., Zapata, J., Pastor, D., & Cervelló, E. (2017). The acute effects of exercise intensity on inhibitory cognitive control in adolescents. *Frontiers in Psychology, 8*, 921-921.

20 Gejl, A. K., Bugge, A., Ernst, M.T., Tarp, J., Hillman, C.H., Have, M., Froberg, K. and Andersen, L.B. (2018). The acute effects of short bouts of exercise on inhibitory control in adolescents. *Mental Health and Physical Activity, 15*, 34-39.

21 Postle, B. R. (2006). Working memory as an emergent property of the mind and brain. *Neuroscience, 139*(1), 23-38.

22 Gothe, N., Pontifex, M. B., Hillman, C., & McAuley, E. (2013). The acute effects of yoga on executive function. *Journal of Physical Activity and Health, 10*(4), 488-495.

23 Kawabata, M., Lee, K., Choo, H.-C., & Burns, S. F. (2021). Breakfast and exercise improve academic and cognitive performance in adolescents. *Nutrients, 13*(4), 1278.

24 Herting, M. M., & Chu, X. (2017). Exercise, cognition, and the adolescent brain. *Birth Defects Research, 109*(20), 1672-1679.

25 Ellemberg, D., & St-Louis-Deschênes, M. (2010). The effect of acute physical exercise on cognitive function during development. *Psychology of Sport and Exercise, 11*(2), 122-126.

26 Giedd, J. N., Blumenthal, J., Jeffries, N. O., Castellanos, F. X., Liu, H., Zijdenbos, A., Paus, T., Evans, A. C., & Rapoport, J. L. (1999). Brain development during childhood and adolescence: a longitudinal MRI study. *Nature Neuroscience, 2*(10), 861-863.

27 Pontifex, M. B., Hillman, C. H., Fernhall, B., Thompson, K. M., & Valentini, T. A. (2009). The effect of acute aerobic and resistance exercise on working memory. *Medicine & Science in Sports & Exercise, 41*(4), 927-934.

28 Clarkson-Smith, L., & Hartley, A. A. (1989). Relationships between physical exercise and cognitive abilities in older adults. *Psychology and Aging, 4*(2), 183.

29 Hogervorst, E., Riedel, W., Jeukendrup, A., & Jolles, J. (1996). Cognitive performance after strenuous physical exercise. *Perceptual and Motor Skills, 83*(2), 479-488.

30 McNaughten, D., & Gabbard, C. (1993). Physical exertion and immediate mental performance of sixth-grade children. *Perceptual and Motor Skills, 77*(3_suppl), 1155-1159.

31 Fuster, J. (2015). *The prefrontal cortex*. Academic Press.

32 Latham, N. K., Bennett, D. A., Stretton, C. M., & Anderson, C. S. (2004). Systematic review of progressive resistance strength training in older adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 59*(1), M48-M61.

33 Cavani, V., Mier, C. M., Musto, A. A., & Tummers, N. (2002). Effects of a 6-week resistance-training program on functional fitness of older adults. *Journal of Aging and Physical Activity, 10*(4), 443-452.

34 Landrigan, J.-F., Bell, T., Crowe, M., Clay, O. J., & Mirman, D. (2020). Lifting cognition: a meta-analysis of effects of resistance exercise on cognition. *Psychological Research, 84*(5), 1167-1183.

35 Chang, Y.-K., Pan, C.-Y., Chen, F.-T., Tsai, C.-L., & Huang, C.-C. (2012). Effect of resistance-exercise training on cognitive function in healthy older adults: a review. *Journal of Aging and Physical Activity, 20*(4), 497-517.

36 Heyn, P., Abreu, B. C., & Ottenbacher, K. J. (2004). The effects of exercise training on elderly persons with cognitive impairment and dementia: a meta-analysis. *Archives of Physical Medicine and Rehabilitation, 85*(10), 1694-1704.

37 Li, Z., Peng, X., Xiang, W., Han, J., & Li, K. (2018). The effect of resistance training on cognitive function in the older adults: a systematic review of randomized clinical trials. *Aging Clinical and Experimental Research, 30*(11), 1259-1273.

38 Broadhouse, K. M., Singh, M. F., Suo, C., Gates, N., Wen, W., Brodaty, H., Jain, N., Wilson, G. C., Meiklejohn, J., Singh, N., Baune, B. T., Baker, M., Foroughi, N., Wang, Y., Kochan, N., Ashton, K., Brown, M., Li, Z., Mavros, Y., Sachdev, P. S., & Valenzuela, M. J. (2020). Hippocampal plasticity underpins long-term cognitive gains from resistance exercise in MCI. *NeuroImage: Clinical, 25*, 102182.

39 Harveson, A. T., Hannon, J. C., Brusseau, T. A., Podlog, L., Papadopoulos, C., Hall, M. S., & Celeste, E. (2019). Acute exercise and academic achievement in middle school students. *International Journal of Environmental Research and Public Health, 16*(19), 3527.

40 Li, J. W., O'Connor, H., O'Dwyer, N., & Orr, R. (2017). The effect of acute and chronic exercise on cognitive function and academic performance in adolescents: A systematic review. *Journal of Science and Medicine in Sport, 20*(9), 841-848.

41 Esteban-Cornejo, I., Tejero-Gonzalez, C. M., Sallis, J. F., & Veiga, O. L. (2015). Physical activity and cognition in adolescents: A systematic review. *Journal of Science and Medicine in Sport, 18*(5), 534-539.

42 Sibley, B. A., & Etnier, J. L. (2002). The effects of physical activity on cognition in children: A meta-analysis. *Medicine & Science in Sports & Exercise, 34*(5), S214.

43 Lifetips. *What is a BOSU ball and how does it improve balance?* Retrieved 2021, https://balance.lifetips.com/faq/120190/0/what-is-a-bosu-ball-and-how-does-it-improve-balance/index.html.

44 Mirwald, R. L., Baxter-Jones, A. D., Bailey, D. A., & Beunen, G. P. (2002). An assessment of maturity from anthropometric measurements. *Medicine and Science in Sports and Exercise, 34*(4), 689-694.

45 Leger, L. A., & Lambert, J. (1982). A maximal multistage 20-m shuttle run test to predict VO_{2max}. *European Journal of Applied Physiology and Occupational Physiology, 49*(1), 1-12.

46 Cohen, J. (2013). *Statistical power analysis for the behavioral sciences*. Academic Press.

47 Welk, G. J., Maduro, P. F. D. S.-M., Laurson, K. R., & Brown, D. D. (2011). Field evaluation of the new FITNESSGRAM® criterion-referenced standards. *American Journal of Preventive Medicine, 41*(4), S131-S142.

48 Audiffren, M. (2009). Acute exercise and psychological functions: A cognitive-energetic approach. In T. McMorris, P. Tomporowski, & M. Audiffren (Eds.), *Exercise and Cognitive Function* (pp. 3–39). Wiley-Blackwell.

49 Mavros, Y., Gates, N., Wilson, G. C., Jain, N., Meiklejohn, J., Brodaty, H., Wen, W., Singh, N., Baune, B. T., Suo, C., Baker, M. K., Foroughi, N., Wang, Y., Sachdev, P. S., Valenzuela, M., & Fiatarone Singh, M. A. (2017). Mediation of cognitive function improvements by strength gains after resistance training in older adults with mild cognitive impairment: Outcomes of the study of mental and resistance training. *Journal of the American Geriatrics Society, 65*(3), 550-559.

50 Banich, M. T. (2009). Executive function: The search for an integrated account. *Current Directions in Psychological Science, 18*(2), 89-94.

51 Lezak, M. D., Howieson, D. B., Loring, D. W., & Fischer, J. S. (2004). *Neuropsychological Assessment*. Oxford University Press, USA.

52 Rabbitt, P. (1997). Introduction: Methodologies and models in the study of executive function. In P. Rabbitt (Ed.), *Methodology of Frontal and Executive Function* (pp. 1-38). Routledge.

53 Davis, C. L., Tomporowski, P. D., Boyle, C. A., Waller, J. L., Miller, P. H., Naglieri, J. A., & Gregoski, M. (2007). Effects of aerobic exercise on overweight children's cognitive functioning: a randomized controlled trial. *Research Quarterly for Exercise and Sport, 78*(5), 510-519.

54 Crowe, S. F., Barclay, L., Brennan, S., Farkas, L., Gould, E., Katchmarsky, S., & Vayda, S. (1999). The cognitive determinants of performance on the Austin Maze. *Journal of the International Neuropsychological Society, 5*(1), 1-9.

55 Gordon, E., Barnett, K. J., Cooper, N. J., Tran, N., & Williams, L. M. (2008). An" integrative neuroscience" platform: application to profiles of negativity and positivity bias. *Journal of Integrative Neuroscience, 7*(03), 345-366.

56 Watters, A. J., & Williams, L. M. (2011). Negative biases and risk for depression; integrating self-report and emotion task markers. *Depression and Anxiety, 28*(8), 703-718.

57 Craft, L. L., & Landers, D. M. (1998). The effect of exercise on clinical depression and depression resulting from mental illness: A meta-analysis. *Journal of Sport and Exercise Psychology, 20*(4), 339-357.

58 Mandolesi, L., Polverino, A., Montuori, S., Foti, F., Ferraioli, G., Sorrentino, P., & Sorrentino, G. (2018). Effects of physical exercise on cognitive functioning and wellbeing: Biological and psychological benefits [Review]. *Frontiers in Psychology, 9*(509).

59 Tomson, L. M., Pangrazi, R. P., Friedman, G., & Hutchison, N. (2003). Childhood depressive symptoms, physical activity and health related fitness. *Journal of Sport and Exercise Psychology, 25*(4), 419-439.

60 Rodriguez-Ayllon, M., Cadenas-Sanchez, C., Esteban-Cornejo, I., Migueles, J. H., Mora-Gonzalez, J., Henriksson, P., Martín-Matillas, M., Mena-Molina, A., Molina-García, P., & Estévez-López, F. (2018). Physical fitness and psychological health in overweight/obese children: A cross-sectional study from the ActiveBrains project. *Journal of Science and Medicine in Sport, 21*(2), 179-184.

61 Knapen, J., Sommerijns, E., Vancampfort, D., Sienaert, P., Pieters, G., Haake, P., Probst, M., & Peuskens, J. (2009). State anxiety and subjective well-being responses to acute bouts of aerobic exercise in patients with depressive and anxiety disorders. *British Journal of Sports Medicine, 43*(10), 756-759.

62 Scully, D., Kremer, J., Meade, M. M., Grahan, R., & Dudgeon, K. (1998). Exercise and psychological well being: A critical review. *British Journal of Sports Medicine, 32*, 111-120.

63 de Melo Coelho, F. G., Gobbi, S., Andreatto, C. A. A., Corazza, D. I., Pedroso, R. V., & Santos-Galduróz, R. F. (2013). Physical exercise modulates peripheral levels of brain-derived neurotrophic factor (BDNF): a systematic review of experimental studies in the elderly. *Archives of Gerontology and Geriatrics, 56*(1), 10-15.

Appendix

Table A1. Mean (± SD) scores for cognitive function across baseline, interventions and post-testing

	Baseline	Aerobic	Resistance	Stretching	Post-Testing
	Mean ± SD	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**
Thinking Overall	0.17 ± 0.52	0.04 ± 0.62	0.22 ± 0.46	0.26 ± 0.42	0.11 ± 0.54
Response variability	0.37 ± 0.70	0.34 ± 0.96	0.14 ± 0.80	0.35 ± 0.80	0.03 ± 0.93
Impulsivity	0.09 ± 0.87	0.40 ± 0.93	0.64 ± 0.67	0.65 ± 0.92	0.40 ± 0.95
Sustained attention	-0.15 ± 0.78	-0.30 ± 0.98	-0.07 ± 0.84	0.02 ± 0.81	-0.40 ± 1.06
Information processing	0.40 ± 0.61	0.07 ± 0.88	0.16 ± 0.80	0.32 ± 0.62	0.49 ± 0.60
Memory	-0.40 ± 0.88	-0.43 ± 1.02	-0.78 ± 1.27	-0.65 ± 1.14	-0.80 ± 1.25
Executive function	0.72 ± 0.99	0.16 ± 1.02	1.25 ± 0.94	0.83 ± 0.76	0.93 ± 0.85
Feeling Overall	-0.01 ± 1.18	0.39 ± 0.13	0.48 ± 0.11	0.49 ± 0.10	0.59 ± 0.11
Depression	0.12 ± 0.86	0.44 ± 0.11	0.53 ± 0.09	0.55 ± 0.08	0.60 ± 0.09
Anxiety	-0.23 ± 1.85	0.15 ± 0.19	0.29 ± 0.15	0.31 ± 0.15	0.50 ± 0.14
Stress	0.07 ± 1.27	0.58 ± 0.14	0.62 ± 0.12	0.62 ± 0.10	0.68 ± 0.12
Self-Regulation Overall	-0.03 ± 0.67	0.17 ± 0.73	0.18 ± 0.61	0.19 ± 0.67	0.16 ± 0.73
Negativity bias	-1.02 ± 1.22	-0.47 ± 1.28	-0.50 ± 0.97	-0.44 ± 0.97	-0.32 ± 1.03
Emotional resilience	0.02 ± 0.91	0.25 ± 1.09	0.38 ± 0.97	0.26 ± 1.16	0.27 ± 1.09
Social skills	0.92 ± 0.73	0.73 ± 0.91	0.67 ± 0.97	0.74 ± 0.79	0.53 ± 0.91

CHAPTER 7

Discussion and future directions

DISCUSSION

This thesis aimed to investigate the relationship between physical fitness, body composition, physical activity (PA) and cognitive function (CF) and academic performance (AP) in adolescent males. This was completed through three studies; a cross-sectional study to examine the relationship between fitness and CF and AP, a randomised controlled trial to examine the effects of chronic body and brain training on CF and AP, and an acute dose-response study to examine the effects of acute aerobic and resistance training on CF and AP. The first two studies were conducted with Singaporean adolescents, while the acute study was conducted with Australian adolescents. Based on current literature, the hypotheses for each study proposed a positive relationship between fitness and CF and AP, where fitter participants would have better CF and AP scores. The hypotheses also proposed that exercise, both chronic and acute, would have a positive impact on CF and AP. Throughout the investigations, cognition was examined through its three subdomains of thinking, feeling and self-regulation, while AP was examined through the subdomains of verbal, numeracy and abstract reasoning.

The findings from the cross-sectional study were not congruent with the hypotheses that physical fitness and body composition are positively associated with CF and AP. Contrary to expectation, participants who were less fit (cardiorespiratory fitness categorised in the "needs improvement zone") had higher thinking and AP scores compared to fitter (cardiorespiratory fitness categorised in the "healthy fitness zone") participants. Less healthy body composition was also found to be negatively associated with thinking performance and AP, such that participants who were overweight and obese had higher thinking and AP scores compared to normal-weight participants. However, the results were supportive of the hypotheses with respect to the cognitive subdomains of feeling and self-regulation. Participants who were fitter and of normal weight had better feeling and self-regulation scores compared to those both less fit and overweight or obese. A key finding of the thesis was that regardless of fitness and body composition status, this cohort of Singaporean adolescent boys had poor scores on feeling and negativity bias (a subdomain of self-regulation which reflects an individual's sensitivity to stress), with z-scores generally at -0.5 or less.

After exploring the relationship between fitness and body composition and CF and AP in the cross-sectional study, two experimental studies were conducted to investigate different types of exercise (chronic and acute as well as aerobic and resistance training) that might confer improvements to CF and AP. The first experimental study showed that an eight-week body training program, comprising twice weekly 50 minute-sessions of high intensity exercise and structured game play at an intensity of 75 to 90%HRmax, led to significant improvement in cardiorespiratory fitness, but this did not translate into improvements in CF and AP scores. Likewise, an eight-week brain training intervention, consisting of twice weekly structured cognitive exercises (targeting the domains of thinking, feeling and self-regulation), produced no improvements in CF and AP. The second experimental study, comprising one-and-a-half-hour sessions each of aerobic (at 75-85% HRmax), resistance (at 75-85% HRmax) or stretching (below 60% HRmax) exercise, conducted at weekly intervals, showed that these acute bouts of exercise produced no improvements in CF or AP.

There were some differences between the Singaporean and Australian participants that are worthy of note. The mean thinking z-scores in the Singaporean schoolboys were positive across all domains, while the Australian schoolboys had negative thinking scores for sustained attention and memory. The feeling z-scores in the Australian schoolboys were almost all positive, whereas those in the Singaporean schoolboys were all negative, with most scores below -0.5 and many below -1. It was notable that both cohorts had mean negativity bias scores that were all negative, but the scores were particularly low in both Singaporean cohorts, with most below -2. The difference observed in feeling scores as well as negativity bias indicate a possible socio-cultural effect on these domains of cognition. In the 2015 Organisation for Economic Cooperation and Development (OECD) PISA report where students' well-being and life satisfaction were measured, variables impacting a student's well-being include time students spent with parents, quality of teaching, enjoyment of school, socioeconomic status, use of time outside of school and other environmental factor such as being a victim of bullying[1]. Future studies examining the cognitive domains of feeling and self-regulation should take into consideration the environmental factors in addition to the cognitive assessment and their implication on cognitive function.

Physical fitness is an important and modifiable health marker among children and adolescents.[2,3] Higher fitness levels have been found to be associated with healthy body composition and weight status,[3-5] to positively affect CF and as a result, to be associated with better AP outcomes as well.[6-10] In a recent review of studies in the adolescent population from 2005 to 2015,[11] examining the effect of fitness and body composition on CF and AP, three studies[12-14] showed that cardiorespiratory fitness was associated with higher CF (attention[12,14] and working memory[13]), while 10 studies[15-23] were associated with better AP, and one study[24] was associated with higher intelligence scores. Additionally, three studies[24-26] showed that physical activity and not fitness was associated with AP, while one study showed that interval running[27] was positively associated with AP and one study showed that gross motor skill[28] was positively associated with AP. Lastly, four studies showed positive associations between coordinative[29] and acute exercise[12,13] and CF (information processing, attention,[12,29] concentration[29] and working memory[13]). Contrary to literature, our findings demonstrated that adolescent boys with lower fitness and less habitual physical activity had generally better thinking scores. This discrepancy might be attributable to the participant demographic of academically selective Singaporean high schools where academic performance is highly prioritised. These students may have prioritised schoolwork and studying over physical activity. In the 2012 OECD survey, 15-year-old Singaporean students were ranked third globally on the amount of time spent weekly on homework and were found to spend 9.4 hours per week on homework, a figure which is significantly higher than the global average of five hours.[30]

The effect of weight on CF and AP has been examined in five previous studies, of which one[25] found no significant effect of weight status on CF, another[17] reported a weak and non-significant relationship with AP, while three other studies[20,22,26] reported that lower weight was associated with better AP outcomes. Contrary to this literature, the findings indicated that adolescent boys with unhealthy body composition had thinking scores that were comparable with those in the healthy range. Again, this discrepancy may be attributable to the particular characteristics of our cohort noted above.

One important finding from this thesis is that effect of body composition status on the cognitive domains of Self-regulation Feeling. The results indicate that overweight/obese adolescent boys as well as boys with excess central adiposity, had poorer depression, anxiety, stress and negativity bias scores. This is consistent with existing literature that an unhealthy body composition is associated with a higher risk of suffering from depression in children and adolescents[31-33]. This findings also adds to the limited literature[34] on male adolescents as the relationship between body composition and Feeling have been found to be stronger in females[33,34].

