Effect of physical activity on the cognitive performance of middle aged New Zealand workers

Judith A. Thomas

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School of Applied Science

Faculty of Health and Environmental Sciences

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Attestation of Authorship

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

Signature _____

Date _____

Ethical approval was granted by AUTEC (Auckland University of Technology Ethics Committee) for the studies reported within:

9 December 2008 - Effect of a workplace physical activity program on occupational stress and cardiovascular risk factors: a pilot and feasibility study (Study 1) (08/265)

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Abstract

Given the projected ageing of the population over the next twenty years, age-related cognitive decline will become a significant contributor to New Zealand's burden of disease, unless factors which provide some protection against these changes are identified. Proponents of the cognitive reserve model postulate that cognitive ageing is highly individual and that healthy behaviours can ameliorate age-related declines in cognitive performance through building of neural reserve. Physical activity has been purported to enhance cognitive performance. However, the literature focuses largely on older populations which does not capture the potential protective effects of physical activity throughout adulthood. The majority of these studies are correlative and do not provide sufficient detail on the type of physical activity which is most beneficial. Given the vast number of neuropsychological tests employed across cognitive domains, good quality research is needed which employs reliable and valid instruments. **Objectives:** The primary aim was to determine whether cognitive performance in middle age could be enhanced by either of two contrasting exercise interventions compared to no exercise. The secondary aim was to investigate whether cardiovascular function would moderate changes in cognitive performance. **Methods:** A pilot study was employed to test a high intensity exercycle protocol for its feasibility and its effectiveness in improving cardiovascular function. Five females aged 45-61 years participated in a six-week intervention. Cardiovascular function was assessed prior to and upon completion of the program. A postintervention survey was used to gather information on the perceived advantages of the program and on recommendations for improvement. For the main study, sixty-two healthy but low-active individuals (aged 40-64 y) participated in one of three 16-week programs: walking, exercycling or control. Episodic memory (verbal recall) was assessed using the Wechsler Memory Scale-III-A Logical Memory and Family Pictures subtests. Executive function (set shifting) was assessed by the Wisconsin Card Sorting Test. Cardiovascular variables included: body mass index, systolic and diastolic blood pressure, fasting blood cholesterol profiles and glucose. Pretest to posttest changes in cognitive performance were compared among the intervention groups, with respect to participant cardiovascular function and risk level. **Results:** Results from the pilot study supported the feasibility of the exercycle program, indicating that participants enjoyed the program's activity and social support aspects. Participant recommendations for program development included: greater choice of music, more convenient session times and more motivational tools. Cardiovascular function variables did not significantly improve over the short intervention period. Results from the main study did not indicate any effect of exercise on memory. However, compared to low cardiovascular risk participants, those of high risk improved immediate story recall to a greater extent. Decreases in systolic blood pressure were significantly correlated with improvement in immediate story recall, with correlations stronger for those of high

cardiovascular risk. Although executive function was not differentially affected by a specific exercise program, involvement in *any* physical activity resulted in greater improvement in set shifting compared to controls. Cardiovascular function did not significantly modify changes in executive function. **Conclusions:** Engagement in a physical activity program of any type can improve set shifting in middle age. However, memory-dependent processes such as verbal recall depend more on the improvement in cardiovascular function, particularly for individuals of high risk. Multi-faceted programs focused on cardiovascular health may have important flow-on effects for maintaining the memory function of the ageing population.

General Introduction

Population projections based on 2009 census data predict that half of New Zealand's population will be aged over 40 years by 2031, with one in five New Zealanders over the age of 65 years (Statistics New Zealand, 2009). The New Zealand Vote Health expenditure highlights the cost of caring for an ageing population. Based on 2001/02 data, the Vote Health expenditure/person between 15-64 years was $1329, between 65-74 years was $3643, between 75-84 years was $6863, and for those 85 years and over was $13,568 (Ministry of Health, 2002). Growing prevalence of neuropathology (e.g. Alzheimer Disease) alongside other causes of age-related cognitive decline will contribute to increasing expenditure (Brookmeyer, Johnson, Ziegler-Graham, & Arrighi, 2007). Besides the economic burden, there are the inestimable personal effects of cognitive decline, not only with respect to the quality of life of the affected individual but also of those responsible for their care.

Cognitive decline is not an inevitable result of the ageing process. Cognitive ageing represents a series of changes which are highly individual and continue from early adulthood through to death. An overview of age-related changes in major domains of cognitive function will be discussed in Chapter 1 (Section 1.1) with an emphasis on memory and executive function which may be particularly vulnerable (Richards, Sacker, & Deary, 2007). It has been purported that middle age could be a particularly sensitive time for changes in cognitive health, despite being oft neglected in ageing research (Finch, 2009; Grady, 2007). Cognitive ageing in middle adulthood will also be discussed through Section 1.1.