To the candidate's knowledge, no study thus far has examined self-regulation and feeling as domains of cognition, especially amongst the adolescent population. Self-regulation, the regulation of and by oneself, is the intrinsic modulation of an individual's internal state (both emotion and cognition), and involves both top down-(deliberate) and bottom-up (automatic) regulatory processes.[35] Top-down self-regulation can be thought of as the overarching control of executive function, which includes working memory, information processing, attention switching and planning.[36] Since self-regulation and executive functions are closely related, the thesis findings add to the breadth of current literature on cognition and exercise. As already noted, a key finding here was that independent of fitness, body composition and nationality, our participants all obtained negative mean z-scores in the self-regulation subdomain of negativity bias.

Negativity bias represents a hypersensitivity to stress, poorer regulation of emotions and the expectation of negative outcomes, which elevates the risk for poor brain health.[37-39] A high negativity bias score is also associated with a greater risk of depression.[40] In adolescents, greater negativity bias can adversely impact self-esteem, self-identity and self-worth, as individuals focus on their worst qualities, lowest results and areas of weakness rather than strength.[41] Adolescence is also a challenging developmental stage where individuals may face disruptions and stressors within their interpersonal relationships. Coupled with the delayed integration and coordination of prefrontal cortex functions with emotional reactive and reward-sensitive regions such as the amygdala and nucleus accumbens,[42] the adolescent phase is a period in the lifespan where individuals are more vulnerable and susceptible to depression[43] and anxiety.[44] The findings suggest that the adolescent age group may be more vulnerable to stress sensitivity. Amidst the concerning global trend among children and adolescents of physical activity decreasing over time,[45] this thesis supports the notion that increasing physical activity and exercise prescription is particularly important for the adolescent age group. There is evidence that by increasing physical education hours in a school's curriculum, while reducing time allocated for academic tuition, children may still achieve at a similar level despite the reduced teaching time.[46]

Although not measured in the studies, there is emerging evidence that muscular strength is positively associated with CF, in particular with enhanced working memory.[47] Higher muscular strength has been found to be associated with better executive function in children with autism.[48] Therefore, future studies examining the relationship between fitness and cognition in adolescents should include measurement of muscular strength.

Neither the Body nor Brain training interventions led to improvements in cognitive function in this study. In an earlier study in overweight children, a significant improvement in executive function was observed using a protocol of aerobic exercise for 40 minutes at a heart rate greater than 150 beats per minute, five days per week for 15 weeks.[49] The selected intervention period was eight weeks and it is possible that this was not sufficiently long to impact cognition. In addition, however, adolescence may be a difficult phase of development in which to observe such changes, due to often heavy school-related commitment as well as the complex effects of puberty.[43] The psychosocial confounders brought about by hormonal changes in the adolescent years may impact cognition[43,50,51] and as such mask the effects of exercise. To more thoroughly evaluate the impact of exercise on cognition, participants may be required to commit to an intervention protocol outside of school time, a requirement that may be difficult to satisfy in practice.[52-54]

Academic performance also did not improve after the body training exercise intervention in the RCT study. This outcome is at odds with literature demonstrating the positive impact of physical activity on academic performance in both children and youth.[46,55] According to a recent study in primary school children, over half (60%) of the variance in academic performance can be accounted for by physical activity and cognition.[56] There are, however, many other factors inside and outside of school, unrelated to physical fitness and activity levels, that affect AP.[57] Some general factors include age, gender, ethnicity, socioeconomic status, and parental education level, profession, language and income.[58] Other factors found to significantly impact AP include time spent studying, quality of learning (studying with peers or parents)[59] and socio-economic status,[46,57,60-62] but such factors were not examined here. Participants, regardless of fitness status (72% were classified in the "healthy fitness zone", had strong thinking scores (z-scores ranging from 0.5 to 1.4) and AGAT scores (most above 70%). Hence, there may have been less scope for improvement from the exercise intervention.

Exercise can clearly help to keep an individual healthy, such that it confers protection against age-related cognitive decline,[63,64] and is an important part of daily life due to other health benefits.[65,66] Hence, exercise may protect but not enhance cognition.[67] In finding that eight weeks of exercise did not substantially change cognitive function and brain biochemical markers in young and healthy adults, despite significant improvements in cardiorespiratory fitness, Gourgouvelis et al.[68] concluded that 'You can't fix what isn't broken'. Their outcome is similar to that of this thesis and a similar conclusion appears to be justified.

STRENGTH AND LIMITATIONS

A key strength of this thesis was the study design and incorporation of randomised controlled models in Studies II and III. Exercise dose (frequency, intensity, type, and duration) was clearly described and reported in each intervention protocol with details supplemented in the Appendices (ref). Exercise intensity was also objectively measured using heart rate monitors where possible, adding to the quality of research methodology. Both cognitive and academic performance were measured using validated[69,70] and standardised[71] assessments tools, respectively. The measurement of maturation through age of peak height velocity (APHV) as well as the presentation of body composition status through Waist to Height ratio (WtHR) were secondary participants' characteristics that are novel to studies investigating the relationship between exercise and cognition in the adolescent population. Also novel to the exercise-cognition database is the investigation of the impact exercise has on the cognitive domain of Self-regulation and its subdomain of negativity bias in adolescents. Other novel research findings and contribution of this thesis to the exercise-cognition research field include the first study to examine the relationship of exercise and cognition in a Singaporean adolescent population as well as detailed documentation of an adolescent specific eight weeks exercise intervention protocol that significantly improves aerobic fitness in Singaporean schoolboys.

A key limitation of this thesis was that only three schools, with a majority of participants (87%) coming from one school, participated in the three studies. Due to the time needed to holistically assess participants' physical fitness, cognitive function and academic performance, as well as to carry out the intervention protocols in Studies II (10 weeks) and III (5 weeks), participants as well as their schools and parents, found it difficult to commit to the study. This severely limited recruitment and resulted in the participants' characteristics being skewed towards high-achieving students and high-fit students, not representative of a general adolescent population. This could possibly confound the effect of the exercise dose on cognitive function. Ideally, more schools could be recruited and widely across a diverse adolescent population.

All three studies were also implemented in the school environment. This resulted in the testing and intervention sessions being limited to the time-tabling and term schedule of the schools. This meant that studies could only be carried out during schooling days (excluding public holidays) as well as during fix schooling hours and class periods. As such, the frequency between interventions, as well as the study duration is very much affected the school's time table. Make up sessions were difficult to schedule as well in the event where participants were absent for a session. Other limitations related to the logistical challenges and budget constraints of this thesis include, non-blinding of experimenter and participants and small sample size. The number of HR monitors was a limitation. Preferably, each participant should have had a monitor for each training session

Another limitation was the use of the 20m shuttle run to assess cardio respiratory fitness in adolescents. Although the shuttle run was selected due to its effectiveness in mass testing as well as being low in cost, it is not a robust measure of cardiorespiratory fitness and relies on extrapolation and equations to obtain VO_{2peak} scores.[72] A recent study has indicated that the moderate validity of the 20m shuttle run and recommends that the VO_{2peak} scores obtained should be considered an estimate of aerobic fitness.[73] Additionally, the cognitive and academic assessment used have not been trialled or validated in

Singaporean students. This is important as generally Singaporean students tend to perform above the global average academically[74], this may have resulted in less scope for improvements in CF and AP.

FUTURE DIRECTIONS

The literature on the effects of exercise on cognition in youth and young adults presents inconsistent findings. [75-77] In contrast, there is consistent evidence for positive effects of exercise in elderly adults with varying degrees of age-related cognitive decline, as well as in patients with traumatic brain injury[78-80] and children with autism[81-83] and Attention Deficit Hyperactivity Disorder.[84-86] These divergent findings suggest that it may be more difficult to modify brain function in a healthy population. Although there have been many studies supporting the notion that the brain is not hardwired and plasticity can be demonstrated, evidence remains conflicting in healthy populations where the both brain and body are functioning in an efficient manner.[87] Future studies in healthy population should focus on the differential effect of exercise intensity on physiological responses taking into consideration cardiorespiratory fitness status and age, before designing the intervention protocol to examine the relationship between exercise and cognition.

With regard to studies pertaining to the role of brain training in neuroplasticity, a distinction needs to be made between habits and behaviours that benefit from neuroplasticity[88-90] versus measurable cognitive gains that translate to benefits in day-to-day functioning[91,92] This will help to facilate a tighter focus on future research scope such that key cognitve domains that are more suscpetible to intervention effects can be identified. Additonally, greater consensus amongst researchers concerning the defintion of cogntion and the measurement of both cognitive domains and academic performance is warranted to improve the literature quality. [93]

A key finding of this study is that high- achieving Singaporean adolescent males were found to have negative Feeling and Self-regulation scores which indicates high levels of anxiety, stress as well as sensitivity to stress, and depression. This incidental but concerning finding highlights the need for a call-to-action to the various authorities and student governing bodies in both the schools and the nation to actively implement interventions and measure that can be taken, to prevent the worsening of students' mental health which in turn has been shown to adversely[94] impact cognition (verbal and spatial working memory,[95] inhibitory control,[96] working memory, cognitive flexibility and processing speed[97]).

CONCLUSION

In summary, findings from this thesis did not support the hypothesis that exercise can improve the cognitive function and academic performance in adolescent schoolboys. Contrary to the general literature, this thesis indicated that fitter and more active boys had poorer Thinking scores and body composition was not found to have an effect on CF and AP. High-achieving Singaporean adolescents school boys were found to have negative scores in the cognitive domains Feeling and Self-regulation scores which indicates high levels of anxiety, stress and depression as well as having poor negativity bias (this translates to being hypersensitive to stressors).

Additionally, this thesis also demonstrated a positive association between unhealthy body composition and Feeling and Self-regulation in adolescent males. This adds to the current literature supporting the hypothesis of unhealthy body composition as a predictor of depression. The investigation of the effects of exercise on Self-regulation in adolescents is novel to current literature. Findings from this thesis also highlight the effectiveness of an eight-week exercise intervention protocol, specifically designed for adolescent schoolboys, tin improving cardiorespiratory fitness.

Although this thesis did not find a beneficial effect of acute aerobics exercise or resistance exercise on cognition, the study design and methods gives valuable insights on the exercise dose and protocol for future studies to take reference from. This thesis also clearly reports details of the exercise protocols used, exercise dose prescribed, as well as a comprehensive battery of cognitive assessments, adding to both the quality and quantity of evidence in the adolescent research field of exercise, cognition and academic performance.

In conclusion, a three-pronged approach was used to investigate the effects of exercise on cognitive function and academic performance in adolescent schoolboys. No beneficial effect was found between exercise and the cognitive domain of Thinking as well as academic performance. However, physical fitness and body composition were found to be positively associated with the cognitive domain of Feeling and Self-regulation.

REFERENCES

1 OECD. (2017). *PISA 2015 Results (Volume III): Students' Well-being*. PISA. http://dx.doi.org/10.1787/9789264273856-en.

2 Moradi, A., Sadri Damirchi, E., Narimani, M., Esmaeilzadeh, S., Dziembowska, I., Azevedo, L. B., & Luiz do Prado, W. (2019). Association between physical and motor fitness with cognition in children. *Medicina, 55*(1), 7.

3 Ortega, F. B., Ruiz, J. R., Castillo, M. J., & Sjöström, M. (2008). Physical fitness in childhood and adolescence: a powerful marker of health. *International Journal of Obesity, 32*(1), 1-11.

4 Hruby, A., Chomitz, V. R., Arsenault, L. N., Must, A., Economos, C. D., McGowan, R. J., & Sacheck, J. M. (2012). Predicting maintenance or achievement of healthy weight in children: the impact of changes in physical fitness. *Obesity, 20*(8), 1710-1717.

5 Smith, K. L., Straker, L. M., McManus, A., & Fenner, A. A. (2014). Barriers and enablers for participation in healthy lifestyle programs by adolescents who are overweight: a qualitative study of the opinions of adolescents, their parents and community stakeholders. *BMC Pediatrics, 14*(1), 1-14.

6 Chaddock, L., Pontifex, M. B., Hillman, C. H., & Kramer, A. F. (2011). A review of the relation of aerobic fitness and physical activity to brain structure and function in children. *Journal of the International Neuropsychological Society, 17*(6), 975-985.

7 Donnelly, J. E., Hillman, C. H., Castelli, D., Etnier, J. L., Lee, S., Tomporowski, P., Lambourne, K., & Szabo-Reed, A. N. (2016). Physical activity, fitness, cognitive function, and academic achievement in children: a systematic review. *Medicine and Science in Sports and Exercise, 48*(6), 1197.

8 Hillman, C. H., Erickson, K. I., & Kramer, A. F. (2008). Be smart, exercise your heart: exercise effects on brain and cognition. *Nature Reviews Neuroscience, 9*(1), 58-65.

9 Mora-Gonzalez, J., Esteban-Cornejo, I., Cadenas-Sanchez, C., Migueles, J. H., Molina-Garcia, P., Rodriguez-Ayllon, M., Henriksson, P., Pontifex, M. B., Catena, A., & Ortega, F. B. (2019). Physical fitness, physical activity, and the executive function in children with overweight and obesity. *The Journal of Pediatrics, 208*, 50-56. e51.

10 Torrijos-Niño, C., Martínez-Vizcaíno, V., Pardo-Guijarro, M. J., García-Prieto, J. C., Arias-Palencia, N. M., & Sánchez-López, M. (2014). Physical fitness, obesity, and academic achievement in schoolchildren. *The Journal of Pediatrics, 165*(1), 104-109.

11 Ruiz-Ariza, A., Grao-Cruces, A., de Loureiro, N. E. M., & Martinez-Lopez, E. J. (2017). Influence of physical fitness on cognitive and academic performance in adolescents: A systematic review from 2005–2015. *International Review of Sport and Exercise Psychology, 10*(1), 108-133.

12 Hogan, M., Kiefer, M., Kubesch, S., Collins, P., Kilmartin, L., & Brosnan, M. (2013). The interactive effects of physical fitness and acute aerobic exercise on electrophysiological coherence and cognitive performance in adolescents. *Experimental Brain Research, 229*(1), 85-96.

13 Soga, K., Shishido, T., & Nagatomi, R. (2015). Executive function during and after acute moderate aerobic exercise in adolescents. *Psychology of Sport and Exercise, 16*, 7-17.

14 Stroth, S., Kubesch, S., Dieterle, K., Ruchsow, M., Heim, R., & Kiefer, M. (2009). Physical fitness, but not acute exercise modulates event-related potential indices for executive control in healthy adolescents. *Brain Research, 1269*, 114-124.

15 Kwak, L., Kremers, S. P., Bergman, P., Ruiz, J. R., Rizzo, N. S., & Sjöström, M. (2009). Associations between physical activity, fitness, and academic achievement. *The Journal of Pediatrics, 155*(6), 914-918.

16 Welk, G. J., Jackson, A. W., Morrow Jr, J. R., Haskell, W. H., Meredith, M. D., & Cooper, K. H. (2010). The association of health-related fitness with indicators of academic performance in Texas schools. *Research Quarterly for Exercise and Sport, 81*(sup3), S16-S23.

17 Chen, L. J., Fox, K. R., Ku, P. W., & Taun, C. Y. (2013). Fitness change and subsequent academic performance in adolescents. *Journal of School Health, 83*(9), 631-638.

18 Coe, D. P., Peterson, T., Blair, C., Schutten, M. C., & Peddie, H. (2013). Physical fitness, academic achievement, and socioeconomic status in school-aged youth. *Journal of School Health, 83*(7), 500-507.

19 Bezold, C. P., Konty, K. J., Day, S. E., Berger, M., Harr, L., Larkin, M., Napier, M. D., Nonas, C., Saha, S., & Harris, T. G. (2014). The effects of changes in physical fitness on academic performance among New York City youth. *Journal of Adolescent Health, 55*(6), 774-781.

20 Janak, J. C., Gabriel, K. P., Oluyomi, A. O., Peréz, A., Kohl, H. W., & Kelder, S. H. (2014). The association between physical fitness and academic achievement in Texas state house legislative districts: an ecologic study. *Journal of School Health, 84*(8), 533-542.

21 Esteban-Cornejo, I., Tejero-González, C. M., Martinez-Gomez, D., del-Campo, J., González-Galo, A., Padilla-Moledo, C., Sallis, J. F., Veiga, O. L., & Up & Down Study Group. (2014). Independent and combined influence of the components of physical fitness on academic performance in youth. *The Journal of Pediatrics, 165*(2), 306-312. e302.

22 Sardinha, L. B., Marques, A., Martins, S., Palmeira, A., & Minderico, C. (2014). Fitness, fatness, and academic performance in seventh-grade elementary school students. *BMC Pediatrics, 14*(1), 1-9.

23 Bass, R. W., Brown, D. D., Laurson, K. R., & Coleman, M. M. (2013). Physical fitness and academic performance in middle school students. *Acta Paediatrica, 102*(8), 832-837.

24 Ardoy, D. N., Fernández-Rodríguez, J., Jiménez-Pavón, D., Castillo, R., Ruiz, J., & Ortega, F. (2014). A physical education trial improves adolescents' cognitive performance and academic achievement: the EDUFIT study. *Scandinavian Journal of Medicine & Science in Sports, 24*(1), e52-e61.

25 Ruiz, J. R., Ortega, F. B., Castillo, R., Martín-Matillas, M., Kwak, L., Vicente-Rodríguez, G., Noriega, J., Tercedor, P., Sjöström, M., & Moreno, L. A. (2010). Physical activity, fitness, weight status, and cognitive performance in adolescents. *The Journal of Pediatrics, 157*(6), 917-922. e915.

26 Kantomaa, M. T., Stamatakis, E., Kankaanpää, A., Kaakinen, M., Rodriguez, A., Taanila, A., Ahonen, T., Järvelin, M.-R., & Tammelin, T. (2013). Physical activity and obesity mediate the association between childhood motor function and adolescents' academic achievement. *Proceedings of the National Academy of Sciences, 110*(5), 1917-1922.

27 Travlos, A. K. (2010). High intensity physical education classes and cognitive performance in eighth-grade students: An applied study. *International Journal of Sport and Exercise Psychology, 8*(3), 302-311.

28 Morales, J., Gonzalez, L.-M., Guerra, M., Virgili, C., & Unnithan, V. (2011). Physical activity, perceptual-motor performance, and academic learning in 9-to-16-years-old school children. *International Journal of Sport Psychology, 42*(4), 401.

29 Budde, H., Voelcker-Rehage, C., Pietraßyk-Kendziorra, S., Ribeiro, P., & Tidow, G. (2008). Acute coordinative exercise improves attentional performance in adolescents. *Neuroscience Letters, 441*(2), 219-223.

30 Teng, A. (2014). *Singapore ranks third globally in time spent on homework*. The Straits Times. https://www.straitstimes.com/singapore/education/singapore-ranks-third-globally-in-time-spent-on-homework.

31 Russell-Mayhew, S., McVey, G., Bardick, A., & Ireland, A. (2012). Mental health, wellness, and childhood overweight/obesity. *Journal of Obesity, 2012*.

32 Roberts, R. E., & Duong, H. T. (2016). Do anxiety disorders play a role in adolescent obesity? *Annals of Behavioral Medicine, 50*(4), 613-621.

33 Mühlig, Y., Antel, J., Föcker, M., & Hebebrand, J. (2016). Are bidirectional associations of obesity and depression already apparent in childhood and adolescence as based on high-quality studies? A systematic review. *Obesity Reviews, 17*(3), 235-249.

34 Mannan, M., Mamun, A., Doi, S., & Clavarino, A. (2016). Prospective associations between depression and obesity for adolescent males and females-a systematic review and meta-analysis of longitudinal studies. *PLOS One, 11*(6), e0157240.

35 Eisenberg, N., & Zhou, Q. (2016). Conceptions of executive function and regulation: When and to what degree do they overlap? In *Executive Function in Preschool-age Children:*

Integrating Measurement, Neurodevelopment, and Translational Research. (pp. 115-136). American Psychological Association.