As with other chronic diseases, the degree of cognitive decline may be accelerated throughout adulthood by longer-term exposure to negative behavioural and environmental factors (World Health Organization, 2002). Recent evidence suggests, however, that at any given age healthy lifestyle behaviours may be able to enhance cognitive performance (or protect it from decline) (Richards et al., 2007). This evidence underpins the concept of *brain* or *cognitive reserve* which posits that reserve may be "built" through increased neural network size and complexity or through more efficient use of existing or alternative neural networks (Small, Hughes, Hultsch, & Dixon, 2007). The cognitive reserve model will be discussed in more detail in Chapter 1 (Section 1.2).

There is a growing body of evidence obtained through epidemiological and experimental research suggesting that engagement in regular physical activity enhances cognitive performance in adulthood (Kramer, Erickson, & Colcombe, 2006). Thus, physical activity has been proposed as a healthy behaviour which could build cognitive reserve and protect against age-related declines in cognitive performance. Although the research base is large, the heavy dependence on correlative research, the

many definitions of “physical activity” utilised, the varying robustness of neuropsychological tests, and the limited age range of participants studied make any conclusions problematic. A detailed review and evaluation of the existing literature will be conducted in Chapter 1 (Section 1.3).

A number of mechanisms have been suggested to mediate the effect of physical activity on cognitive reserve and function. Chapter 1 (Section 1.4) outlines the premise that these effects could be mediated through improved cardiovascular function and thus blood supply to neural tissue. If indicated, this evidence would provide further support for the use of lifestyle behaviours such as physical activity for maintaining the vascular *and* cognitive health of the ageing population.

Despite the evidence linking an active lifestyle to improved health (World Health Organization, 2004), physical activity participation rates in New Zealand are low (Ministry of Health NZ, 2008). Chapter 1 (Section 1.5) will discuss the use of workplace health programs as a vehicle for improving uptake of physical activity. Supporting evidence for the workplace physical activity programs employed in this thesis are also presented in Section 1.5.

The aims of this thesis were designed to provide an original contribution to the existing literature as follows. The ability to enhance cognitive function (and build cognitive reserve) in normal middle aged people is not well understood, particularly with respect to physical activity. Therefore, the primary aim of this thesis was to determine whether physical activity can enhance cognitive function in middle aged individuals. As memory and executive function may be particularly vulnerable to age-related decline, episodic memory (verbal recall) and set shifting would be the primary domains of interest. Given the varying neuropsychological instruments employed to test these domains in previous research, this thesis would employ a battery of fully detailed validated instruments with large standardisation samples to provide greater robustness of methods and results. In order to determine whether one mode of activity would be more effective, two highly contrasting programs (walking versus high intensity exercycling) would be compared against a control group. The secondary aim of the thesis was to investigate whether cardiovascular function moderates changes in cognitive function. This aim was designed not only to advance the knowledge on underlying mechanisms, but also to determine if risk level would determine the degree of cognitive change - a unique contribution to the cognitive reserve literature.

Chapter 2 sets out the first study which was designed to test the feasibility of implementing a high intensity exercycle protocol into a workplace physical activity program. Participant feedback upon completion of the six-week program would inform its development and use for the main study. This single group pre-post study also investigated the effect of this program on cardiovascular function.

Study 2 (Chapter 3) comprised the main study of the thesis. Participants were assigned to one of three 16-week interventions (walking, exercycle or control). Neuropsychological assessments (episodic memory and set shifting) and cardiovascular function testing were conducted both prior to and upon completion of the intervention period. Statistical analyses of cognitive changes from pretest to posttest among the interventions and their interactions with cardiovascular variables were utilised to assess the study objectives.

Chapter 1. Review of literature

1.1 Age-related changes in cognitive function

Cognitive ageing is highly individual and the degree of variability between individuals grows with increasing age (Morse, 1993). However, substantial evidence indicates that a number of cognitive functions are subject to age-related changes, beginning in the 20s and 30s and continuing throughout adulthood, independent of known pathology (Park et al., 2002; T. Salthouse, 2009).

Behavioural tasks assessing constructs of memory have been shown to be differentially affected by age. Episodic memory (visual- or verbal-based memory for past events and experiences) has been reported to decline steadily throughout adulthood, particularly for tasks dependant on recall rather than recognition (Anderson et al., 2008; Haaland, Price, & Larue, 2003; Mejia, Pineda, Alvarez, & Ardila, 1998; Park et al., 2002). Park et al. (2002) reported that declines in long-term memory performance are continuous across adulthood, with no acceleration of decline at any stage. However, a study by Haaland, Price, & Larue (2003) of age-related performance on the Wechsler Memory Scale-III noted that the downward trends for episodic recall were punctuated by steeper drops in early middle age and then again in the 80s. Working memory capacity can also be negatively affected by age, resulting in reduced ability to actively hold and manipulate information (Luo & Craik, 2008; McCabe & Hartman, 2008). In contrast to episodic and working memory, procedural memory (memory for performance of skills) and semantic memory (memory for general information and verbal knowledge) tend to be sustained well into older adulthood (Anderson et al., 2008; Luo & Craik, 2008; Park et al., 2002).

Executive function is a broad construct generally thought to represent a number of higher order cognitive functions linked to frontal lobe activity (Etnier & Chang, 2009). Executive functions have been purported to include: planning, scheduling, mental set shifting, inhibition of prepotent responses, information updating and monitoring, and coordination of working memory with long-term memory (Etnier & Chang, 2009). Aspects of executive functioning have been reported to be particularly sensitive to ageing (Axelrod & Henry, 1992; Fisk & Sharp, 2004; Gaeta, Friedman, Ritter, & Cheng, 2001; Gunstad et al., 2006; Juncos-Rabadan, Pereiro, & Facal, 2008; Rhodes, 2004; Sorel & Pennequin, 2008; Treitz, Heyder, & Daum, 2007; Zimmerman et al., 2006). In fact, age-related changes in frontal lobe processes may explain a large proportion of the decrement in performance in other cognitive domains (e.g. episodic memory) which require management of information flow (Friedman, 2007). Decline in executive functioning is not limited to older aged individuals, with these cognitive changes already beginning to manifest in middle age (Gunstad et al., 2006; Juncos-Rabadan et al., 2008; Silver, Goodman, & Bilker, 2009).

Performance on a variety of cognitive tasks may be affected by the progressive slowing of processing speed beginning in young adulthood (Park et al., 2002). Slower cognitive speed limits the time available to complete each step in a task and early products of processing may be lost by the time later stages of processing are complete (T. A. Salthouse, 1996). Therefore, valid assessment of other domains of cognitive function (e.g. verbal recall, set shifting, etc.) should employ tests which do not require a speeded response in order to remove the confounding effects of reduced processing (and motor) speed.

Underlying neurophysiological changes tend to be associated with increasing age. Age-related morphological changes have been reported including reductions in grey matter volume across a number of regions, which may reflect decreases in neuronal number and/or synaptic density (Allen, Bruss, Brown, & Damasio, 2005; Raz et al., 2005; Zimmerman et al., 2006). White matter integrity has also been reported to deteriorate with age, showing accelerated atrophy around the fifth decade of life (Allen et al., 2005; Griebe et al., 2011; Raz & Rodrigue, 2006). Ageing also contributes to alterations in neuronal circuitry, characterized by differences in neurochemical activity at synapses and by changes in electrophysiological patterns of brain activation (Dustman, Emmerson, & Shearer, 1996; Friedman, 2010; Hof & Morrison, 2004). Neurological changes are not uniformly distributed, however. Rather, frontal and hippocampal regions seem to be particularly sensitive to deterioration (Allen et al., 2005; Simic, Kostovic, Winblad, & Bogdanovic, 1997; Zimmerman et al., 2006). Although there has been much debate about the extent to which regional brain volumes explain age-related cognitive decline (T. Salthouse, 2011; Van Petten et al., 2004), intact hippocampal and frontal regions are still considered prerequisites for successful performance on behavioural tests of memory and executive function, respectively (Dobbins, Kroll, Tulving, Knight, & Gazzaniga, 1998; Stuss et al., 2000).

Given that changes to both neurological integrity and cognitive performance are evident during middle age and may even become more precipitous at this time period, brain ageing should no longer be considered as a later age phenomenon. Finch (2009) suggests that the “neurobiology of middle age” is of particular importance for understanding how brain changes reflect the interaction between environmental and genetic modifiers. Given the increasing variability of function with increasing age, understanding the neurobiology of middle age may provide insight into ways of modifying the course of age-related changes in cognitive performance.

1.2 Brain and cognitive reserve

Despite its vulnerability, the adult brain has been shown to demonstrate remarkable plasticity and cognitive functions can undergo modifications throughout adulthood (Richards et al., 2007). Katzman and colleagues reported an “unexpected finding” in

1988 that a group of elderly subjects, showing preserved mental health status despite Alzheimer-related pathology, had larger brains compared to age-matched subjects (Katzman et al., 1988). These high-functioning individuals were thought to have developed a greater "reserve" which compensated for the effects of the disease.