36 Nigg, J. T. (2017). Annual Research Review: On the relations among self-regulation, self-control, executive functioning, effortful control, cognitive control, impulsivity, risk-taking, and inhibition for developmental psychopathology. *Journal of Child Psychology and Psychiatry, 58*(4), 361-383.

37 Wichers, M., Myin-Germeys, I., Jacobs, N., Peeters, F., Kenis, G., Derom, C., Vlietinck, R., Delespaul, P., & Van Os, J. (2007). Genetic risk of depression and stress-induced negative affect in daily life. *The British Journal of Psychiatry*, *191*(3), 218-223.

38 Williams, L. M., Gatt, J. M., Grieve, S. M., Dobson-Stone, C., Paul, R. H., Gordon, E., & Schofield, P. R. (2010). COMT Val108/158Met polymorphism effects on emotional brain function and negativity bias. *Neuroimage, 53*(3), 918-925.

39 Williams, L. M., Gatt, J. M., Schofield, P. R., Olivieri, G., Peduto, A., & Gordon, E. (2009). 'Negativity bias' in risk for depression and anxiety: Brain–body fear circuitry correlates, 5-HTT-LPR and early life stress. *Neuroimage, 47*(3), 804-814.

40 Watters, A. J., & Williams, L. M. (2011). Negative biases and risk for depression; integrating self-report and emotion task markers. *Depression and Anxiety, 28*(8), 703-718.

41 Hardie, D. (2020). *Overcoming the negativity bias – how a teen's brain is sabotaging their self-worth*. MyStrengths. https://hub.mystrengths.com.au/mental-health/overcoming-the-negativity-bias/.

42 Boxe, A. (2020). *The teen brain, in flux, vulnerable to mental health disorders*. BrainFacts. https://www.brainfacts.org/diseases-and-disorders/mental-health/2020/the-teen-brain-in-flux-vulnerable-to-mental-health-disorders-061220.

43 Davey, C. G., Yücel, M., & Allen, N. B. (2008). The emergence of depression in adolescence: Development of the prefrontal cortex and the representation of reward. *Neuroscience & Biobehavioral Reviews, 32*(1), 1-19.

44 Gee, D. G., Fetcho, R. N., Jing, D., Li, A., Glatt, C. E., Drysdale, A. T., Cohen, A. O., Dellarco, D. V., Yang, R. R., & Dale, A. M. (2016). Individual differences in frontolimbic circuitry and anxiety emerge with adolescent changes in endocannabinoid signaling across species. *Proceedings of the National Academy of Sciences, 113*(16), 4500-4505.

45 Knuth, A. G., & Hallal, P. C. (2009). Temporal trends in physical activity: a systematic review. *Journal of Physical Activity and Health, 6*(5), 548-559.

46 Trudeau, F., & Shephard, R. J. (2008). Physical education, school physical activity, school sports and academic performance. *International Journal of Behavioral Nutrition and Physical Activity, 5*(1), 1-12.

47 Kao, S.-C., Westfall, D. R., Parks, A. C., Pontifex, M. B., & Hillman, C. H. (2017). Muscular and aerobic fitness, working memory, and academic achievement in children. *Medicine and Science in Sports and Exercise, 49*(3), 500-508.

48 Ludyga, S., Pühse, U., Gerber, M., & Mücke, M. (2021). Muscle strength and executive function in children and adolescents with autism spectrum disorder. *Autism Research, 14*(12), 2555-2563.

49 Davis, C. L., Tomporowski, P. D., Boyle, C. A., Waller, J. L., Miller, P. H., Naglieri, J. A., & Gregoski, M. (2007). Effects of aerobic exercise on overweight children's cognitive functioning: a randomized controlled trial. *Research Quarterly for Exercise and Sport, 78*(5), 510-519.

50 Angold, A., Costello, E., Erkanli, A., & Worthman, C. (1999). Pubertal changes in hormone levels and depression in girls. *Psychological Medicine, 29*(5), 1043-1053.

51 Brooks-Gunn, J., & Warren, M. P. (1989). Biological and social contributions to negative affect in young adolescent girls. *Child Development*, 40-55.

52 Ware, R. S., McPherson, L., & Lennox, N. G. (2017). Drop-out during a randomized trial with adolescents with intellectual disability was associated with participant burden, while drop-out at study exit was associated with carer and household characteristics. *Research in Developmental Disabilities, 71*, 53-60.

53 O'Keeffe, S., Martin, P., Goodyer, I. M., Kelvin, R., Dubicka, B., Reynolds, S., Barrett, B., Byford, S., Hill, J., & Holland, F. (2019). Prognostic implications for adolescents with

depression who drop out of psychological treatment during a randomized controlled trial. *Journal of the American Academy of Child & Adolescent Psychiatry, 58*(10), 983-992.
54 Wassenaar, T., Wheatley, C., Beale, N., Nichols, T., Salvan, P., Meaney, A., Atherton, K., Diaz-Ordaz, K., Dawes, H., & Johansen-Berg, H. (2021). The effect of a one-year vigorous physical activity intervention on fitness, cognitive performance and mental health in young adolescents: the Fit to Study cluster randomised controlled trial. *International Journal of Behavioral Nutrition and Physical Activity, 18*(1), 1-15.
55 Sibley, B. A., & Etnier, J. L. (2003). The relationship between physical activity and cognition in children: a meta-analysis. *Pediatric Exercise Science, 15*(3), 243-256.
56 McPherson, A., Mackay, L., Kunkel, J., & Duncan, S. (2018). Physical activity, cognition and academic performance: an analysis of mediating and confounding relationships in primary school children. *BMC Public Health, 18*(1), 1-9.
57 Farooq, M. S., Chaudhry, A. H., Shafiq, M., & Berhanu, G. (2011). Factors affecting students' quality of academic performance: a case of secondary school level. *Journal of Quality and Technology Management, 7*(2), 1-14.
58 Mickelson, R. A. (1990). The Sociology of Education: A Systematic Analysis. *Teaching Sociology, 18*(4), 565.
59 Leone, C. M., & Richards, H. (1989). Classwork and homework in early adolescence: The ecology of achievement. *Journal of Youth and Adolescence, 18*(6), 531-548.
60 Dunbar, R. L., Dingel, M. J., Dame, L. F., Winchip, J., & Petzold, A. M. (2018). Student social self-efficacy, leadership status, and academic performance in collaborative learning environments. *Studies in Higher Education, 43*(9), 1507-1523.
61 Dwyer, T., Sallis, J. F., Blizzard, L., Lazarus, R., & Dean, K. (2001). Relation of academic performance to physical activity and fitness in children. *Pediatric Exercise Science, 13*(3), 225-237.
62 Florence, M. D., Asbridge, M., & Veugelers, P. J. (2008). Diet quality and academic performance. *Journal of School Health, 78*(4), 209-215.
63 Wetherell, J. L., Ripperger, H. S., Voegtle, M., Ances, B. M., Balota, D., Bower, E. S., Depp, C., Eyler, L., Foster, E. R., & Head, D. (2020). Mindfulness, education, and exercise for age-related cognitive decline: Study protocol, pilot study results, and description of the baseline sample. *Clinical Trials, 17*(5), 581-594.
64 Lovegrove, R. A., & Bahr, M. (2020). Muscle strength to mental strength: Exercise and age-related cognitive decline. *Psychology, 11*(05), 763.
65 Yang, Y. R., & Kwon, K.-S. (2020). Potential roles of exercise-induced plasma metabolites linking exercise to health benefits. *Frontiers in Physiology, 11*, 1620.
66 Ruegsegger, G. N., & Booth, F. W. (2018). Health benefits of exercise. *Cold Spring Harbor Perspectives in Medicine, 8*(7), a029694.
67 Hertzog, C., Kramer, A. F., Wilson, R. S., & Lindenberger, U. (2008). Enrichment effects on adult cognitive development: can the functional capacity of older adults be preserved and enhanced? *Psychological Science in the Public Interest, 9*(1), 1-65.
68 Gourgouvelis, J., Yielder, P., Clarke, S. T., Behbahani, H., & Murphy, B. (2018). You can't fix what isn't broken: eight weeks of exercise do not substantially change cognitive function and biochemical markers in young and healthy adults. *PeerJ, 6*, e4675.
69 Williams, L. M., Cooper, N. J., Wisniewski, S. R., Gatt, J. M., Koslow, S. H., Kulkarni, J., DeVarney, S., Gordon, E., & John Rush, A. (2012). Sensitivity, specificity, and predictive power of the "Brief Risk-resilience Index for SCreening," a brief pan-diagnostic web screen for emotional health. *Brain and Behavior, 2*(5), 576-589.
70 Williams, L., Simms, E., Clark, C., Paul, R., Rowe, D., & Gordon, E. (2005). The test-retest reliability of a standardized neurocognitive and neurophysiological test battery:"neuromarker". *International Journal of Neuroscience, 115*(12), 1605-1630.
71 Geoff N. Masters, M. F. (2000). *The assessments we need*. Australian Council for Educational Research. https://research.acer.edu.au/ar_misc/27.
72 Mayorga-Vega, D., Aguilar-Soto, P., & Viciana, J. (2015). Criterion-related validity of the 20-m shuttle run test for estimating cardiorespiratory fitness: a meta-analysis. *Journal of Sports Science & Medicine, 14*(3), 536.

73 Armstrong, N., & Welsman, J. (2019). Youth cardiorespiratory fitness: evidence, myths and misconceptions. *Bulletin of the World Health Organization*, *97*(11), 777-782.

74 OECD. (2016). *PISA 2015: PISA Results in Focus*. https://www.oecd.org/education/pisa-2015-results-volume-i-9789264266490-en.htm.

75 O'Leary, J. D., Hoban, A. E., Cryan, J. F., O'Leary, O. F., & Nolan, Y. M. (2019). Differential effects of adolescent and adult-initiated voluntary exercise on context and cued fear conditioning. *Neuropharmacology, 145*, 49-58.

76 O'Leary, J. D., Hoban, A. E., Murphy, A., O'Leary, O. F., Cryan, J. F., & Nolan, Y. M. (2019). Differential effects of adolescent and adult-initiated exercise on cognition and hippocampal neurogenesis. *Hippocampus, 29*(4), 352-365.

77 Ho, T.-W., Tsai, H.-H., Lai, J.-F., Chu, S.-M., Liao, W.-C., & Chiu, H.-M. (2020). Physical fitness cognition, assessment, and promotion: A cross-sectional study in Taiwan. *PLOS One, 15*(10), e0240137.

78 Lin, C. J., & Lercher, K. (2019). Exercise benefits in patients recovering from traumatic brain injury. *Current Physical Medicine and Rehabilitation Reports, 7*(4), 357-361.

79 Sharma, B., Allison, D., Tucker, P., Mabbott, D., & Timmons, B. W. (2020). Cognitive and neural effects of exercise following traumatic brain injury: A systematic review of randomized and controlled clinical trials. *Brain Injury, 34*(2), 149-159.

80 Morris, T., Gomes Osman, J., Tormos Munoz, J. M., Costa Miserachs, D., & Pascual Leone, A. (2016). The role of physical exercise in cognitive recovery after traumatic brain injury: A systematic review. *Restorative Neurology and Neuroscience, 34*(6), 977-988.

81 Srinivasan, S. M., Pescatello, L. S., & Bhat, A. N. (2014). Current perspectives on physical activity and exercise recommendations for children and adolescents with autism spectrum disorders. *Physical Therapy*, *94*(6), 875-889.

82 Raluca, P. E., & Luminita, G. (2019). Implementation of complex combined programs: learning-therapeutic physical exercise–dynamic play in order that pupils within special facilities of inclusive education may diminish their scoliotic attitude. *Journal of Physical Education and Sport, 19*, 2241-2245.

83 Jia, W., & Xie, J. (2021). Improvement of the health of people with autism spectrum disorder by exercise. *Revista Brasileira de Medicina do Esporte, 27*, 282-285.

84 Ng, Q. X., Ho, C. Y. X., Chan, H. W., Yong, B. Z. J., & Yeo, W.-S. (2017). Managing childhood and adolescent attention-deficit/hyperactivity disorder (ADHD) with exercise: A systematic review. *Complementary Therapies in Medicine, 34*, 123-128.

85 Neudecker, C., Mewes, N., Reimers, A. K., & Woll, A. (2019). Exercise interventions in children and adolescents with ADHD: a systematic review. *Journal of Attention Disorders, 23*(4), 307-324.

86 Villa-González, R., Villalba-Heredia, L., Crespo, I., Del Valle, M., & Olmedillas, H. (2020). A systematic review of acute exercise as a coadjuvant treatment of ADHD in young people. *Psicothema, 32*(1), 67-74.

87 Faerman, A., & Spiegel, D. (2021). Shared cognitive mechanisms of hypnotizability with executive functioning and information salience. *Scientific Reports, 11*(1), 1-12.

88 Snowball, A., Tachtsidis, I., Popescu, T., Thompson, J., Delazer, M., Zamarian, L., Zhu, T., & Kadosh, R. C. (2013). Long-term enhancement of brain function and cognition using cognitive training and brain stimulation. *Current Biology*, *23*(11), 987-992.

89 Gillick, B. T., & Zirpel, L. (2012). Neuroplasticity: an appreciation from synapse to system. *Archives of Physical Medicine and Rehabilitation, 93*(10), 1846-1855.

90 Marc, L. (2017). Addiction and the brain: development, not disease. *Neuroethics, 10*(1).

91 Mavros, Y., Gates, N., Wilson, G. C., Jain, N., Meiklejohn, J., Brodaty, H., Wen, W., Singh, N., Baune, B. T., & Suo, C. (2017). Mediation of cognitive function improvements by strength gains after resistance training in older adults with mild cognitive impairment: outcomes of the study of mental and resistance training. *Journal of the American Geriatrics Society, 65*(3), 550-559.

92 Gallen, C. L., & D'Esposito, M. (2019). Brain modularity: a biomarker of intervention-related plasticity. *Trends in Cognitive Sciences*, *23*(4), 293-304.

93 Li, J. W., O'Connor, H., O'Dwyer, N., & Orr, R. (2017). The effect of acute and chronic exercise on cognitive function and academic performance in adolescents: A systematic review. *Journal of Science and Medicine in Sport*, *20*(9), 841-848.

94 Mamrot, P., & Hanć, T. (2019). The association of the executive functions with overweight and obesity indicators in children and adolescents: A literature review. *Neuroscience & Biobehavioral Reviews*, *107*, 59-68.

95 Alarcón, G., Ray, S., & Nagel, B. J. (2016). Lower working memory performance in overweight and obese adolescents is mediated by white matter microstructure. *Journal of the International Neuropsychological Society*, *22*(3), 281-292.

96 Huang, T., Tarp, J., Domazet, S. L., Thorsen, A. K., Froberg, K., Andersen, L. B., & Bugge, A. (2015). Associations of adiposity and aerobic fitness with executive function and math performance in danish adolescents. *The Journal of Pediatrics*, *167*(4), 810-815.

97 Schwartz, D. H., Leonard, G., Perron, M., Richer, L., Syme, C., Veillette, S., Pausova, Z., & Paus, T. (2013). Visceral fat is associated with lower executive functioning in adolescents. *International Journal of Obesity*, *37*(10), 1336-1343.

Manual of Procedures: Part I

Protocol for Outcome Measure

Aerobic Fitness

- Subjects will be required to perform the 20m Shuttle Run(beep Test) using the PACER(Progressive Aerobic Cardiovascular Endurance Run) Protocol developed by theCooper Institute
- The PACER laps will be converted to the subjects VO_{2max} by using the PACER Quadratic Modeldeveloped and validated by Mahar et al(2011)
    - **VO_{2max} = 41.76799 + (0.49261×PACER) –(0.00290 ×$PACER^2$) – (0.61613×BMI) + (0.34787 × gender ×age)**
    - R = 0.75,R2= 0.56, SEE = 6.17 ml ⁄ kg ⁄min,
    - where PACER is the number of laps completed; for gender, 1= boy, 0 = girl
- The Protocol:
    - Equipment and Facilities:
        - Administering the PACER requires a flat, nonslippery surface at least20 meters long, and preferably indoors(to ensure that cadence/beeps can be heard)
        - CD or cassette player with adequate volume, CD or audiocassette, measuring tape, marker cones, pencil, and copies of score sheets.
        - Students should wear shoes with nonslip soles.
        - Plan for each student to have approximately a 1m-wide space for running. Lanes may be demarcated with tape or chalk lines if permitted.
        - A designated area for finished runners and for scorekeepers (A teacher and an assistant would be preferable to have around).
    - Test Instructions:
        - The start point and end point between the 20m should be demarcate clearly with cones or tape
        - Make copies of score sheet
        - It is preferable to allow students to listen to several minutes of the tape before the actual test so that they know what to expect.
        - Students should then be allowed at least two practice sessions (PACER Protocol).
        - Have students who are being tested line up behind the start line.
        - The PACER CD will have a 5-second countdown and would tell the students when to start.
        - Students should run across the 20-meter distance and touch the line with their foot by the time the beep sounds.
        - At the sound of the beep, they turn around and run back to the other end.
        - If some students get to the line before the beep, they must wait for the beep before running the other direction. Students continue in this manner until they fail to reach the line before the beep for the second time.
        - A single beep will sound at the end of the time for each lap. A triple beep sounds at the end of each minute (stage), indicating the start of the next level (beeps between the 20m shorten, students have to increase their speed to stay in the test). The triple beep serves the same function as the single beep and also alerts the runners that the pace will get faster.
        - Inform students that when the triple beep sounds they should not stop but should continue the test by turning and running toward theother end of the area.

- The first time a student does not reach the line by the beep, the student stops where he or she is and reverses direction immediately, attempting to get back on pace. ***The test is completed for a student the next time (second time) he or she fails to reach the line by the beep (the two misses do not have to be consecutive;the test is over after two total misses).***
- Students just completing the test should continue to walk and stretch in the designated cool-down area.
- Note: A student who remains at one end of the testing area through two beeps (does not run to the other end and back) should be scored as having two misses and the test is over (PACER Protocol)

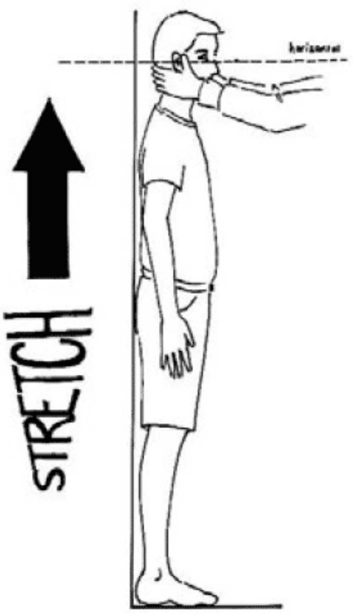
▪ Scoring:
- Have the scorer record the lap number (crossing off each lap number) on a PACER score sheet
- The recorded score is the total number of laps completed by the student.
- Use the above PACER Quadratic Equation to convert scores toVO2max

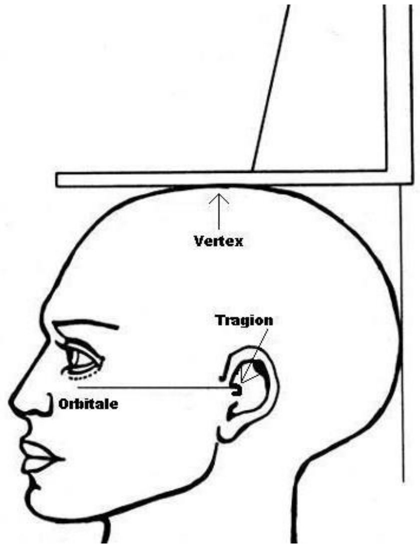
Anthropometric Measurements

- Height(m), Body mass(kg), Body Mass Index(kgM-2) and waist circumference measurements will be required
- Anthropometric measurements protocols will be carried out according to the International Society for the Advancement of Kinanthropometry (ISAK)

Protocol for Height (Stretch Stature)

- Definition: The perpendicular distance (m) between the top of the head (the vertex) and the bottom of the feet.
- Equipment and facilities:
  - Stadiometer, preferably attached firmly to a wall
  - Anthropometry box for anthropometrist to stand on if subject is too tall
  - An assistant
  - Sports Laboratory
- The measurements must be performed without footwear and in light clothing
- The subject stands facing forward, heels together, with buttock and upper back (greatest protrusion) touching the Stadiometer back-plate.
- The head is placed in the Frankfort plane: when orbitale is in same horizontal plane as the tragion. To do this, place the tips of the thumbs on each orbitale and middle fingers on mastoid process (palms of each hand gently under the jaw) and horizontally align the orbitale and tragion.
- When the head is in position, the subject is instructed to take and hold a deep breath while you apply a gentle but firm upward lift through the mastoid process (not jaw).
- Have an assistant lower the head board to the top of the skull (vertex), compressing the hair down, with the poition of head maintained in Frankfort plane.
- The measurement is taken at end-inspiration by the anthropometrist.