To account for the oft found discrepancy between levels of pathology and behavioural performance, Stern (2006) postulated the concept of cognitive reserve. This hypothetical reserve represents an extra "capacity" which can moderate the clinical expression of disease and/or normal age-related changes (Stern, 2006).

A model of cognitive reserve is depicted in Figure 1 adapted from Richards and Deary (2005). According to this model, cognitive reserve, represented by pre-morbid cognitive ability, can modify the clinical expression of neurological disease (path a). This model may also be applied to ageing and is equally viable to explain individual differences in the degree of cognitive ageing (Richards et al., 2007). The term cognitive reserve is generally used to encompass the concepts of both brain reserve and cognitive reserve. Brain reserve is the concept that protection of cognitive function occurs via "bigger brains" which contain a higher number of healthy neurons and synapses (Stern, 2006). Scarmeas (2007) has referred to this as a passive reserve or a hardware change. Having a greater and more complex neural network would allow individuals to tolerate a relatively greater loss of neurons before exhibiting impaired function (Scarmeas & Stern, 2003). Or, protection may be afforded by more efficient use of existing or alternative brain networks, so-called cognitive reserve, an active or software change (Scarmeas, 2007; Scarmeas & Stern, 2003; Stern, 2007). Having available the use of alternative neural circuits would provide compensatory pathways for impaired networks (Scarmeas & Stern, 2003).

This model purports that different life exposures such as education, occupation and engagement in social, intellectual and physical activities contribute to cognitive reserve through neuronal plasticity (path c) (Richards & Deary, 2005). Thus, these influencing factors not only determine cognitive ability at any given age, but also are capable of enhancing ability (or protecting it from decline) (Richards et al., 2007). These factors also influence general health, either directly (e.g. lifestyle behaviours such as physical activity) or indirectly (e.g. education and socioeconomic status can affect uptake of healthy behaviours). General health can modify the extent of CNS (central nervous system) lesions, in particular through cerebrovascular disease (path d). Central nervous system lesions affect the brain's functional capacity (path e) and, therefore, cognitive function (path b). Cognitive reserve is purported to modify clinical expression of disease or age-related changes (path a), alongside moderating factors of personality and cultural norms (path f) (Richards & Deary, 2005). Stern (2007) has suggested that

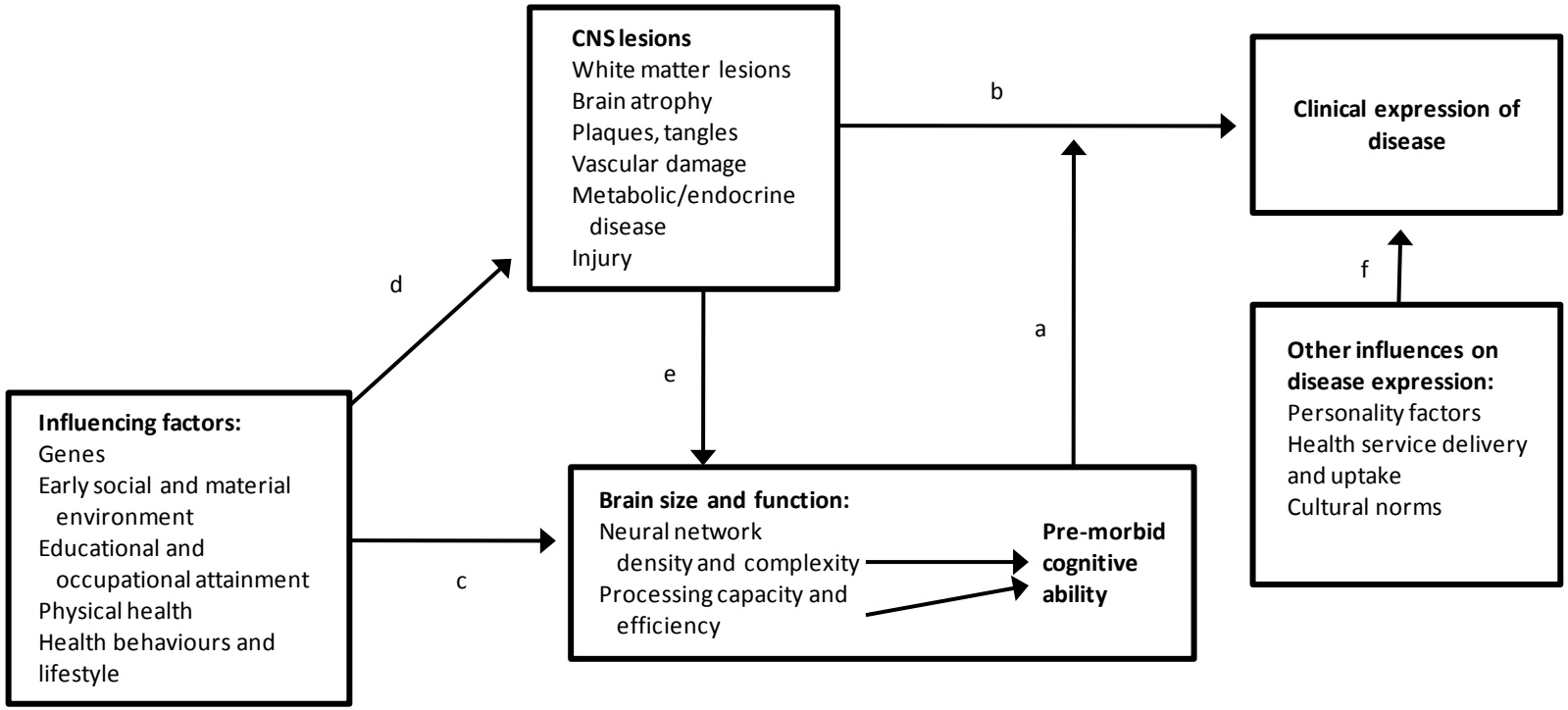

Figure 1. A model of the cognitive reserve hypothesis.

CNS = central nervous system. a. Cognitive reserve is represented by peak pre-morbid cognitive ability which modifies the clinical expression of CNS lesions (b). c. Cognitive reserve is influenced by many factors across the life course. d. These same factors influence the accumulation of CNS lesions. e. CNS lesions in turn affect brain size and function. f. There are factors other than CNS lesions that affect disease expression. Adapted from, "A life course approach to cognitive reserve. A model for cognitive aging and development," by M. Richards and I. J. Deary, 2005, Annals of Neurology, 58, p. 619, Copyright 2005 by John Wiley & Sons.

cognitive reserve deserves a lifespan approach as it is "… a malleable entity, whose level at any point in time is dependent on the summation of life experience and exposures up to that time" (p. 2). This concept has instigated research on the identification of modifiable lifestyle factors which may build cognitive reserve and enhance cognitive function. Physical activity could be an effective and widely accessible means for contributing to cognitive reserve throughout the lifespan, thus mitigating age-related declines in cognitive health.

1.3 Physical activity and cognitive function

Many researchers have sought evidence for a relationship between physical activity and brain / cognitive reserve through measures of behavioural performance. The literature in this area is burgeoning with a large variety of research designs and behavioural measures employed to investigate whether, and how, physical activity may influence cognitive function.

The literature is divided between studies of physical activity behaviour versus aerobic fitness. A meta-regression of the relationship between aerobic fitness and cognitive function has recently concluded that the empirical literature at this stage does not support the so-called "cardiovascular fitness hypothesis" (Etnier, Nowell, Landers, & Sibley, 2006). As well, evidence which supports physical activity behaviour rather than fitness can be more readily understood and utilised by laypeople and their health practitioners. For these reasons, it was decided to limit the literature review presented in this thesis to those studies which have investigated the effects of physical activity behaviour.

A critical discussion follows of the designs and key cognitive outcomes of relevant studies published between 1966 and July 2011. Criteria for inclusion in this discussion were that the studies had to involve human subjects, be published in English, contain a cohort of adults, use a sample of participants with no co-morbid disorders, be related to physical activity behaviour, where that physical activity was aerobic in nature and have cognitive function as a primary outcome. Literature searches were conducted through MEDLINE, PsycINFO, and PEDro using the keyword search "(exercise or physical activity) and (cognition or cognitive function)". References cited within each included study and within other literature reviews were also screened for relevance. A total of 91 publications (53 epidemiological studies and 38 experimental studies) met the criteria so were included in this discussion.

1.3.1 Epidemiological studies

Of the 53 epidemiological studies reviewed, 22 were prospective, 3 were retrospective, 23 were cross sectional, and 5 studies combined prospective and cross sectional designs. Table 1 alongside detailed descriptions of each included study (Appendix A) were developed to guide the following evaluation of the existing literature.

Although five studies did not support any association between physical activity and cognitive function (Carlson et al., 2008; Cassidy et al., 2004; Powell & Pohndorf, 1971; Sturman et al., 2005; Verghese et al., 2006), the large majority (48 studies) reported some positive association. Engagement in physical activity has been reported to benefit perceptual motor performance, episodic memory (recall and recognition), working memory, executive function, visuospatial ability, acquired knowledge (e.g. vocabulary) and global cognitive function scores (see Appendix A for more details on cognitive outcomes). This benefit was shown for longitudinal studies (i.e. people who were active when younger demonstrated improved cognitive function in later life) and for cross sectional studies (i.e. concurrent relationship between activity level and cognitive performance). However, many of these epidemiological studies exhibit methodological weaknesses as described below.