“Head in Frank Fort plane”, Adapted from the ISAK Manual, 2001

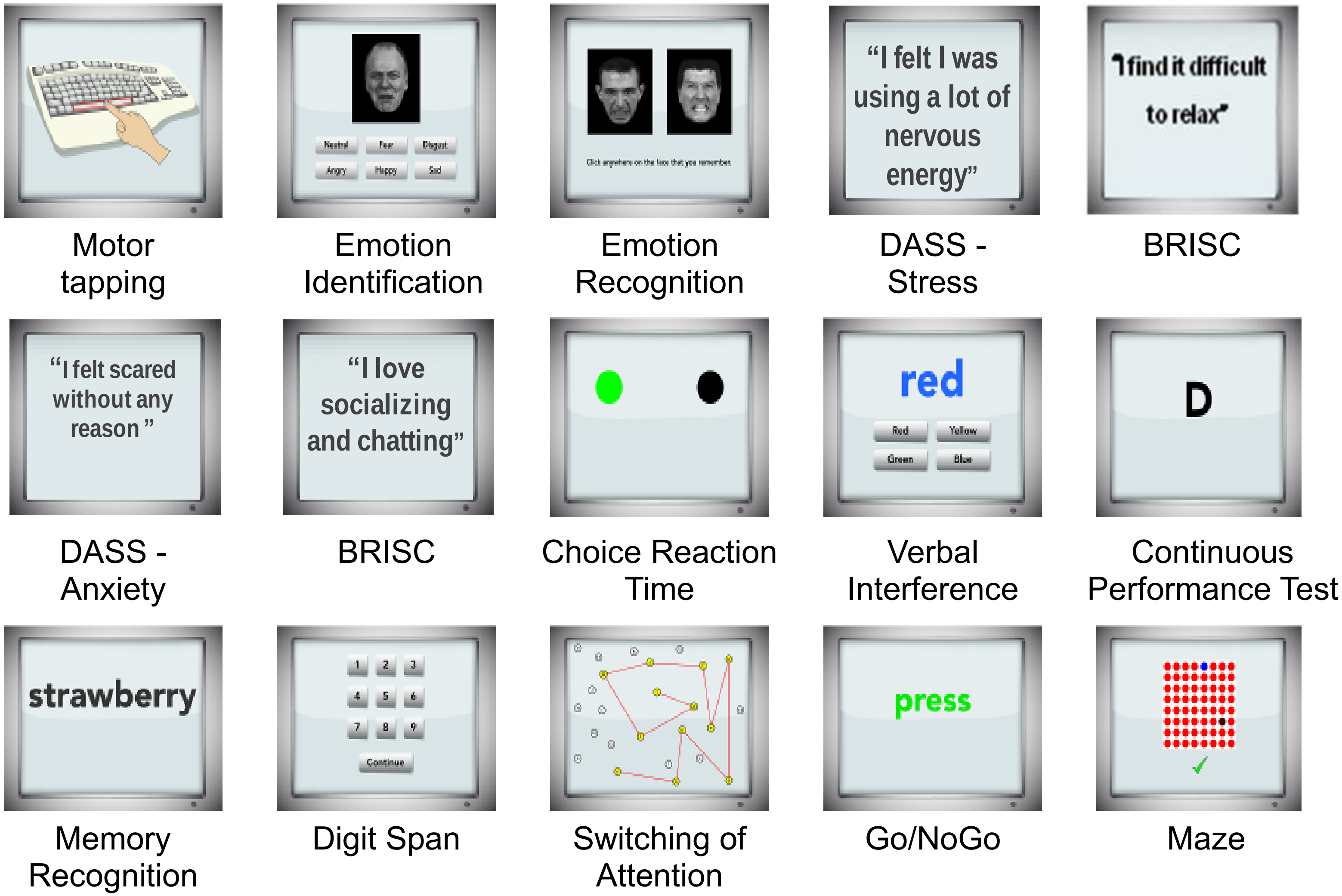
Protocol for body mass

- Definition: Body mass is the force the matter in the body exerts in a standard gravitational field.
- Equipment and Facilities:
  - An electronic weighing scale that has been calibrated
- The measurements must be performed without footwear and in light clothing.
- Turn on the scales.
- Once the zeros appear, ask the subject to stand on the scales.
- Subject should stand on the center of the scales without support, with their arms loosely by their sides, head facing forward and with their weight distributed evenly on both feet.
- A reading will appear in the digital screen, with its numbers fluctuating.
- Once the numbers have stopped fluctuating, the reading may be recorded.
- Instruct the subject to gently step off the scale

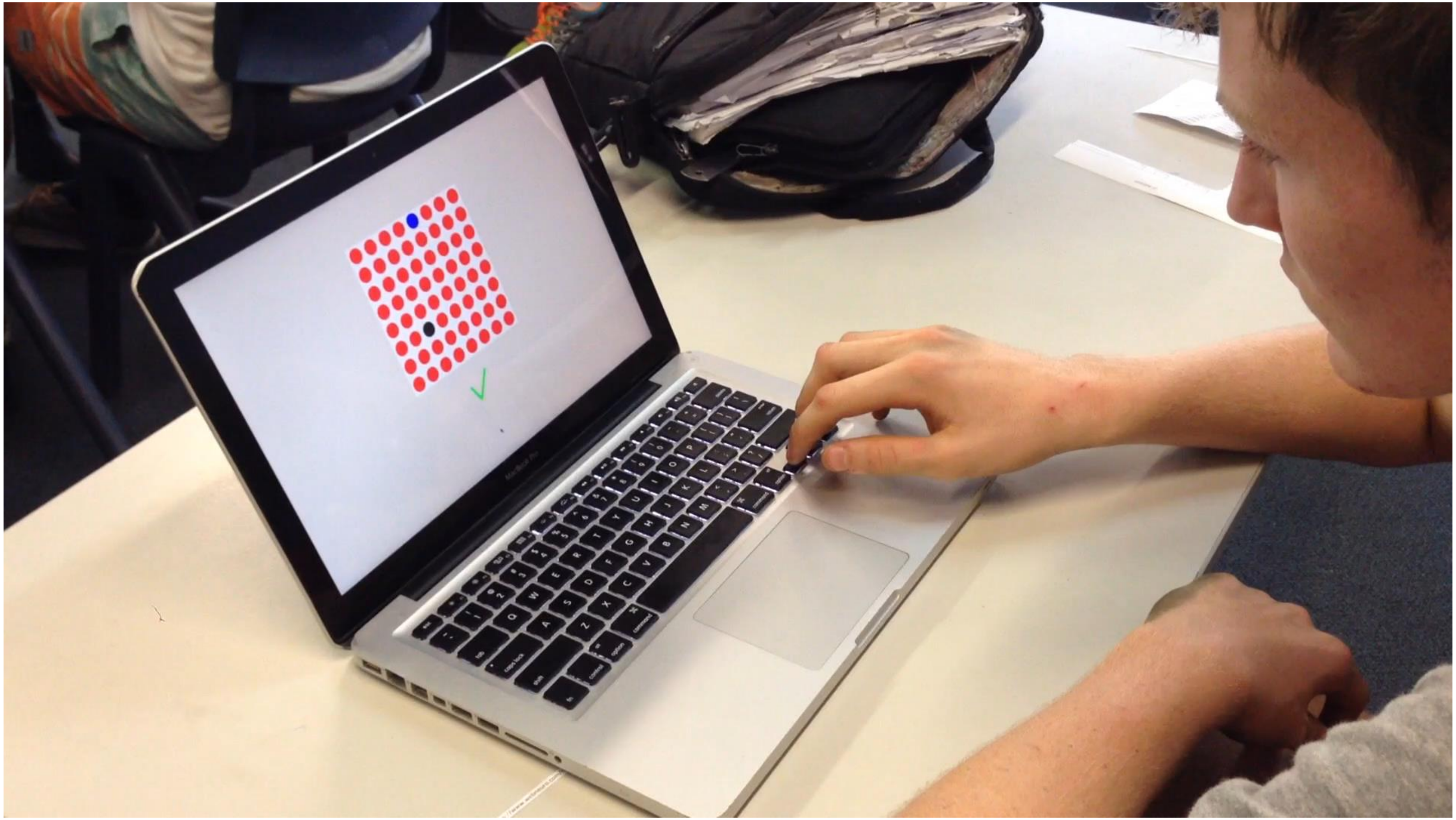
Protocol for waist circumference

- Definition: The circumference of the abdomen at its narrowest point between the lower costal (10th rib) border and the top of the iliac crest, perpendicular tothe long axis of the trunk.
- Equipment and facilities:
  - Measuring tape
- Instruct the subject to stand upright in a relaxed manner, feet comfortably apart, weight evenly balanced on both feet and with their arms hanging by their side.
- If possible, kindly ask subject to remove shirt or lift up shirt to the appropriate position.
- Ask the subject to cross their arms in front of their chest in a “mummy position”
- Identification of the lower costal border and iliac crest:
  - The anthropometrist palpates the lower costal margin by walking fingers down the rib cage in the midline.
  - Palpate the most superior and lateral point of the iliac tubercle at the midline.
  - The midpoint is the linear distance between these bony landmarks.
- The anthropometrist stands at the side of the subject with the stub of the tape and housing both held in the right hand.
- If needed, ask subject to stand on the anthropometry box
- The left hand is used to pass the tape around the back of the subject
  - The assistant may help at this point
- The tape is crossed at the front to facilitate easy identification of the zero point on the tape and ease of measurement.
- Together with the assistant, adjust the tape so that it is parallel to the ground and check that tape is at the narrowest point.
- Apply gentle pressure and sufficient tension to the tape
- The subject should breathe normally: measurement is taken at end- expiration
- Reading should be taken at eye level

Cognitive Testing - WebNeuro™ assessment battery



Cognitive Testing - A participant attempting the WebNeuro™ Maze task



Manual of Procedures: Part II

Data Collection Sheets

THE UNIVERSITY OF SYDNEY

20m Shuttle Rub Group Score Sheet

Score-keeper:_______________________________Group:__________ Date: _____________

Laps(20-meter lengths)

Min	Laps													
1	1	2	3	4	5	6	7							
2	8	9	10	11	12	13	14	15						
3	16	17	18	19	20	21	22	23						
4	24	25	26	27	28	29	30	31	32					
5	33	34	35	36	37	38	39	40	41					
6	42	43	44	45	46	47	48	49	50	51				
7	52	53	54	55	56	57	58	59	60	61				
8	62	63	64	65	66	67	68	69	70	71	72			
9	73	74	75	76	77	78	79	80	81	82	83			
10	84	85	86	87	88	89	90	91	92	93	94			
11	95	96	97	98	99	100	101	102	103	104	105	106		
12	107	108	109	110	111	112	113	114	115	116	117	118		
13	119	120	121	122	123	124	125	126	127	128	129	130	131	
14	132	133	134	135	136	137	138	139	140	141	142	143	144	
15	145	146	147	148	149	150	151	152	153	154	155	156	157	

Lane	**Student Name**	**Laps completed**	**Trial Test 1**	**Trial Test 2**	**Actual Test**

Adapted fromFITNESSGRAM/ACTIVITYGRAM Test Administration Manual, Fourth Edition by the CooperInstitute, 2005, Champaign, IL:Human Kinetics

Appendix 2

THE UNIVERSITY OF SYDNEY

BODY VS BRAIN TRAINING

Participant Demographic Sheet

Surname		Given Name	
Address			
Phone	(H)	(M)	
Date of Birth		Age	years
Class		Email	
Parent Contact	Relationship		
Surname		Given Name	
Phone	(W)	(M)	
Email			

What is your ethnic background? <u>Tick as many as applicable</u>.

❑ Australian ❑ Aboriginal or Torres Strait Islander ❑ Pacific Islander ❑ Lebanese / Middle Eastern

❑ Asian ❑ North American or European ❑ Central or South American ❑ African

Medical History

Do you suffer from any of the following?			If yes, how long have you had this condition?
Asthma	❑ Yes	❑ No	years
Type 1 Diabetes	❑ Yes	❑ No	years
Type 2 Diabetes	❑ Yes	❑ No	years
Epilepsy	❑ Yes	❑ No	years
Heart Conditions	❑ Yes	❑ No	years
Allergies	❑ Yes	❑ No	years
Other	❑ Yes	❑ No	years
Are you taking any of the following?			If yes, please list
Medications	❑ Yes	❑ No	
Vitamins and/or Supplements	❑ Yes	❑ No	
Other	❑ Yes	❑ No	

Appendix 2

Do you have any other conditions the researchers should be aware of?

____

____

Do you experience any of the following signs or symptoms when you do physical activity?		
Undue Shortness of Breath	❑ Yes	❑ No
Chest Pain	❑ Yes	❑ No
Dizziness/Fainting	❑ Yes	❑ No
Becoming Tired/Fatigued easily	❑ Yes	❑ No

Do you have any other issues or comments you would like to make the researchers aware of?

____

____

____

Injury and Surgery History

Have you suffered from any of the following in the past 12 months?			Give location (where relevant)
Concussion	❑ Yes	❑ No	
Broken Bones	❑ Yes	❑ No	
Have you undergone surgery due to any of the following in the past 12 months?			
Sports injury	❑ Yes	❑ No	
A medical Condition	❑ Yes	❑ No	
Non-sports related injury e.g., an accident	❑ Yes	❑ No	

Appendix 2

Do you have any other conditions the researchers should be aware of?

____

____

Participant's Extra-curricular Activities

What are you hobbies? e.g. reading, cycling,drawing, swimming, watching television, etc	
Do you do any of them more than 3 times a week?	❑ **Yes** ❑ **No** If Yes, state which ones: ________________ ________________ ________________ ________________ ________________
Do you take part in non-school related sports?	❑ **Yes** ❑ **No** If Yes; Sport:________________ Number of times per week: ________________
Do you enjoy physical activities?	❑ **Yes** ❑ **No**
Do you prefer non-physical to physical activities? e.g. playing music to football, or watching the television to cycling	❑ **Yes** ❑ **No**

Anthropometric Measurement

Name: ____

Measurement 1:

Waist Circumference (cm)	Height (cm)	Sitting Height (cm)	Body Mass (kg)

Measurement 2:

Waist Circumference (cm)	Height (cm)	Sitting Height (cm)	Body Mass (kg)

Measurement 3 (if required):

Waist Circumference (cm)	Height (cm)	Sitting Height (cm)	Body Mass (kg)

Manual of Procedures: Part III

Participants' information and consent

Discipline of Exercise and Sports Science
Faculty of Health Sciences

ABN 15 211 513 464

Dr Rhonda Orr
Senior Lecturer

Room 130
Block K
C42 Cumberland Campus
The University of Sydney, Lidcombe
NSW 2141 AUSTRALIA
Telephone: +61 2 9351 9475
Facsimile: +61 2 9351 9204
Email: rhonda.orr@sydney.edu.au
Web: http://www.sydney.edu.au/

[Body versus brain training for improving cognitive function in schoolboys]

PARENTAL (OR CAREGIVER) INFORMATION STATEMENT

(1) What is the study about?

You are invited to permit your child to participate in a study which aims to investigate the effects that fitness have on students' cognitive function and academic performance. The study will examine possible relationships between aerobic fitness and adolescents' brain function as shown by test scores in students.

Your child was selected as a possible participant in this study because he is between the ages of 13-17 years, is a student at R**affles Institution**.

(2) Who is carrying out the study?

The study is being conducted by Miss Joanna Li and will form the basis for the degree of Doctor of Philosophy at The University of Sydney under the supervision of Dr Rhonda Orr, Senior Lecturer, Dr Helen O' Connor, Senior Lecturer and Dr Nicholas O'Dwyer, Honorary Associate Professor.

(3) What does the study involve?

- A total of 2.5h of testing in one after school session.
- These tests will include:
  - Height, sitting height, weight and waist circumference measurements (approximately 5 minutes)
  - 20m Shuttle Run (Beep test) where participants will be required to run 20m back and forth between 2 cones according to a recorded "beep" sound till they cannot run any further (approximately 10-20minutes)
  - Cognitive testing (computer-based) which measures participants' emotions, feeling, thinking and self-regulation (approximately 45minutes); and
  - Academic Performance which will be measured using the ACER General Ability Test for Secondary 1 to 4(approximately 40 minutes).
- The researchers may also request the students' English and Maths results from the school as an additional but secondary measure of academic performance.
- This study will be held within the premises of **Raffles Institution**.
- Participants will be required to do some physical activity as well as some computer-based activities.
- Because the nature of the study requires participants to take part in a brief structured and supervised physical activity, the usual risks of musculoskeletal injury associated with physical activity will apply.

(4) **How much time will the study take?**

2.5h.

(5) **Can my child withdraw from the study?**

Participation in this study is completely voluntary. You are not under any obligation to consent to your child's participation.

Your decision whether or not to permit your child to participate will not prejudice you or your child's future relations with The University of Sydney. If you decide to permit your child to participate, you are free to withdraw your consent and to discontinue your child's participation at any time without affecting your relationship with the **University of Sydney and Raffles Institution.**

(6) **Will anyone else know the results of the study?**

All aspects of the study, including results, will be strictly confidential and only the research team will have access to information on participants. Parents can choose whether to disclose their child's result to **Raffles Institution** at the end of the study.

A report of the study may be submitted for publication, but individual participants will not be identifiable in such a report.

(7) **Will the study benefit me?**

We cannot and do not guarantee or promise that your child will receive any benefits from the study. However, you child will receive a comprehensive report about his aerobic fitness as well as cognitive function.

(8) **Can I tell other people about the study?**

Yes.

(9) **What if I require further information about the study or my child's involvement?**

When you have read this information, Miss Joanna Li is available to discuss it with you further and answer any questions you may have. If you would like to know more at any stage, please feel free to contact Miss Joanna Li, PhD Student at email: weli5165@sydney.edu.au.

(10) **What if I have a complaint or any concerns?**

Any person with concerns or complaints about the conduct of a research study can contact The Manager, Human Ethics Administration, University of Sydney on +61 8627 8176 (Telephone); +61 8627 8177 (Facsimile) or ro.humanethics@sydney.edu.au (Email).

This information sheet is for you to keep.