Firstly, epidemiological research does not allow the determination of causation nor the direction of association between physical activity and cognition. That is, are people who engage in exercise more likely to remain cognitively intact or are people who maintain good cognitive function more likely to remain physically active?

Although most of these studies adjust for a variety of potential confounders related to other lifestyle or demographic factors, there is often the assumption taken that it is physical activity alone which is associated with cognitive outcomes. Rather, with sometimes long time gaps between physical activity assessment and follow-up cognitive testing (i.e. anywhere up to 36 years) any number of factors may co-vary with physical activity engagement. For example, it has been proposed that education, occupation and socioeconomic status may affect cognitive performance directly or through differential uptake of healthy behaviours such as physical activity (Richards et al., 2007). And, if it is physical activity which directly influences cognitive function, is it the health and/or social benefits which confer this protection?

Table 1. Characteristics of Epidemiological Studies

n	No.	Age at Baseline (y)	No.[a]	Design(s)	No.[a]	Follow-up (years)	No.	PA Score Components	No.[a]	Domain(s) Assessed	No.[a]
≤100	7	≤20	4	Prospective	27	≤5	12	Part only	9	PM	14
>100 – 500	13	>20 – 40	8	Retrospective	3	>5 – 10	8	Part+Type	11	WM	9
>500 – 1000	11	>40 – 60	14	Cross section	28	>10 – 20	3	Part+Time	8	EM	15
>1000	22	>60 – 80	43			>20	5	Part+Type+ Time	23	E	15
		>80	21			n/a	25	# of Activities	5	AK	7
								Distance	2	VS	3
								Actual	1	G	25
										CD	12

Note. No.= a count of the number of studies described by each characteristic subcategory, *n* = sample size, PA = physical activity, Part = participation (yes/no), Type = type or intensity of activities, Time = time (hours) spent engaged in activity, # = number (variety) of activities, Distance = distance walked (miles/blocks), Actual = objective measure of PA (accelerometer output), PM = perceptual motor performance (tasks which assess information processing speed with a simple behavioural response), WM = working memory (tasks requiring short-term rehearsal and manipulation of information), EM = episodic memory (tests assessing declarative recall or recognition of verbal or visual information), E = executive function (tasks requiring strategy development, set shifting, reasoning, problem solving, verbal and visual fluency, interference control, response inhibition and/or conflict resolution), AK = acquired knowledge (tests of semantic knowledge, vocabulary, and general information), VS = visuospatial ability, G = global cognitive function composite score, CD = clinical diagnosis of dementia.

[a] Multiple choices were allowed for Age at Baseline, Design(s), PA Score Components and Domain(s) Assessed.

Another concern is that epidemiological studies have placed a large focus on the cognitive outcomes in individuals aged 60 and over. In Table 1, "age at baseline" characterises the number of studies having participants in each range. Multiple entries were allowed for studies with age ranges spanning more than one category. For studies not reporting the age range of participants, the mean age or minimum age (e.g. "65+") was used. Forty-three of the fifty-three studies included subjects in the range of 60-80 years with 21 studies having participants aged 80 and over. One concern, however, is that the upper limit of age ranges is sometimes not reported, leaving the reader to make assumptions based on the mean age only. For example, a number of studies only report that their participants are aged "60+" or "65+" (Laurin, Verreault, Lindsay, MacPherson, & Rockwood, 2001; Lee et al., 2009; Lytle, Vander Bilt, Pandav, Dodge, & Ganguli, 2004; Middleton et al., 2010; Podewils et al., 2005; Psaltopoulou et al., 2008; Ravaglia et al., 2008; Sturman et al., 2005; M. S. Wu et al., 2011). Thus, an even greater number of studies may utilise individuals who are 80+ than that depicted in Table 1. Given the increased variability in cognitive outcomes with advancing age (Morse, 1993), knowing the exact age ranges would provide a truer account of the cognitive changes resulting from physical activity throughout adulthood.

As well, when employing a sample of individuals who are in an old-old category, exclusion criteria should be in place to ensure that the participants do not have underlying cognitive impairment. In a study by Eggermont et al. (2009) of 544 individuals aged 70-97 years, the threshold for exclusion due to cognitive impairment included: a score of less than 18 on the Mini-Mental State Examination (MMSE) and an inability to complete a monthly calendar or written description of the study. Whether this threshold is sufficient to exclude those with prior impairment is questionable. Although the MMSE is a common screening tool, it is brief and scores between 18-24 points could indicate the presence of cognitive impairment in this age range (Strauss, Sherman, & Spreen, 2006). As such this sample may not necessarily represent a "normal" older aged population making generalisability uncertain.