Discipline of Exercise and Sports Science
Faculty of Health Sciences

ABN 15 211 513 464

Dr Rhonda Orr
Senior Lecturer

Room 130
Block K
C42 Cumberland Campus
The University of Sydney, Lidcombe
NSW 2141 AUSTRALIA
Telephone: +61 2 9351 9475
Facsimile: +61 2 9351 9204
Email: rhonda.orr@sydney.edu.au
Web: http://www.sydney.edu.au/

PARENTAL (OR CAREGIVER) CONSENT FORM

I,...[PRINT NAME], agree to permit ....……..[PRINT CHILD'S NAME], who is aged .... years, to participate in the research project

TITLE: Body versus brain training for improving cognitive function in schoolboys

In giving my consent I acknowledge that:

1. The procedures required for the project and the time involved for my child's participation in the project have been explained to me, and any questions I have about the project have been answered to my satisfaction.

2. I have read the Information Statement and have been given the opportunity to discuss the information and my child's involvement in the project with the researcher/s.

3. I understand that being in this study is completely voluntary – I am not under any obligation to consent to my child's participation.

4. I understand that my child's involvement is strictly confidential. I understand that research data gathered from the results of the study may be published however no information about my child nor I will be used in any way that is identifiable.

5. I understand that I can withdraw my child from the study at any time without prejudice to my or my child's relationship with the researcher/s or **The University of Sydney** and **Raffles Institution** now or in the future.

6. I consent to:

- Receiving Feedback YES ☐ NO ☐

If you answered YES to the "Receiving Feedback" question, please provide your details i.e. mailing address, email address.

Feedback Option

Address: ____

____

Email: ____

....
Signature of Parent/Caregiver

....
Please PRINT name

....
Date

....
Signature of Child

....
Please PRINT name

....
Date

THE UNIVERSITY OF SYDNEY PRESENTS..

WHAT IS IT…?

A research collaboration between The University of Sydney and RI.

AIM…

"To investigate the correlation between FITNESS and COGNITION."

WHO ARE WE LOOKING FOR…

- **13-17 years old boys**
- **Boys who are keen to learn about their fitness**
- **Boys who want to find out more about their cognitive function**
- **Boys who love playing brain games e.g. Luminosity , Fit Brains, Peak etc**

WHAT DOES THIS STUDY INVOLVE…?

- **Week 1 :**
  - Height, weight, sitting height, waist circumference
  - Brain Assessment (computer-based)
- **Week 2:**
  - General Ability Test for reasoning, numeracy and literacy.
  - VO_{2peak} (your aerobic fitness capacity)

HOW MUCH TIME DOES THIS TAKE UP?

2 WEEKS OF TESTING

- Wk 1: Testing Pt 1 (1h)
- Wk 2: Testing Pt 2 (1.5h)

WHY ME...?

- **Be the first in Singapore to take part in this revolutionary Research Opportunity!**
- **You will benefit physically, mentally and psychologically.**

WHAT WILL I GET…?

- **A comprehensive report on your:**
  - Fitness
  - Cognitive Function
  - General Ability Test

PILOT STUDY IN AUSTRALIA…

The Scots College
Sydney Australia

- **We have piloted this study at The Scots College, Sydney and here's what we found out**
  - Fitter boys are associated with better cognitive function
  - Fitter boys can regulate their responses better under stress
  - Fitter boys tend to be more optimistic and hence have better well-being
  - Fitter boys are associated with higher self-esteem and confidence

A Scots's boy getting his body composition measured in a BODPOD©.

THANK YOU

Discipline of Exercise and Sports Science
Faculty of Health Sciences

ABN 15 211 513 464

Dr Rhonda Orr
Senior Lecturer

Room 130
Block K
C42 Cumberland Campus
The University of Sydney, Lidcombe
NSW 2141 AUSTRALIA
Telephone: +61 2 9351 9475
Facsimile: +61 2 9351 9204
Email: rhonda.orr@sydney.edu.au
Web: http://www.sydney.edu.au/

PARENTAL (OR CAREGIVER) CONSENT FORM

I,..[PRINT NAME], agree to permit ....……..[PRINT CHILD'S NAME], who is aged .... years, to participate in the research project

TITLE: The effects of acute exercise on improving cognitive function in schoolboys.

In giving my consent I acknowledge that:

1. The procedures required for the project and the time involved for my child's participation in the project have been explained to me, and any questions I have about the project have been answered to my satisfaction.

2. I have read the Information Statement and have been given the opportunity to discuss the information and my child's involvement in the project with the researcher/s.

3. I understand that being in this study is completely voluntary – I am not under any obligation to consent to my child's participation.

4. I understand that my child's involvement is strictly confidential. I understand that research data gathered from the results of the study may be published however no information about my child nor I will be used in any way that is identifiable.

5. I understand that I can withdraw my child from the study at any time without prejudice to my or my child's relationship with the researcher/s or **The University of Sydney** and **The Scots College** now or in the future.

6. I consent to:

- Receiving Feedback YES ☐ NO ☐

If you answered YES to the “Receiving Feedback” question, please provide your details i.e. mailing address, email address.

Feedback Option

Address: ____

____

Email: ____

....
Signature of Parent/Caregiver

....
Please PRINT name

....
Date

....
Signature of Child

....
Please PRINT name

....
Date

Information Sheet for Students and Parents

Introduction

My name is Joanna Li from The University of Sydney.

As part of the school's efforts to raise the standards of fitness and learning, I am collaborating with the E W Barker Institute of Sports on a research project involving one hundred and fifty RI students entitled**: Body versus Brain Training Research Study**

I wish to invite your child to take part in the research study. The period of participation is from 5 January – 13 March 2015.

Purpose

The purpose of this project is as follows:

The aim of the study is to compare the benefits of aerobic exercise with those of brain training for improvement in cognitive function and academic performance in adolescent boys. Having already proven the importance of fitness in cognitive and academic performance from our pilot study with The Scots College, Sydney, this study attempts to establish the same beneficial effects of exercise and brain training in a Singaporean secondary school setting. This study will also seek to investigate energy expenditure and nutrition in Singaporean teenagers as well through the completion of specific questionnaires.

Procedure

The research with your child will involve the following:

This study comprises of two weeks of pre and post-testing and eight weeks intervention to be carried out during two PE sessions per week across ten weeks.

- These pre and post-testing sessions will include:
    - Height, sitting height, weight and waist circumference measurements (approximately 5 minutes).
    - 20m Shuttle Run (Beep test) where participants will be required to run 20m back and forth between 2 cones according to a recorded "beep" sound till they cannot run any further (approximately 10-20 minutes).
    - Cognitive testing (computer-based) which measures participants' emotions, feeling, thinking and self-regulation (approximately 45minutes); and
    - Academic Performance which will be measured using the ACER General Ability Test for Secondary 1 to 4 (approximately 40 minutes).

- Depending on the random allocation of the class, the class will be allocated into one of these three groups
  - "Body training"- a structured aerobic exercise programme specifically designed for adolescents. Each session will take approximately 50 minutes (including warm up and cool down) and will take place twice a week.
  - "Brain training"- a computer-based program designed by the Brain Resource Company (BRC). Participants will be required to participate in two 45-minute sessions per week.
  - "Control"- participants will just take part in the testing session in Week 1 and 10. They will go about their normal activities from Week 2 to 9 without any intervention.

- This study will be held within the premises of Raffles Institution.
- Participants will be required to do some physical activity as well as some computer-based activities.
- Because the nature of the study requires participants to take part in a brief structured and supervised physical activity, the usual risks of musculoskeletal injury associated with physical activity will apply.
- The physical activity that the participants will undergo during the test is of a similar level to the exertion during a typical physical education lesson.

Benefits

Your child will receive a comprehensive report about his aerobic fitness as well as cognitive function.

Although we are unable to guarantee or promise that your child will receive any or all benefits from this study, the study may have the following benefits for its participants:

1. Enhance physical, mental and psychological well-being;
2. Understand the approach to research study and first-hand experience in Sports Science;
3. Capitalise on PE curriculum time when the study is being carried out;
4. Enable RI in better understanding, managing and encouraging students to be fit and to help them improve their cognitive function, better manage stress levels and, improve well-being, self-esteem and confidence; and
5. Receive an individual **comprehensive report** reflecting their fitness level, cognitive function and general ability performance.

Confidentiality

Confidentiality of data collected from your child will be protected. He will remain anonymous and/or pseudonyms will be used in any publication or reporting. Personal information will be de-identified/coded as far and as early as possible, and will be stored and transferred as de-identified/coded information. All names will be kept confidential and identity will not be used in the reporting of the research data nor in any intended publication of any sort, be it electronic or print media. All records containing personal information will remain confidential and no information that could lead to identification of any individual will be released.

All research data compiled during the study will be stored in a secure site at RI/University of Sydney for a period of 2 years from the completion of the research. After that time all data will be destroyed. The data will be protected against loss or theft and unauthorized access, disclosure, copying, use, and modification. Security measures taken will involve restricted access and password protection.

Original data stored on computer/laptop will be deleted after they have been transferred to more robust form of storage, e.g., DVD or CD and stored securely as described above. Audiotapes (if any) will be similarly stored but notes derived from them (if any) will be destroyed at the conclusion of the study.

In addition, individual data collected from the students will not be shared with their school teachers. In the event that teachers would like access to the data of individual students, permission will be sought from the students and parents first.

The research findings from this study will be summarised as a report that may be presented in a conference and published in a journal/conference proceeding or other scholarly avenue.

Participation in this study is fully voluntary. If you agree to let your child participate in the study, you and your child will be requested to sign an informed consent form before your child begins participation.

You are free to withdraw your child from this study at any time prior to publication without penalty, prejudice, negative consequences, repercussion, or disadvantage. Your decision to withdraw from this study will be kept confidential. Upon withdrawal, all data obtained from you and associated with you will be erased and destroyed.

If you have any questions, or concerns about this study, please contact:

Miss Joanna Li, Researcher at The Sydney University (weli5165@uni.sydney.edu.au)
Mr Azmy Rizman, Head, Physical Education /Y1-4 (azmy.rizman@ri.edu.sg)
Mr Michael Jeyaseelan, Dean, EW Barker Institute of Sports (michael.j@ri.edu.sg

....

Signature of Researcher **Date**

....

Signature of Dean / EWBIS **Date**

Informed Consent Form for Students & Parents

Name of Student Participant	
Name of Parent / Guardian	 **Relationship:**
Name of Researcher	Ms Joanna Li (University of Sydney)
Name of Staff in Charge	Mr Eng Han Seng (Dean CCA & PE)
Title of Research Project	**Body versus brain training for improving cognitive function in schoolboys**

I have been given and read the information sheet describing the study and the nature of the study, including data collection and other procedures. I understand the purpose and process of the research project and my child's involvement in it.

I hereby consent to my child's participation in the above research.

I also understand that

- I can at any time prior to publication withdraw my consent for my child's participation without penalty, prejudice, negative consequences, repercussion, or disadvantage and demand that my child's personal data/information be permanently deleted from the database.
- The researcher will use my child's personal data/information solely for this study.
- The researcher will render my child's personal data/information anonymous and protect the privacy and confidentiality of my child's personal data/information.
- While information gained during the study may be published, my child will not be identified and my child's personal data/information will remain confidential.
- The research records will be securely kept under lock and key.
- If there is any video or audio taping of my child during the study, the tape will be securely stored and key.
- The ethical aspects of the project have been approved by the ethics committee of RI.

If I have any questions about the research at any point in time, I may contact the researcher, Miss Joanna Li, at email: weli5165@uni.sydney.edu.au or Mr Azmy Rizman (Head/ PECCA) at azmy.rizman@ri.edu.sg or Mr Michael Jeyaseelan (Dean/EWBIS) at michael.j@ri.edu.sg at Raffles Institution.

Signature of Parent / Guardian	
Signature of Student Participant	

Date	

Researcher's confirmation statement

I have provided information about the research to the student and the legal parent/guardian and believe that he/she understands the nature of the study, the expectations of the procedures, and the rights of a research participant.

To the best of my knowledge, the student and the legal parent/guardian have voluntarily signed this informed consent form, without coercion or undue influence.

Researcher's signature	
Date	

Dean/CCA & PE signature	
Date	

THE UNIVERSITY OF SYDNEY

Discipline of Exercise and Sports Science
Faculty of Health Sciences

ABN 15 211 513 464

Dr Rhonda Orr
Senior Lecturer

Room 130
Block K
C42 Cumberland Campus
The University of Sydney, Lidcombe
NSW 2141 AUSTRALIA
Telephone: +61 2 9351 9475
Facsimile: +61 2 9351 9204
Email: rhonda.orr@sydney.edu.au
Web: http://www.sydney.edu.au/

The effects of acute exercise on improving cognitive function in schoolboys

PARENTAL (OR CAREGIVER) INFORMATION STATEMENT

(1) What is the study about?

You are invited to permit your child to participate in a study which aims to investigate the effects of acute bouts of exercise (aerobic and resistance) on the cognitive function and academic performance of students. The study attempts to establish a relationship between exercise and improvement of brain function as shown by test scores in students. A comparison between aerobic exercise and resistance exercise will be carried out to investigate which kind of training may be more beneficial, as well as to establish the importance of physical activity in a student's life.

Your child was selected as a possible participant in this study because he is between the ages of 13-17 years and does not suffer from any physical disability preventing him from participating fully in physical activities.

(2) Who is carrying out the study?

The study is being conducted by Miss Joanna Li and will form the basis for the degree of Doctor of Philosophy at **The University of Sydney** under the supervision of Dr Rhonda Orr, Senior Lecturer, Dr Helen O' Connor, Senior Lecturer and Dr Nicholas O'Dwyer, Honorary Associate Professor.

(3) What does the study involve?

This is a five week long study held within the premises of **The Scots College** and includes doing some physical activity as well as computer based activities. There will be five testing sessions, and three different blocks of physical training. Week 1: Baseline Testing, Week 2, 3 and 4: three training and cognitive testing sessions, Week 5: Post-testing of academic performance via the ACER General ability Test (AGAT). Tests for baseline testing, especially the fitness tests, are tests that are generally performed on an annual basis by the school.

- These tests include:
  - Height, sitting height, weight and waist circumference measurements (approximately 5 minutes)
  - 20m Shuttle Run(Beep test) whereby participants will be required to run 20m back and forth between 2 cones according to a recorded "beep" sound till he cannot run any further. (approximately 10-20 minutes)
  - Cognitive testing (computer-based) which measure participants' emotions, feeling, thinking and self-regulation. (approximately 35 minutes)
  - Academic Performance which will be measured using the ACER General ability Test (AGAT) for year 7-10 students. (approximately 35 minutes)
- Each block of training session will be 40minutes long (including warm up and cool down and will take place once a week.

- During these sessions participants will be required to wear two devices to help researchers quantify their physical activity levels. The accelerometers will be worn on the hip, while the heart rate monitors will be worn round the chest.
- Additionally, participants may be asked to wear the accelerometers for three days to assess their individual energy expenditure.

- The three different training blocks are, “Aerobic”, “Resistance” and “Calisthenics”.
- The order of the training blocks will be randomised for each student. E.g. Week 2 does not equal to “Aerobic Training”, it can be “Calisthenics Training” or “Resistance Training”.
- Approximately fifteen minutes after each training block, students will participate in a similar but shorter computer-based cognitive test (35 minutes).
- Because the nature of the study requires participants to take part in structured and supervised physical activities, there is a risk that musculoskeletal injury associated with physical activity may occur. Some muscle soreness may also occur but should dissipate in one to two days.

(4) How much time will the study take?

A total of 10 hours across a span of five weeks is needed. Five one and a half hour sessions, each session approximately one week apart, for five consecutive weeks will be required after school in the third or fourth term of the year 2014.

(5) Can my child withdraw from the study?

Participation in this study is completely voluntary. You are not under any obligation to consent to your child’s participation.

Your decision whether or not to permit your child to participate will not prejudice you or your child's future relations with The University of Sydney. If you decide to permit your child to participate, you are free to withdraw your consent and to discontinue your child's participation at any time without affecting your relationship with **The University of Sydney and The scots College**

(6) Will anyone else know the results of the study?

All aspects of the study, including results, will be strictly confidential and only the research team will have access to information on participants. Parents can choose whether to disclose their child’s result to **The Scots College** at the end of the study.

A report of the study may be submitted for publication, but individual participants will not be identifiable in such a report.

(7) Will the study benefit me?

We cannot and do not guarantee or promise that your child will receive any benefits from the study. However, there may be some improvements in cognitive function as well as physical fitness.

(8) Can I tell other people about the study?

Yes.

(9) What if I require further information about the study or my child’s involvement?

When you have read this information, Miss Joanna Li is available to discuss it with you further and answer any questions you may have. If you would like to know more at any stage, please feel free to contact Miss Joanna Li, Doctor of Philosphy Student at email: weli5165@uni.sydney.edu.au or Mr Tenzing Tsewang, Director of Sports science at email: t.tsewang@tsc.nsw.edu.au .

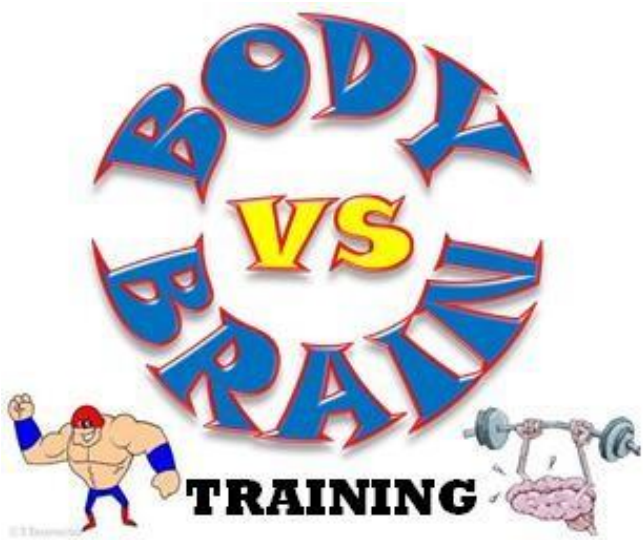
(10) What if I have a complaint or any concerns?

Any person with concerns or complaints about the conduct of a research study can contact The Manager, Human Ethics Administration, University of Sydney on 8627 8176 (Telephone); 8627 8177 (Facsimile) or ro.humanethics@sydney.edu.au (Email).

This information sheet is for you to keep

Manual of Procedures: Part IV

Body Training Program



BVBT - BODY TRAINING PROGRAM

An eight weeks exercise intervention protocol designed specifically for adolescents males, conducted twice a week. Each training session is one hour in duration comprising of five minutes of dynamic warmup, 30 minutes of structured high-intensity exercise, 20 minutes of team games (e.g. soccer, floorball, touch rugby) and five minutes of cooling down with stretching.

Week 1: Day 1

Activity	Instructions	Time	Venue	Equipment
Dynamic warmup	Line them up across baseline, walking lunges, side step, sumo stretch, etc	5 mins	Field	
Tababta's	(a) High knees on the spot – 1min (b) Push up – 1min (c) Butt kicks on the spot – 1min (d) Rest – 1min 3 sets = 5min*3	15 mins	Field	Whistle and stopwatch
One-leg Gladiator	Each student balances on one leg while holding partner's hand. They must try to out maneuver each other so that their partner loses balance and their foot touches the ground. 30s each leg, 5 times	5 mins	Field	Whistle and stopwatch
Suicides	Each student must sprint 10m, backpedal, sprint 20m back pedal, sprint 30m backpedal and sprint through to 40m 3 sets	10 mins	Field	Whistle and stopwatch
Game	Soccer	20mins	Field	Soccer balls and bibs
Cool down	Basic static and dynamic stretches	5 mins	Field	

Week 1: Day 2

Activity	Instructions	Time	Venue	Equipment
Dynamic warmup	Line them up across baseline, walking lunges, side step, sumo stretch, etc	5 mins	Field	
50m sprinkled sprints	Sprint 50m - 5 pushups Sprint 50m - 5 squats Sprint 50m - 5 jumping jacks Sprint 50m - rest 1min 5 sets 12-15mins	15 mins	Field	Cones, stopwatch and whistle
Walking lunge – burpee and crunch	Split class into pairs Student A: Lunge across 50m(25 each way) Student B: Does burpees/crunches in the mean time Students swap over when partner returns from the lunges 5 sets of 2 burpees and 3 crunches	10 mins	Field	Cones, stopwatch and whistle
Wrestling Drill	In their pairs, students stand facing each other with their hands on each others shoulders. They must try to push their partner across 5m No twisting, all in a straight line 30sec on/off * 6	5 mins	Field	Stopwatch and whistle
Game	Soccer	20 mins	Field	Soccer balls and bibs
Cool down	Basic static and dynamic stretches	5 mins	Field	

Week 2: Day 1

Activity	Instructions	Time	Venue	Equipment
Dynamic warmup	Line them up across baseline, walking lunges, side step, sumo stretch, etc	5 mins	Field	
Halves and Halves (50m)	Start off lying prone On whistle students do High knee for 50m They resume prone position On whistle they sprint back 50m High knees - Butt kicks - backpedal - 1min rest 3 sets = 10min	10 mins	Field	Cones, stopwatch and whistle
Wrestling Drill	In their pairs, students stand facing each other with their hands on each other's shoulders. They must try to push their partner across 5m No twisting, all in a straight line 30sec on/off * 6	5 mins	Field	Stopwatch and whistle
Iron Giant (I hate you Circuit)	Pair students up (same ability, as they race against each other) 7 jumping jacks, sprint the length 7 pushups, sprint the breadth 7 burpees, sprint the length 7 crunches, sprint to finish 1set = 2-3mins	10 mins	Field	Stopwatch and whistle
Game	Soccer	25 mins	Field	Soccer balls and bibs
Cool down	Basic static and dynamic stretches	5 mins	Field	

Week 2: Day 2

Activity	Instructions	Time	Venue	Equipment
Dynamic warmup	Line them up across baseline, walking lunges, side step, sumo stretch, etc	5 mins	Field	
Jog-a-thon	Students jog the length of the field and sprint the breadth. Can pair up students of the same ability too for the sprints 3 rounds – 8min	8 mins	Field	Whistle and stopwatch
Fox and Hounds	One student is designated as the hound while the rest are foxes. Cones (trees) are set up around the area (one less than the number of foxes). When the teacher blows the whistle, the foxes must run to a tree for refuge. The fox that is caught will become the hound. Set up safe zones where the foxes can seek refuge but have to do 10 push-ups or 10 jumping jacks	10 – 12 mins	Field	Cones and touch rugby tags
Sprint around the field	Sprint one round around the field. Timing will be recorded.	5 mins	Field	Stopwatch
Game	Soccer	25 mins	Field	Soccer balls and bibs
Cool down	Basic static and dynamic stretches	5 mins	Field	

Week 3: Day 1

Activity	Instructions	Time	Venue	Equipment
Dynamic warmup	Line them up across baseline, walking lunges, side step, sumo stretch, etc	5 mins	Field	
Tabatas	1 min skipping - 1 min push ups 1 min skipping - 1 min crunches 1 min rest 4 sets	20 mins	Field	Stopwatch and whistle
Sprints	Sprints (length of allocated field) Sprint-walk back(rest) 5 sets	20 mins	Field	Stopwatch and whistle
Pull-ups	Spilt class into "can do" and "cannot do" Those who cannot do, do assisted on the lower bars Those who can try to do as many as they can. Do crunches and plank while waiting for turn.	5 mins	Fitness Corner	Pull-up bar
Game	Soccer	5 mins	Field	Soccer balls and bibs
Cool down	Basic static and dynamic stretches	5 mins	Field	

Week 3: Day 2

Activity	Instructions	Time	Venue	Equipment
Dynamic warmup	Line them up across baseline, walking lunges, side step, sumo stretch, etc	5 mins	Field	
Pull-ups	Spilt class into "can do" and "cannot do" Those who cannot do, do assisted on the lower bars Those who can try to do as many as they can. Do crunches and plank while waiting for turn.	5 mins	Fitness Corner	Pull-up bar
Fiery burpees	Students run 30m back and forth. Count down from 10, 8, 6, 4, and 2 laps. Each set is separated with 10, 8, 6, 4, and 2 burpees respectively. Time student's performance	20 mins	Field	Stopwatch
Relay in groups of 4 (30m)	1st activity-wheel barrow 2nd - bear crawl 3rd - reverse bear crawl 4th - spider crawl 5th - one leg hop	20 mins	Field	Cones, stopwatch and whistle
Game	Soccer two playing areas	5 mins	Field	Soccer balls and bibs
Cool down	Basic static and dynamic stretches	5 mins	Field	

Week 4: Day 1

Activity	Instructions	Time	Venue	Equipment
Dynamic warmup	Line them up across baseline, walking lunges, side step, sumo stretch, etc	5 mins	Field	
Pull-ups	Spilt class into "can do" and "cannot do" Those who cannot do, do assisted on the lower bars Those who can try to do as many as they can. Do crunches and plank while waiting for turn.	10 mins	Fitness corner	Pull-up bar
Iron giant	(3 sets, 1.5min rest in between sets Pair students up (same ability, as they race against each other) 7 jumping jacks, sprint the length 7 pushups, sprint the breadth 7 burpees, sprint the length 7 crunches, sprint to finish	10 mins	Field	Stopwatch and whistle
Stair run and sprints	Pair students up Quick feet up stadium steps Slow jog down steps Sprint across the breadth (70m) Walk to recover back to steps 3 sets	7 mins	Field	Stopwatch and whistle
Beach flag style suicides	Prone- Sprint 10m – Prone – Sprint back 10m Prone- Sprint 20m – Prone – Sprint back 20m Prone- Sprint 30m – Prone – Sprint back 30m Prone- Sprint 40m – Prone – Sprint 40m rest 1/1.5min 3 sets	10 mins	Field	Cones, stopwatch and whistle
Game	Soccer	13 mins	Field	Soccer balls and bibs
Cool down	Basic static and dynamic stretches	5 mins	Field	

Week 4: Day 2

Activity	Instructions	Time	Venue	Equipment
Dynamic warmup	Line them up across baseline, walking lunges, side step, sumo stretch, etc	5 mins	Field	
Sprint	In pairs sprint the length and jog the breadth 2 sets	12 mins	Field	Whistle and stopwatch
Sprint the whole field	In the same pairs sprint the whole field. Rest the same amt 1-1.5min 2 sets	7 mins	Field	Whistle and stopwatch
Magneto	In pairs, line up in the middle of the field facing each other. 15 sit ups, backpedal 35m to opposite ends, sprint the whole 70m length 15 push-ups, backpedal 35m to opposite ends, sprint the whole 70m length 3 sets Prone position, backpedal 35m to opposite ends, sprint the whole 70m length 2 sets	20 mins	Field	Whistle, stopwatch and cones
Game	Soccer, 2 playing areas	11 mins	Field	Soccer balls and bibs
Cool down	Basic static and dynamic stretches	5 mins	Field	

Week 5: Day 1

Activity	Instructions	Time	Venue	Equipment
Dynamic warmup	Line them up across baseline, walking lunges, side step, sumo stretch, etc	5 mins	Field	
Sprints 340m	Pair students up with equal capability, make them sprint one round. Equal Amt of rest 1.5min 4 sets	20 mins	Field	Stopwatch and whistle
Beach flag style suicides	Start in a prone position, sprint to 50m baseline, backpedal and sprint back to 50m line. Equal Amt of rest 6 sets	10 mins	Field	Stopwatch, whistle and cones
Tabata’s	Plank 45s while partner do high knee lifts Rest 45s 3-4 sets	10 mins	Field	Stopwatch and whistle
Game	Soccer and touch rugby	10 mins	Field	Soccer balls, bibs, rugby balls, touch rugby tags
Cool down	Basic static and dynamic stretches	5 mins	Field	

Week 5: Day 2

Activity	Instructions	Time	Venue	Equipment
Dynamic warmup	Line them up across baseline, walking lunges. Side step, sumo stretch, etc.)	5 mins	Field	
Push ups and crunches	3 sets of 20 push-ups and 20 crunches.	10 mins	Field	Whistle
Fiery burpees	Students run 30m back and forth. Count down from 10, 8, 6, 4, and 2 laps. Each set is separated with 10, 8, 6, 4, and 2 burpees respectively. Time student's performance	20 mins	Field	Stopwatch, cones and whistle
Game	Soccer and touch rugby (10 mins each) swap over	20 mins	Field	Soccer balls, bibs, rugby balls and touch rugby tags
Cool down	Basic static and dynamic stretches	5 mins	Field	

Week 6: Day 1

Activity	Instructions	Time	Venue	Equipment
Dynamic warmup	Line them up across baseline, walking lunges. Side step, sumo stretch, etc.)	5 mins	Field	
Run	2 sets of 2 rounds. In pairs. Rest 1.5min between sets	10 mins	Field	Whistle, cones and stopwatch
Magneto	In pairs, line up in the middle of the field facing each other. 15 sit ups, backpedal 35m to opposite ends, sprint the whole 70m length 15 push ups, backpedal 35m to opposite ends, sprint the whole 70m length 3 sets Prone position, backpedal 35m to opposite ends, sprint the whole 70m length 2 sets	20 mins	Field	Whistle, cones and stopwatch
Game	Floorball and dodgeball	20 mins	Indoor Sports Hall	Floorball sticks, balls, bibs, dodgeballs, Floorball goal posts and cones
Cool down	Basic static and dynamic stretches	5 mins	Indoor Sports Hall	

Week 6: Day 2

Activity	Instructions	Time	Venue	Equipment
Dynamic warmup	Line them up across baseline, walking lunges. Side step, sumo stretch, etc.)	5 mins	Field	
Magneto	In pairs, line up in the middle of the field facing each other. 15 sit ups, backpedal 35m to opposite ends, sprint the whole 70m length 15 push ups, backpedal 35m to opposite ends, sprint the whole 70m length 3 sets Prone position, backpedal 35m to opposite ends, sprint the whole 70m length 2 sets	20 mins	Field	Whistle, stopwatch and cones
Beach flag style suicides	Prone- Sprint 10m – Prone – Sprint back 10m Prone- Sprint 20m – Prone – Sprint back 20m Prone- Sprint 30m – Prone – Sprint back 30m Prone- Sprint 40m – Prone – Sprint 40m rest 1/1.5min 4/5 sets	15 mins	Field	Whistle, stopwatch and cones
Muscle Recovery	Jog one round around the field	5 mins	Field	Whistle and stopwatch
Game	Soccer and touch rugby	10 mins	Field	Soccer balls, bibs, rugby balls, touch rugby tags
Cool down	Basic static and dynamic stretches	5 mins	Field	

Week 7: Day 1

Activity	Instructions	Time	Venue	Equipment
Dynamic warmup	Line them up across baseline, walking lunges. Side step, sumo stretch, etc.)	5 mins	Field	
Fiery burpees	Students run 30m back and forth. Count down from 10, 8, 6, 4, and 2 laps. Each set is separated with 10, 8, 6, 4, and 2 burpees respectively. Time student's performance	20 mins	Field	Stopwatch
Relay in groups of 4 (30m)	1st - left leg single leg hop 2nd - bear crawl 3rd - right leg hop 4th - spider crawl 5th - double leg hop	20 mins	Field	Whistle, cones and stopwatch
Game	Floorball and dodgeball	10 mins	Indoor Sports Hall	Floorball sticks, balls, bibs, dodgeballs, Floorball goal posts and cones
Cool down	Basic static and dynamic stretches	5 mins	Indoor Sports Hall	

Week 7: Day 2

Activity	Instructions	Time	Venue	Equipment
Dynamic warmup	Line them up across baseline, walking lunges. Side step, sumo stretch, etc.)	5 mins	Indoor Sports Hall	
Sprinkled sprints	Sprint length of hall - 5 push-ups Sprint length of hall - 5 squats Sprint length of hall - 5 jumping jacks Sprint length of hall - rest 1.5min 5 sets	20 mins	Indoor Sports Hall	Whistle, cones and stopwatch
Stair run	2/3 sets	10 mins	Indoor Sports Hall	Stopwatch and whistle
Game	Floorball and dodgeball	20 mins	Indoor Sports Hall	Floorball sticks, balls, bibs, dodgeballs, Floorball goal posts and cones
Cool down	Basic static and dynamic stretches	5 mins	Indoor Sports Hall	

Week 8: Day 1

Activity	Instructions	Time	Venue	Equipment
Dynamic warmup	Line them up across baseline, walking lunges. Side step, sumo stretch, etc.)	5 mins	Field	
Magneto	In pairs, line up in the middle of the field facing each other. 15 sit ups, backpedal 35m to opposite ends, sprint the whole 70m length 15 push ups, backpedal 35m to opposite ends, sprint the whole 70m length 3 sets Prone position, backpedal 35m to opposite ends, sprint the whole 70m length 2 sets	20 mins	Field	Stopwatch, whistle and cones
Beach flag style suicides	Prone- Sprint 10m – Prone – Sprint back 10m Prone- Sprint 20m – Prone – Sprint back 20m Prone- Sprint 30m – Prone – Sprint back 30m Prone- Sprint 40m – Prone – Sprint 40m rest 1/1.5min 4/5 sets	15 mins	Field	Stopwatch, whistle and cones
Muscle recovery	Jog one round around the field	5 mins	Field	Whistle and stopwatch
Game	Soccer and touch rugby	10 mins	Field	Soccer balls, bibs, rugby balls, touch rugby tags
Cool down	Basic static and dynamic stretches	5 mins	Field	

Week 8: Day 2

Activity	Instructions	Time	Venue	Equipment
Dynamic warmup	Line them up across baseline, walking lunges. Side step, sumo stretch, etc.)	5 mins	Field	
Tabata's	Mountain climbers 1min Stair run Plank 1min Rest 1min 3/4sets	20 mins	Field	Whistle and stopwatch
Iron giant	Jumping jacks, push-up, burpees, squats 4sets	20 mins	Field	Whistle and stopwatch
Sprint	1 set of 370m sprint	5 mins	Field	Whistle, stopwatch and cones
Game	Soccer and touch rugby	5 mins	Field	Soccer balls, bibs, rugby balls, touch rugby tags
Cool down	Basic static and dynamic stretches	5 mins	Field	

Journal of Science and Medicine in Sport 20 (2017) 841–848

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

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

Review

The effect of acute and chronic exercise on cognitive function and academic performance in adolescents: A systematic review

Joanna W. Li[a,*], Helen O'Connor[a,b], Nicholas O'Dwyer[a,c], Rhonda Orr[a]

[a] Discipline of Exercise and Sport Science, Faculty of Health Sciences, The University of Sydney, Australia
[b] Charles Perkins Centre, The University of Sydney, Australia
[c] School of Human Movement Studies, Charles Sturt University, Australia

ARTICLE INFO

Article history:
Received 10 May 2016
Received in revised form
14 November 2016
Accepted 16 November 2016
Available online 24 January 2017

Keywords:
Physical activity
Physical fitness
Learning
Executive function
Thinking
School achievements

ABSTRACT

Objectives: To investigate whether exercise, proposed to enhance neuroplasticity and potentially cognitive function (CF) and academic performance (AP), may be beneficial during adolescence when important developmental changes occur.
Design: Systematic review evaluating the impact of acute or chronic exercise on CF and AP in adolescents (13–18 years).
Methods: Nine databases (AMED, AusportMed, CINAHL, COCHRANE, Embase, Medline, Scopus, SPORTdiscus, Web of Science) were searched from earliest records to 31st October 2016, using keywords related to exercise, CF, AP and adolescents. Eligible studies included controlled trials examining the effect of any exercise intervention on CF, AP or both. Effect size (ES) (Hedges g) were calculated where possible.
Results: Ten papers (11 studies) were reviewed. Cognitive domains included: executive function (n = 4), memory (n = 4), attention/concentration (n = 2), visuo-motor speed (n = 1), logical sequencing (n = 1) and psychometric aptitude (n = 1). All papers, nine of 10 being acute studies, reported at least one parameter showing a significant effect of exercise in improving CF and AP. However, the CF parameters displayed substantial heterogeneity, with only 37% favouring acute and chronic exercise. Where ES could be calculated, 52% of the acute CF parameters favoured rest. Memory was the domain most consistently improved by exercise. Academic performance demonstrated a significant improvement with exercise in one of two acute studies and the only chronic study ($p \leq 0.001$).
Conclusions: The evidence for the effect of exercise on CF and AP in adolescents is equivocal and limited in quantity and quality. Well-designed research is therefore warranted to determine the benefits of exercise in enhancing CF and AP and reducing sedentary behaviour.

1. Introduction

Adolescence, identified as the period in human growth which occurs during ages 13–18 years,[1] is a time marked by considerable hormonal, behavioural and physical changes.[2–4] Significant cognitive re-organisation and development also occur at this life stage and neuroimaging studies show that the pre-frontal cortex (PFC) is the last brain region to mature,[5] continuing to myelinate into early adulthood.[6,7] This region is responsible for highly integrative cognitive functions (CFs) such as executive control, which is generally understood to encompass complex cognitive processing such as planning, task-switching, problem solving and strategy generation to achieve a particular goal.[8] Given the protracted period of frontal lobe plasticity, the impact of environmental factors is hypothesised to be greater in this brain region.[6] Lifestyle factors, including physical activity and dietary intake, may therefore play a major role in supporting and ideally optimising frontal lobe cognitive development during adolescence.

Over the past decade, there has been increased interest in the influence of exercise or physical activity (PA), particularly aerobic activity, on CF in both elderly[9] and school-aged populations.[10] In school-aged children, there is also research on exercise and academic performance (AP). Two recent critical reviews[11,12] have identified that there is limited research in adolescents, with four studies confined to participants aged 13–18 years.[13–16] These four studies highlighted the inconsistent effects of exercise on CF, whereby both exercise and the control condition were observed

* Corresponding author.
E-mail address: weien.li@sydney.edu.au (J.W. Li).

http://dx.doi.org/10.1016/j.jsams.2016.11.025
1440-2440/

to improve cognitive tasks in participants. None of the four studies assessed AP.[13–16]

Given that adolescents mostly remain enrolled at school, a number of intervention studies at this age stage have involved acute, single bouts of exercise designed to deliver a more immediate impact on CF or AP. Acting via the noradrenergic and dopaminergic pathways, acute exercise can be viewed as an arousing stressor somewhat akin to a psychoactive stimulant, potentially affecting arousal, attention and effort.[17] This effect may have merit in a school setting where increasing the functional capacity of students during set times throughout the day might improve their ability to learn. A number of studies in children (5–12 years) have also used this design to examine whether learning is improved in the immediate post-exercise period.[18,19] Clearly, the mechanism(s) responsible for cognitive or learning enhancement are likely different for acute compared to chronic exercise. Acute exercise will not result in significant fitness changes while chronic exercise will likely increase fitness, as well as deliver other adaptations such as potential improvements in metabolic health, systemic inflammation and psychological function including better mental health and self-esteem.[20–22]

Given evidence that levels of PA are declining during adolescence in Australia[23] and internationally,[24] and that PA at school is increasingly eroded by pressure to increase classroom learning and AP,[24] research supporting a positive role on CF and AP would advocate for maintaining, if not increasing, the inclusion of PA in the school curriculum. Hence, particularly in view of the potential health and cognitive benefits, especially in relation to neuroplasticity at this age stage, it was deemed crucial to remain current with a thorough understanding of literature through updating developments on this topic in adolescents. Therefore, this study aimed to systematically review studies examining the relationship between both acute and chronic exercise and cognition and/or AP in adolescents (13–18 years).