Another issue with this limited age focus is that other age ranges throughout adulthood have not been sufficiently studied. This is not surprising given the increased incidence of cognitive decline in later life and its detrimental effect on quality of life. Only 12 studies considered individuals under 40 years, with 14 studies tapping into the effects on middle aged populations. Fewer studies have focused specifically on how physical activity may influence function through middle age (Richards, Hardy, & Wadsworth, 2003; Sabia et al., 2009). It could be argued that enhancing cognitive function throughout the lifespan is as important as reducing the risk of cognitive decline in old age. Indeed further research with younger and middle aged participants is needed to test the generalisability of the results from older aged individuals to

younger populations. Further research may also be used to test the notion that middle age may be a sensitive time to build cognitive reserve and for physical activity to act as a prophylactic for declines in cognitive function.

Epidemiological research has been utilised to enable the study of very large study samples, not able to be achieved in experimental designs. However, in order for these large-scale studies to be feasible, participant physical activity behaviours tend to be based on self-reports. Laporte, Montoye, & Caspersen (1985) have highlighted the lack of standardised techniques to define and assess levels of physical activity, such that "physical activity" in one study is different from "physical activity" in others. There are at least four ways in which survey procedures of physical activity vary: "… the time frame respondents are asked to remember, the nature and detail of the physical activities, the mode of data collection, and the summary index derived by survey results to rank-order individual physical activity levels" (LaPorte et al., 1985, p. 144).

Self-reports of physical activity levels may lack reliability. Under-reporting of physical activity can occur due to "forgetting". Larson et al. (2006) asked participants to recall the number of days per week they did each of the following activities for at least 15 minutes at a time during the past year: walking, hiking, bicycling, aerobics or calisthenics, swimming, water aerobics, weight training or stretching, or other exercise. A retrospective study by Dik et al. (2003) asked participants (aged 62-85 y) to report the total time per week engaged in sports or other physical activity that caused them to sweat or made them exhausted between the ages of 15 and 25 years of age. Even cognitively intact participants may find this level of reporting difficult. Conversely, volunteers may over-report involvement in exercise, in an effort to please the investigators.

Self-reports may also lack validity. Only one study by Buchman (2008) attempted to verify self-reports with accelerometer data. Interestingly, despite no association between self-reported activity and cognitive function, higher actual activity (accelerometer readings) was associated with positive outcomes across a range of cognitive domains. This discrepancy may be due to the limited range of exercise categories from which to choose on physical activity surveys. For example, Kareholt, Lennartsson, Gatz & Parker (2011) asked participants to report the frequency of their participation in sports, gardening or dancing. And Chang et al. (2010) gathered information on subjects' time per week involved in exercise or sport. With the range of activities being limited, there is the likely exclusion of work and non-recreational activities which are vigorous in nature.

As noted in Table 1, there are many different methods of calculating and reporting physical activity scores. Some studies use detailed reports of frequency, duration and

time of specific activities to estimate energy expenditures based on METs (metabolic equivalents) of those activities (Angevaren et al., 2007; Podewils et al., 2005; Psaltopoulou et al., 2008). This method provides an informative measure of physical activity which includes the relative intensities and time involved in each activity scored. In other studies, physical activity level is reported only in terms of the time (hours/week) involved in all activity (Schuit, Feskens, Launer, & Kromhout, 2001; Sumic, Michael, Carlson, Howieson, & Kaye, 2007). Some studies report on the numbers of activities in which participants are involved (Carlson et al., 2008; Richards et al., 2003). And, finally some authors choose to dichotomise physical activity into "active" or "inactive" categories based on participation only (Huang, Dong, Zhang, Wu, & Liu, 2009; Rasmussen et al., 2006). With the inconsistency of methods for calculating and reporting physical activity participation, it is difficult to come up with a useable "prescription" or guideline for the optimal frequency, duration and intensity of exercise required to most benefit cognitive performance. The use of objective measures (accelerometers) would provide information on total activity, and the time and intensity of activity. However, they do not provide useable information on the mode/type of activity undertaken. The use of controlled experimental studies with detailed programs of physical activity is a more definitive way of investigating the effect of particular types of physical activities on cognitive outcomes.

Arguably the primary concern with the epidemiological studies is the large variety of cognitive outcomes reported in the physical activity and cognition literature. For ease of evaluation, neuropsychological instruments were grouped into the following domains: PM (perceptual motor performance), WM (working memory), EM (episodic memory), E (executive functions), AK (acquired knowledge), VS (visuospatial ability), G (global cognition score) and CD (clinical diagnosis of dementia). The method of allocating tests to each category is outlined in the legends for Table 1 and Appendix A. Overall measures of global or general cognition were the most popular outcomes in the epidemiological literature (Table 1). Twenty-five studies reported on global cognition scores. Episodic memory (15 studies) and executive function (15 studies) were the next most popular domains assessed.