2. Methods and procedures

This systematic review was conducted according to PRISMA guidelines with all criteria addressed.[25] Electronic searches were performed across nine databases: AMED, AusportMed, CINAHL, COCHRANE, Embase, Medline, Scopus, SPORTdiscus and Web of Science from earliest records to 31st October 2016. The search strategy consisted of three main elements: (1) exercise, (2) cognition and (3) population. The respective keywords for each of these categories were (1) '*exercise*'; '*physical fitness*'; '*physical activit**'; '*body training*,' '*physical training*'; '*sport**'; (2) '*cognition*'; '*cognitive function**'; '*executive function**'; '*learning*'; '*mental process**'; '*attention*'; '*academic performance*'; '*academic achievement*'; (3) '*adolescen**'; '*child**'; '*boy**'; '*girl**'. Reference lists of all eligible studies and systematic reviews were searched manually for other potentially eligible studies.

Studies were included if they were interventions examining the relationship between PA and CF in healthy adolescents (mean age 13–18 years or within a one-year age range of these limits). Eligible studies described either a chronic (defined number of bouts over a set period) or acute (single bout) structured exercise intervention (or both) and employed at least one CF or AP measure. Exclusion criteria were: adolescent populations with known learning disorders, non-English language papers, reviews, abstracts or theses.

After removal of duplicates, search results were screened independently by two reviewers (JL, RO) and eliminated by title and abstract using the eligibility criteria. All potential and relevant studies were further assessed by reading the full manuscript. Studies not meeting the eligibility criteria were excluded (Fig. 1). The quality of the included studies was independently assessed by two researchers (JL, RO) using the Physiotherapy Evidence Database (PEDro) scale[26] which scores each paper according to 10 criteria.

Data relating to the participant (e.g., mean age, sex, fitness etc) and study (e.g., design, sample size, intervention type) characteristics, and CF and AP assessments were independently extracted by three researchers (shared by JL, RO, NOD).

Data extracted were reported as mean ± standard deviation (SD). Studies reporting data with standard errors (SE) were converted to SD using the equations: $SD = SE \times \sqrt{\text{sample size}}$. Comprehensive Meta-Analysis (CMA) Software (Biostat Inc. Englewood, New Jersey, USA) was used to calculate effect sizes (ES) from the published data (unadjusted for confounders) when possible and reported as standardised mean differences (SMD). ES was determined by subtracting the mean change in cognitive outcomes in the intervention group from that in the control group and dividing the difference by the pooled baseline SD of both groups. ES was then corrected for small-sample bias (Hedges g) with 95% confidence intervals (CI) and categorised as trivial (<0.02), small (0.02–0.6), moderate (0.6–1.2), large (1.2–2.0) or very large (>2.0).[27] Positive ES favoured exercise while negative favoured rest/control.

3. Results

The initial search netted 23,541 papers plus four identified by hand searching. After removal of duplicates and ineligible manuscripts, 10 papers (published from 1991–2015) were eligible for inclusion. The flow of papers from potentially relevant to inclusion is displayed in Fig. 1. The 10 papers identified[13–16,28–33] described 11 studies, as one paper[13] included both an acute and chronic exercise intervention. Of the nine acute studies,[13–16,29–33] eight[13–16,30–33] examined CF while two[29,32] examined AP. The remaining two studies described chronic exercise interventions, of which one examined CF[13] while one examined both CF and AP[28] (Table 1).

The included studies had a PEDro score ranging from 3 (poor) to 8 (good) (Supplementary Table 1). The major limitations included failure to report details of participant and assessor blinding (all 10 studies) as well as insufficient information on allocation concealment (all but two studies[14,28]).

The included studies recruited 588 healthy adolescent participants (62.9% male) aged from 13.0 to 15.8 years, with a BMI ranging from 17.8 to 23.8 $kg\,m^{-2}$ and aerobic fitness from 42.4 to 50.7 $ml\,kg^{-1}\,min^{-1}$ (Supplementary Table 2).

The studies included randomised controlled (n = 3),[14,15,28] randomised cross-over (n = 2)[30,33] and controlled cross-over (n = 3)[16,29,31] trials. All studies had an intervention and control condition. In eight studies[13,14,16,29–33] the control phase was a resting condition (e.g., watching television, reading and sitting quietly), whereas the control condition was a 'normal PE (Physical Education) lesson' in three studies.[13,15,28]

The nine acute studies used a range of aerobic exercise modalities: outdoor or treadmill running (n = 4),[13,14,29,33] cycle ergometer (n = 2),[16,31] treadmill walking (n = 1)[30] and coordinative exercises (n = 1; aerobic exercise involving bilateral coordination).[15] Eight studies[13–16,29–33] reported exercise intensity, with five quantifying intensity between 60–80% of maximum heart rate (HR_{max}).[14,16,29–31] One study[32] disclosed neither exercise intensity nor modality. Each study consisted of a single exercise session (9–40 min duration) and a control condition which ranged between 10–60 min (Table 1). Only five studies reported a pre-trial aerobic fitness test,[13,14,16,30,31] using a shuttle run[14,30] or incremental cycle test[16,31] to quantify aerobic capacity as percentage of HR_{max}[14] or peak aerobic capacity (VO_{2peak}).[30] The remaining studies did not measure pre-trial aerobic fitness[15,29,32,33] (Supplementary Table 2).

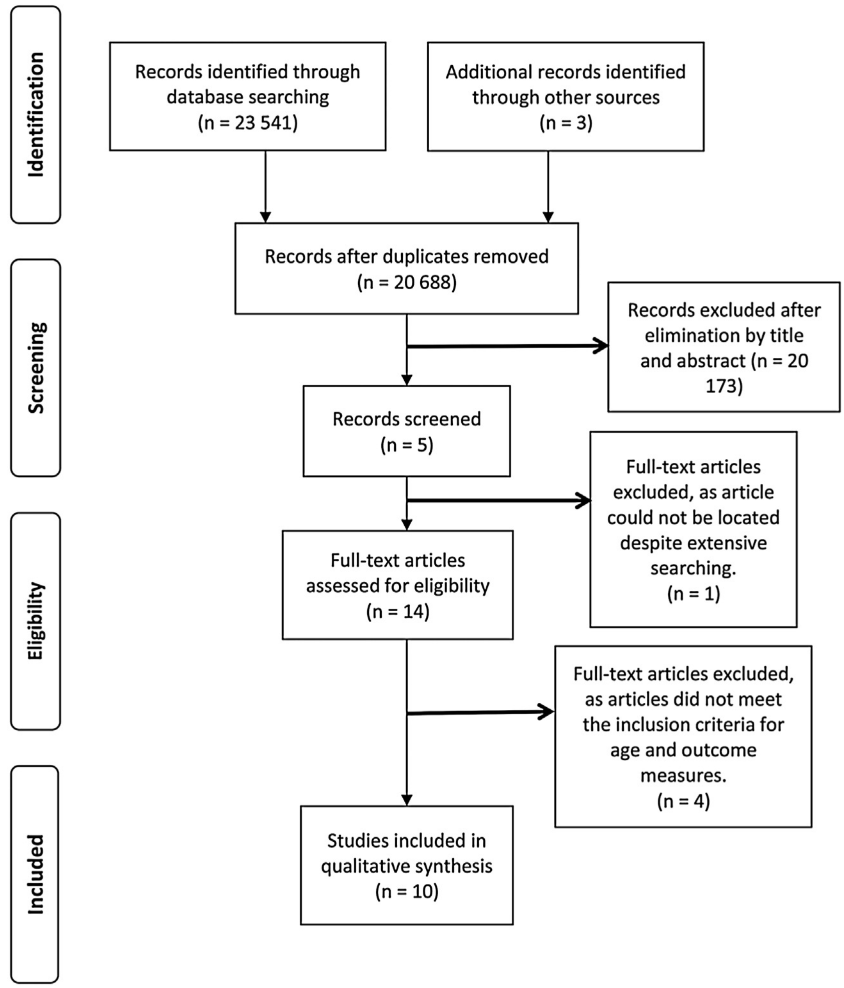


Fig. 1. Prisma flowchart.

The two chronic intervention studies[13,28] were conducted across six and four months, respectively. Exercise intensity was reported in one study[28] using mean heart rate (HR_{mean}) and HR_{max}. In the other study,[13] exercise intensity (participant-specific) was established based on each participant's anaerobic threshold. Intervention details were reported as 'PE activities'[28] and 'interval or continuous running'.[13] Although exercise duration (ranging 55–60 min) was reported,[13,28] organisation and changing/shower time was included in the 'intervention' duration in one study.[28] The control activity in both studies was reported as 'normal PE lesson'[13,28] (Table 1).

In the acute interventions, CF was measured in eight studies[13–16,30–33] while AP was measured in two studies.[29,32] CF was assessed using 12 different cognitive tasks. The domains assessed were executive function (n = 4),[16,31–33] memory (n = 4),[14,30,32,33] attention and concentration (n = 2),[13,15] visuo-motor speed (n = 1)[33] and logical sequencing (n = 1)[32] (Supplementary Table 1). Executive function and memory were the most popular domains assessed, with the Modified Eriksen Flanker task with a Go/NoGo paradigm being most commonly used.[16,31] AP was examined with arithmetic (standardisation/validation of arithmetic tasks was not clearly described in the studies).[29,32] Although all eight studies[13–16,30–33] reported at least one significant effect of acute exercise showing improvement in CF, the majority of cognitive parameters indicated that the effect of exercise was either not significant or the control/resting condition was favoured. CF was assessed across 38 cognitive parameters of which only 15 (40%) showed a significant effect of acute exercise. In six of these studies[13–16,30–33] where an ES could be calculated, 52% of the parameters favoured rest. In the two studies that examined AP, only one reported significance, with 8/10 AP parameters favouring exercise when the ES was calculated[29] (Table 2).

Three studies[16,31,32] reported a significant beneficial effect of acute exercise on executive function ($p < 0.01$) (Supplementary Table 1). Two[16,31] studies additionally assessed the impact of participant fitness on executive function outcomes after acute exercise. Higher-fit participants showed significantly improved performance on the Eriksen Flanker paradigm for executive function,[16,31] while lower-fit participants performed significantly better on the Go/NoGo task.[16] ES could be calculated for two studies (n = 16 parameters)[16,32] (Supplementary Table 5). The effects on executive function favouring a bout of acute exercise ranged from small to large (ES = 0.27 to 1.90; p = 0.00 to 0.25). Overall however, 62.5% of the parameters favoured rest and the effect ranged from small to large (ES = −0.02 to −1.92; p = 0.00–0.93).

The four studies[14,30,32,33] that examined the effects of a bout of acute exercise on the domain of memory showed significant improvements in the n-back task,[30] Sternberg paradigm,[33] Letter Digit Span[14] and Immediate Recall List[32]. Additionally, one study separated participants into low and high performer groups, based on their pre-test Letter Digit Span scores,[14] and examined the effects of exercise intensity (50–65% HR_{max} and 70–85% HR_{max}) on memory. Their results showed that only the lower intensity (50–65% HR_{max}), low performer group improved significantly after

Table 1
Study design characteristics.

Author	Study design, country, sample recruited	Intervention details		Control details		Drop-outs/exclusions
		Sample analysed (n)	Dose: frequency (F), intensity (I), type (T), time (t)	Sample analysed (n)	Dose: frequency (F), intensity (I), type (T), time (t)	
Acute						
Soga et al.[30]	RXT, Japan, (n = 27)	25	(F): single session, (I): 70% HR_{max}, walking speed = 4.5 ± 0.4 km/h, treadmill gradient = 9.5 ± 2.2%, (T): treadmill walking, (t): NR	25	(F): single session, (I): HR_{mean} = 85.6 ± 9.6 bpm, (T): sitting on chair placed on stationary treadmill, (t): NR	2
Hogan et al.[31]	CXT, Germany, (n = 30)	30	(F): single session, (I): moderate but brisk: 60% HR_{max}, 50-60% VO_{2max}, (T): cycle ergometer, (t): 20 min	30	(F): single session, (I): rest, (T): watched movie, (t): 20 min	0
Cooper et al.[33]	RXT, Britain, (n = 60)	45	(F): single session, (I): 20 m, 7 reps, 10 sets, 30 s rest btw sets, vel = 8 km h$^{-1,}$ 172 ± 17 bpm, (T): running, (t): 10 min	45	(F): single session, (I): rest, (T): NR, (t): NR	15
Budde et al.[14]	RCT, Germany, (n = 60)	38	(F): single session, (I): EG1: 50–60% HR_{max}, EG2: 70–85% HR_{max}, (T): running on a 400 m-track, (t): 12 min	21	(F): single session, (I): rest, (T): being sedentary, (t): 12 min	1
Travlos[29]	CXT, Greece, (n = 48)	48	(F): 4 sessions, (I): >85% HR_{max}, 4 min run/4 min walking recovery, four intervals, (T): interval running around a basketball court, (t): 40 min	48	(F): 2 sessions, 1 week before and 1 week after intrv, (I): Low, (T): normal sedentary classroom activities, (t): 60 min	NR
Stroth et al.[16]	CXT, Germany, (n = 35)	33	(F): single session, (I): 60% HR_{max}, (T): cycle ergometer, (t): 20 min	33	(F): single session, (I): rest, (T): watched movie, (t): 20 min	2
Budde et al.[15]	RCT, Germany, (n = 115)	47	(F): single session, (I): moderate HR measured, (T): coordinative exercises, (t): 8.75 min	52	(F): single session, (I): moderate HR measured (T): normal sport lesson, (t): 10 min	16
Gu et al.[32]	CT, Korea, (n = 120)	60	(F): NR, (I): NR, (T): NR, (t): 30 min	60	(F): NR, (I): NR, (T): studying or reading, (t): 40 min	NR
Zervas et al.[13]	CT, Greece, (n = 26)	18	(F): single session, (I): warm-up: vel = 8 to 9 km/h, intrv: 12–14 km/h, at gradient 1%, 187 ± 11 bpm, (T): treadmill running, (t): warm-up: 5 min, intrv: 20 min	8	(F): single session, (I): rest, (T): passive sitting down, (t): 60 min	0
Chronic						
Ardoy et al.[28]	RCT, Spain, (n = 67)	37	(F): 4 day/week, (I): EG1-HR_{mean} = 129 bpm, HR_{max} = 177 bpm; EG2-HR_{mean} = 147bpm, HR_{max} = 193bpm, (T): PE activities specially designed by teachers, (t): 55 min (includes organisation and changing/shower)	17	(F): 2 day/week, (I): HR_{mean} = 116 bpm, HR_{max} = 174 bpm, (T): normal PE lesson, (t): 55 min (includes organisation and changing/shower)	13
Zervas et al.[13]	CT, Greece, (n = 26)	8	(F): 3 day/week for 25 weeks (6 months), (I): personalised speed based on anaerobic threshold of 4 mmol/L, (T): interval or continuous running, (t): warm-up: 15 min, intrv: 60 ± 15 min	18	(F): 2–3 days/week, (I): "light physical activity", (T): normal school-based PE classes, (t): normal length of PE class	0

Data are presented as mean ± standard deviation: (bpm): beats per minute; (btw): between; (CT): controlled trials; (CXT): controlled cross-over trial; (EG): experimental group; (HR_{max}): maximum heart rate; (HR_{mean}): mean heart rate; (km/h): kilometres per hour; (min): minutes; (NR): not reported; (RCT): randomised controlled trial; (reps): repetition; (rpm): revolutions per minute; (RXT): randomised cross-over trial; (s): seconds; (vel): speed; (W): watts.

acute exercise. ES could only be calculated for two studies[14,30] (Supplementary Table 5). The effects favouring exercise were small (ES = 0.07–0.32; p = 0.46 to 0.88), consistent with the observations that the low performer, lower intensity group improved in the memory task. The effects favouring rest ranged from trivial to small (ES = −0.01 to −0.19; p = 0.64–0.97).

Only two studies[13,15] examined the effects of acute exercise on the domain of concentration and attention. Both showed significant improvements following exercise in the accuracy of correct responses in their D2[15] and Cognitrone test[13] after exercise. The D2 test also showed significant improvements after acute exercise in two other test parameters of percentage errors and total number of responses (Supplementary Table 1). ES ranged from moderate to large (ES = 0.68 to 1.46; p = 0.00 to 0.01),[13,15] favouring the acute exercise intervention in most (4/6) of the cognitive parameters. However, two cognitive parameters with effects ranging from small to large (ES: −0.09 to −1.57, p: 0.00 to 0.85) favoured rest[13] (Supplementary Table 5).

Table 2
Summary of the effects of exercise on cognitive function and academic performance.

	Acute studies (n = 9)				Chronic studies (n = 2)			
	Cognitive function (n = 8)		Academic performance (n = 2)		Cognitive function (n = 2)		Academic performance (n = 1)	
	Favours ex n (%)	Favours rest n (%)	Favours ex n (%)	Favours rest n (%)	Favours ex n (%)	Favours rest n (%)	Favours ex n (%)	Favours rest n (%)
Overall studies reporting at least one significant effect	8 (100)	0 (0)	1 (50)	1 (50)	1 (50)	1 (50)	1 (100)	0 (0)
Total number of parameters examined across studies	Cognitive function (n = 38)		Academic performance (n = 11)		Cognitive punction (n = 5)		Academic performance (n = 2)	
	Favours ex n (%)	Favours rest n (%)	Favours ex n (%)	Favours rest n (%)	Favours ex n (%)	Favours rest n (%)	Favours ex n (%)	Favours rest n (%)
Significant effect	15 (40)	2 (5)	8 (73)	2 (18)	1 (20)	0 (0)	1 (50)	0 (0)
Non-significant effect	21 (55)	0 (0)	1 (9)	0 (0)	4 (80)	0 (0)	1 (50)	0 (0)
Overall studies where effect size[a] could be calculated for a parameter	Cognitive function (n = 6)		Academic performance (n = 1)		Cognitive function (n = 1)		Academic performance (n = 1)	
	Favours ex n (%)	Favours rest n (%)	Favours ex n (%)	Favours rest n (%)	Favours ex n (%)	Favours rest n (%)	Favours ex n (%)	Favours rest n (%)
	13 (48)	14 (52)	8 (80)	2 (20)	2 (100)	0 (0)	2 (100)	0 (0)

[a] Effect size was calculated when mean, standard deviation/error and sample size were available, ex = exercise.

The Visual Search Test (baseline and complex levels) was used to assess the domain of visuo-motor speed in one study.[33] Speed improved significantly after a bout of acute exercise only on the complex and not on the baseline level of test performance. No positive effect of exercise was demonstrated on logical sequencing.[32] ES could not be calculated in either study.

Of the two studies[29,32] that examined arithmetic tasks, only one showed a significant improvement after a bout of acute exercise.[29] This study also examined the effects on AP during different time periods of the day. Greater improvements in arithmetic skills were reportedafterexerciseinmorningandearlyafternoonclassescompared to the last class of the school day. The other acute study reported a trend to significance ($p = 0.053$), with post-hoc analysis showing that only male participants' arithmetic scores improved significantly after exercise.[32] ES could be calculated for one study with 8/10 of the AP parameters favouring exercise and ranged from small to large (ES = 0.43 to 1.20; $p = 0.00$ to 0.13). The two remaining parameters favoured rest and ranged from small to moderate (ES = −0.92 to −0.45; $p = 0.01$ to 0.11).[29]

Only two studies[13,28] examined the effects of a chronic exercise intervention on CF (n = 2)[13,28] and AP (n = 1).[28] CF was assessed using an overall psychometric aptitude (general ability) test and the Cognitrone test (attention and concentration). School-based subject grades were used to assess AP. Only one[28] study found a significant effect of chronic exercise in improving CF. Of the five parameters that examined CF in the two studies, only one showed significance. ES could only be calculated for one study with both of its parameters favouring exercise.[28] Only one study examined the effect of chronic exercise on AP and showed significance.[28] Although both of its parameters favoured exercise, only one was reported to be significant (Table 2).

One study[28] examined the effect of a four-month training programme on psychometric aptitude. Exercise frequency and intensity were also examined. Overall psychometric aptitude was found to have improved significantly only for the high-frequency/high-intensity (4 day/week; $HR_{mean} = 147$ beats per minute (bpm)) group and correlated significantly with improvements in cardiorespiratory fitness. The ES favouring exercise training was very large (ES = 4.87; $p = 0.00$). The moderate ES for the high-frequency/normal-intensity (4 day/week; $HR_{mean} = 129$ bpm) group (ES = 1.06; $p = 0.00$) also favoured exercise. In the other chronic exercise study, no significant effects on the Cognitrone test were observed after 25 weeks of exercise,[13] although it is important to note that aerobic fitness also did not change significantly with the chronic exercise intervention.

Similar to the trend observed with CF, overall AP was significantly improved only in the high-frequency/high-intensity group after four months of exercise training.[19] The ES favouring exercise training was small (ES = 0.33; $p = 0.29$). The ES also favouring exercise for the high-frequency/normal-intensity group was trivial (ES = 0.00; $p = 1.00$).

4. Discussion

This review identified a small (10 papers, 11 studies) but relatively recent body of relevant literature, with overall quality ranging from poor to good. All 10 papers, the majority being acute studies[13–16,30–34], reported at least one parameter showing a significant effect of exercise in improving CF and/or AP in adolescents. However, in six studies where effect sizes could be calculated, only 48% of CF parameters favoured acute exercise.[13–16,30,31] Of the one chronic study which allowed for ES calculations, both of the CF parameters favoured chronic exercise.[28] Furthermore, only 37% of all CF parameters across studies offered support for the efficacy of exercise in improving CF. Overall, the evidence for a benefit from acute and/or chronic exercise training on CF in adolescents was equivocal, highlighting the need for robust studies focussed on this age stage. The inconsistent effect of exercise on measures of CF in this review may be explained by the heterogeneity of cohorts, wide disparity in CF assessments and an inadequate or ineffective dose of exercise to provide a stimulus. By contrast, AP was observed to improve significantly after acute and chronic exercise, with 69% of the total AP parameters favouring exercise.

Exercise is proposed to enhance CF by a number of potential mechanisms. These include acute exercise acting as an arousal stimulus, as well as exercise promoting the release of brain-derived neurotrophic factor (BDNF). Both acute and chronic exercise have been reported to upregulate BDNF, resulting from exercise-induced activation of a key complex pathway PGC1α/FNDC5/BDNF (Peroxisome proliferator-activated receptor co-activator alpha/Fibronectin type III domain-containing5/BDNF), identified as an initiator of neuroplasticity[35] via enhanced neuro/synaptogenesis and angiogenesis.[36] This pathway may subsequently promote long-term neural remodelling in brain regions such as the hippocampus.[36–38] Furthermore, BDNF is also reported to play an integral role in mediating persistent network activity and maintaining normal PFC function.[39–42] Interactions between the PFC and hippocampus are facilitated by limbic connections allowing these two brain regions to mediate different levels of cognitive control in the domains of memory and planning/executive function.[43,44]

Increased BDNF levels in the hippocampus are reported after acute exercise which likely confers specific benefits integral to learning and memory performance.[45] Interestingly, in this review, memory[14,30,32,33] showed the most consistent significant improvements from acute exercise. Memory has also been demonstrated to improve after six weeks of moderate intensity aerobic exercise.[46] The results for executive function[16,31–33] and attention and concentration[13,15] domains were mixed, with some tests favouring rest and some exercise. It has been suggested that a transient bout of acute exercise may have a selective influence on CF, specifically enhancing some domains such as information processing but potentially impairing others like executive function which requires more coordinated cognitive processess.[47] A recent review has identified the dearth of evidence for specific mechanisms underpinning the effects of physical activity on cognition in young people and emphasised the need for more high-quality experimental research in this area.[10] Because adolescence is the period where the PFC and the hippocampus remain highly plastic, future research in the cognitive domains which are associated specifically with the function of these two brain regions may prove fruitful.

An important issue with regard to mechanisms of action is whether higher intensities of exercise may be required to produce benefits on CF. Since different exercise doses recruit different muscle masses and hence require different cardiac output,[48–50] increasing exercise intensity especially, may be correlated to the increased blood flow and BDNF-induced stimulation of the hippocampus and PFC.[51] Exercise dose components such as frequency, intensity, type and duration are likely to directly impact cognitive (and even AP) outcomes. In this review, exercise protocols and intensity were poorly reported, which possibly contributed to the inconsistent findings. Significant increases in BDNF levels have been reported following 30 min of moderate intensity cycling as well as a ramp protocol to exhaustion.[52,53] The importance of this dose-response relationship between exercise and cognition is further highlighted in one of the chronic studies reviewed. Participants who completed high-frequency/high-intensity training improved in their cardiorespiratory fitness, which correlated with improvements in their CF,[28] suggesting the need for a sufficient intensity to elicit benefits. This study was consistent with other studies where chronic aerobic exercise has been observed to enhance CF in populations outside of the adolescent age stage, with a higher exercise dose (volume, intensity or both) required to elicit benefits.[9,19] These preliminary findings underscore the need for further research using clearly-defined exercise protocols, as higher intensities of exercise have been found to produce greater physiological effects.[52]

In this review, academic performance measured by arithmetic skills significantly improved with acute[29,32] and chronic exercise.[28] Similar to CF, acute exercise has been postulated to enhance arousal and facilitate improved classroom attention.[12,54,55] However, the timing of the exercise may be an important consideration. The effect of undertaking the exercise in either the first, third, fifth or last period of the school day was investigated. AP was shown to be better (compared with rest) after acute exercise for all but the last period.[29] Hence, it may be more effective to intervene with acute exercise earlier in the day when students are less fatigued. While limited conclusions can be drawn from the few included studies, evidence for the potential benefits of chronic aerobic exercise on AP in primary schoolchildren has been demonstrated by an improvement in or maintenance of AP.[56,57] However, it should be noted that AP can also be influenced by a wide range of non-cognition related factors including social-emotional functioning, motivation, school demographic characteristics and classroom practices.[58,59] Future studies examining the role of aerobic fitness in the exercise-AP relationship, taking into consideration the abovementioned confounders, are warranted.

The key strength of this review is its tight focus on inclusion of studies conducted only in adolescents. Previous reviews have included studies which were predominantly in children under 12 years.[12,54,55] Furthermore, this is the first review to examine the impact of both acute and chronic exercise on AP in adolescents. Other strengths include the systematic search of literature, use of PRISMA guidelines and calculation of effect sizes. The review evaluated the outcomes of a range of cognitive tasks assessing different cognitive domains, the majority of which were validated.

The main limitation of this study is the quality and quantity of the identified papers. Only half of the studies (n = 5) reported exercise intensity using recommended guidelines[60] (HR_{max} or VO_{2max}). Not all acute studies used a cross-over design (56%). Other limitations include bias towards the early adolescent years (13–14 years, seven studies) and sex (63% male). Maturation stage was only reported in one study.[28] Some studies (n = 2)[29,32] used cognitive and academic assessments that were not validated and the effects of exercise on AP were focussed on the arithmetic domain.[29,32] Sample sizes were also relatively small (n < 120). Familiarisation to the exercise stimulus (n = 0) and cognitive tests (n = 5)[13,16,30,31,33] was not always used and therefore learning effects may have confounded the results. Additionally, the absence of a resting condition (one acute, two chronic studies) and the use of a "normal PE lesson" (exercise dose poorly quantified) limited the capacity to make comparisons between groups and studies. The diversity and complexity of CF measures makes comparison between studies more difficult, in respect of which it has been recommended that researchers seek consensus on a focused range of cognitive assessments that include measures of key cognitive domains with clinical and scientific importance.[10,34]

In conclusion, this systematic review demonstrates that there is limited literature in adolescents addressing the effect of either acute or chronic exercise on CF and AP. Although there is strong theoretical evidence for exercise being beneficial particularly during adolescence due to neural plasticity, there is as yet limited and inadequate evidence to support its efficacy. Future studies would benefit from collaboration between neuroscientists with expertise in cognition and its assessment and exercise scientists with expertise in the prescription and measurement of exercise. Although all the papers reviewed reported a significant effect of acute or chronic exercise in improving some aspect of CF and AP, it should also be noted that more than half (55%) of all cognitive and AP parameters either were not significant or were significantly improved for the rest condition. Eliminating possible noise (variability of exercise protocols and cognitive assessments) in the data may improve the quality of future research and support the maintenance and importance of adequate physical activity throughout the school years.

Practical implications

- There is inadequate evidence to recommend a standardised exercise intervention that could consistently improve CF and AP in adolescents, hence more studies are warranted.
- Limited and low-quality literature in this field hinders understanding of the relation between acute and chronic exercise and CF and AP.
- Greater collaboration between exercise scientists and neuroscientists would improve the quality of future research.
- There is a need for greater consensus between researchers on the measurement of both cognitive domains and academic performance.

Acknowledgements

The authors would like to thank Ms Kanchana Ekanayake and Ms Elaine Tam for their invaluable guidance with the literature searches and referencing.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jsams.2016.11.025.

References

1. World Health Organization. http://www.who.int/topics/adolescent_health/en/ 23/11/2015.
2. Blakemore S-J, Choudhury S. Development of the adolescent brain: implications for executive function and social cognition. *J Child Psychol Psychiatry* 2006; 47(3/4):296.
3. Coleman JC, Hendry LB. *The Nature of Adolescence*, New York, London, Routledge, 1990.
4. Feldman SS, Elliott GR. At the threshold: the developing adolescent. *J Nerv Ment Dis* 1992; 180(3):213.
5. Sowell ER, Peterson BS, Thompson PM et al. Mapping cortical change across the human life span. *Nat Neurosci* 2003; 6(3):309–315.
6. Fuster JM. *Anatomy of the Prefrontal Cortex*, 4th ed. San Diego, Academic Press, 2008.
7. Giedd JN, Blumenthal J, Jeffries NO et al. Brain development during childhood and adolescence: a longitudinal MRI study. *Nat Neurosci* 1999; 2(10):861–863.
8. Elliott R. Executive functions and their disorders. *Br Med Bull* 2003; 65(1):49–59.
9. Vidoni ED, Johnson DK, Morris JK et al. Dose-response of aerobic exercise on cognition: a community-based, pilot randomized controlled trial. *PLoS One* 2015; 10(7):e0131647.
10. Lubans D, Richards J, Hillman C et al. Physical activity for cognitive and mental health in youth: a systematic review of mechanisms. *Pediatrics* 2016; 138(3):e20161642.
11. Haapala E. Physical activity, academic performance and cognition in children and adolescents: a systematic review. *Baltic J Health Phys Act* 2012; 4(1):53–61.
12. Lees C, Hopkins J. Effect of aerobic exercise on cognition academic achievement, and psychosocial function in children: a systematic review of randomized control trials. *Prev Chronic Dis* 2013; 10:E174.
13. Zervas Y, Danis A, Klissouras V. Influence of physical exertion on mental performance with reference to training. *Percept Mot Skills* 1991; 72(3 Pt. 2):1215–1221.
14. Budde H, Voelcker-Rehage C, Pietrassyk-Kendziorra S et al. Steroid hormones in the saliva of adolescents after different exercise intensities and their influence on working memory in a school setting. *Psychoneuroendocrinology* 2010; 35(3):382–391.
15. Budde H, Voelcker-Rehage C, Pietraßyk-Kendziorra S et al. Acute coordinative exercise improves attentional performance in adolescents. *Neurosci Lett* 2008; 441(2):219–223.
16. Stroth S, Kubesch S, Dieterle K et al. Physical fitness, but not acute exercise modulates event-related potential indices for executive control in healthy adolescents. *Brain Res* 2009; 1269:114–124.
17. Meeusen R, De Meirleir K. Exercise and brain neurotransmission. *Sports Med* 1995; 20(3):160.
18. Hillman CH, Pontifex MB, Raine LB et al. The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. *Neuroscience* 2009; 159(3):1044–1054.
19. 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.
20. Garber CE, Blissmer B, Deschenes MR et al. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc* 2011; 43(7):1334–1359.
21. McAuley E, Mihalko SL, Bane SM. Exercise and self-esteem in middle-aged adults: multidimensional relationships and physical fitness and self-efficacy influences. *J Behav Med* 1997; 20(1):67–83.
22. Karstoft K, Pedersen BK. Exercise and type 2 diabetes: focus on metabolism and inflammation. *Immunol Cell Biol* 2016; 94(2):146.
23. Australian Bureau of Statistics. http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/4364.0.55.004Chapter1002011-12.
24. Pate RR, Hohn RC. *Health and Fitness Through Physical Education*, Champaign, United States, Human Kinetics Publishers, 1994.
25. Moher D, Liberati A, Tetzlaff J et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *J Clin Epidemiol* 2009; 62(10):1006–1012.
26. Sherrington C, Herbert RD, Maher CG et al. PEDro. A database of randomized trials and systematic reviews in physiotherapy. *Man Ther* 2016; 5(4):223–226.
27. Hopkins WG, Marshall SW, Batterham AM et al. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 2009; 41(1):3–13.
28. Ardoy DN, Fernández-Rodríguez JM, Jiménez-Pavón D et al. A physical education trial improves adolescents' cognitive performance and academic achievement: the EDUFIT study. *Scand J Med Sci Sports* 2014; 24(1):e52–e61.
29. Travlos A. High intensity physical education classes and cognitive performance in eighth-grade students: an applied study. *Int J Sport Exerc Psychol* 2010; 8(3):302.
30. Soga K, Shishido T, Nagatomi R. Executive function during and after acute moderate aerobic exercise in adolescents. *Psychol Sport Exerc* 2015; 16:7–17.
31. Hogan M, Kiefer M, Kubesch S et al. The interactive effects of physical fitness and acute aerobic exercise on electrophysiological coherence and cognitive performance in adolescents. *Exp Brain Res* 2013; 229(1):85–96.
32. Gu HM, Shin DS, Lee KH et al. The relationship between physical exercise and cognitive ability (II). *Korean J Sports Sci* 1992; 4:70–78.
33. Cooper SB, Bandelow S, Nute ML et al. The effects of a mid-morning bout of exercise on adolescents' cognitive function. *Ment Health Phys Act* 2012; 5(2):183–190.
34. Young J, Angevaren M, Rusted J et al. Aerobic exercise to improve cognitive function in older people without known cognitive impairment. *Cochrane Database Syst Rev* 2015; 4(4):CD005381.
35. Wrann CD, White JP, Salogiannnis J et al. Exercise induces hippocampal BDNF through a PGC-1α/FNDC5 pathway. *Cell Metab* 2013; 18(5):649–659.
36. Vaynman S, Ying Z, Gomez-Pinilla F. Hippocampal BDNF mediates the efficacy of exercise on synaptic plasticity and cognition. *Eur J Neurosci* 2004; 20(10):2580–2590.
37. Neeper SA, Góauctemez-Pinilla F, Choi J et al. Exercise and brain neurotrophins. *Nature* 1995; 373(6510), 109–109.
38. Vaynman S, Ying Z, Gomez-Pinilla F. Interplay between brain-derived neurotrophic factor and signal transduction modulators in the regulation of the effects of exercise on synaptic-plasticity. *Neuroscience* 2003; 122(3):647–657.
39. Hashimoto T, Volk DW, Lewis DA. Cortical inhibitory neurons and schizophrenia. *Nat Rev Neurosci* 2005; 6(4):312–324.
40. Savitz J, Solms M, Ramesar R. The molecular genetics of cognition: dopamine, COMT and BDNF Genes. *Brain Behav* 2006; 5(4):311–328.
41. Woo NH, Lu B. Regulation of cortical interneurons by neurotrophins: from development to cognitive disorders. *Neuroscientist* 2006; 12(1):43–56.
42. Galloway EM, Woo NH, Lu B. Persistent neural activity in the prefrontal cortex: a mechanism by which BDNF regulates working memory? *Prog Brain Res* 2008; 169:251–266.
43. Miller EK, Cohen JD. An integrative theory of prefrontal cortex function. *Annu Rev Neurosci* 2001; 24:167.
44. Cohen J, O'Reilly R. A preliminary theory of the interactions between prefrontal cortex and hippocampus that contribute to planning and prospective memory, in *Prospective Memory: Theory and Applications*, Brandimonte M, Einstein G, McDaniel M, editors, Mahwah, New Jersey, Lawrence Erlbaum Associates, 1996.
45. Griffin ÉW, Mullally S, Foley C et al. Aerobic exercise improves hippocampal function and increases BDNF in the serum of young adult males. *Physiol Behav* 2011; 104(5):934–941.
46. Fu H-J, Sheu F-R, Shih M-L. Can aerobic exercise improve memory? *Res Q Exerc Sport* 2014; 85(S1):A62.
47. Audiffren M, Tomporowski PD, Zagrodnik J. Acute aerobic exercise and information processing: energizing motor processes during a choice reaction time task. *Acta Psychol (Amst)* 2008; 129(3):410–419.
48. McArdle WD, Katch FI, Katch VL. *Exercise Physiology: Energy, Nutrition, and Human Performance*, Baltimore, Lippincott Williams & Wilkins, 2007.

49. Warburton DER, Gledhill N, Quinney HA. Blood volume, aerobic power, and endurance performance: potential ergogenic effect of volume loading. *Clin J Sport Med* 2000; 10(1):59–66.
50. Warburton DER, Haykowsky MJ, Quinney HA et al. Blood volume expansion and cardiorespiratory function: effects of training modality. *Med Sci Sports Exerc* 2004; 36(6):991–1000.
51. Kramer AF, Hillman CH, Erickson KI. Be smart, exercise your heart: exercise effects on brain and cognition. *Nat Rev Neurosci* 2008; 9(1):58–65.
52. Rojas Vega S, Strüder HK, Vera Wahrmann B et al. Acute BDNF and cortisol response to low intensity exercise and following ramp incremental exercise to exhaustion in humans. *Brain Res* 2006; 1121(1):59–65.
53. Gold SM, Schulz K-H, Hartmann S et al. Basal serum levels and reactivity of nerve growth factor and brain-derived neurotrophic factor to standardized acute exercise in multiple sclerosis and controls. *J Neuroimmunol* 2003; 138(1):99–105.
54. Keeley TJH, Fox KR. The impact of physical activity and fitness on academic achievement and cognitive performance in children. *Int Rev Sport Exerc Psychol* 2009; 2(2):198–214.
55. Rasberry CN, Lee SM, Robin L et al. The association between school-based physical activity, including physical education, and academic performance: a systematic review of the literature. *Prev Med* 2011; 52:S10–S20.
56. Sallis JF, McKenzie TL, Kolody B et al. Effects of health-related physical education on academic achievement: project SPARK. *Res Q Exerc Sport* 1999; 70(2):127.
57. 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.
58. Wang MC, Haertel GD, Walberg HJ. Toward a knowledge base for school learning. *Rev Educ Res* 1993; 63(3):249–294.
59. Gustafsson J-E, Balke G. General and specific abilities as predictors of school achievement. *Multivariate Behav Res* 1993; 28(4):407–434.
60. American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription*, Lippincott Williams & Wilkins, 2013.