Global cognition scores were ones generally used with older populations as an assessment of overall cognitive function or as a screening tool for cognitive impairment. The MMSE was a popular instrument employed probably due to its common use as a screening tool and its short administration time. Global cognition also represented overall composite scores which were calculated using scores from different instruments across a number of distinct domains (Buchman et al., 2008; Sturman et al., 2005). Having one score represent cognitive function is problematic

and does not allow for the interpretation of the specific effects of physical activity on domains of cognition.

For episodic memory, the number of neuropsychological tests employed to measure this domain was considerable. There were more than ten different instruments used to measure recall and/or recognition of verbal and/or visual information. Some authors chose to use a word list recall task (Eggermont, Milberg, Lipsitz, Scherder, & Leveille, 2009; Rebok & Plude, 2001; Richards et al., 2003). Other researchers chose to employ tasks which require memory for context as well as content (e.g. short story or paragraph recall) (Buchman et al., 2008; Weuve et al., 2004). Still others chose tests which rely more on recognition (Lindwall, Rennemark, & Berggren, 2008). These tests all vary widely from type of information being learned (i.e. words, objects, context), different administration protocols (i.e. written/verbal, computer-based/paper-based, etc.), popularity in clinical use, through to the evidence supporting their reliability and validity. There is often a great deal of variability within even one type of task, such as word recall. Word recall lists can differ by the relative semantic relatedness of the words which will affect learning and recall strategies. And, the composite scores can either indicate the sum of correct responses in each of three learning trials or the sum of correct responses in both learning and delayed trials. Thus, the variety of task requirements, administration protocols and scoring make interpretation of the current literature on episodic memory difficult.

The number of tests purported to measure executive function in the reviewed studies was even greater than for memory (Appendix A). Eggermont et al. (2009) alone used several tests to assess executive functions including: Letter Fluency, Category Fluency, and Trail Making Test (TMT) (part B). These are only but a small sample of tests which have been purported to measure executive functioning. The term “executive function” is a broad, multi-faceted construct which has been said to include: strategic planning, scheduling, mental set shifting, inhibition of prepotent responses, information updating and monitoring. It remains to be shown which test/tests are best employed to operationalise executive function and therefore fully understand how it is affected by exercise. In addition, Etnier & Chang (2009) noted a distinct lack of overlap between executive function measurements used clinically in the neuropsychology field and those usually employed in the physical activity literature. The three most frequently reported instruments used in clinical settings are the Wisconsin Card Sorting Test (WCST), the Stroop Test, and the Trail Making Test. However, the numbers of tests actually employed in the physical activity literature is much more varied. In particular, tests which are timed and require a speeded response seem to be most popular in the literature reviewed within - maybe for time-saving reasons. However, speeded tests may not provide a true measure of an executive process if performance includes

information processing and motor response times which tend to slow with age. Because it is impossible to find a task which provides a "pure" measure of executive function, it should be clearly reported which subcomponent(s) are thought to be assessed by a particular behavioural measure using robust instruments supported by clinicians (Etnier & Chang, 2009).

1.3.1.1 Summary of epidemiological studies

Based on the number of studies purporting a positive relationship between exercise and cognitive function, there is sufficient evidence to warrant further investigation. The major strength of the current literature is the use of large sample sizes improving the generalisability of results to comparable age ranges. However, measures of physical activity rely largely on self-report leaving the nature of physical activity poorly defined. As yet, the existing literature tends to focus on an older aged population, largely neglecting other stages of adulthood which may be able to provide information on the protective effects of physical activity. With a growing field of research has come an equally growing array of neuropsychological tests employed in this field making interpretation of the findings difficult. Finally, epidemiological studies in the end fall short by not allowing the determination of causation.

1.3.2 Intervention studies

Intervention studies provide a means with which to circumvent some of the problems with epidemiological studies by prescribing specific types, durations and intensities of exercise and measuring any changes in cognitive performance over the course of the intervention. The results, however, have been much more equivocal for intervention studies than for epidemiological studies. The research designs and outcomes of thirty-eight intervention studies have been detailed in Appendix B.

Many intervention studies have reported a positive effect of a variety of exercise programs on perceptual motor performance, visuospatial ability, working memory, episodic memory, aspects of executive function and global cognition scores (Albinet et al., 2010; Barry, Steinmetz, Page, & Rodahl, 1966; Carral & Perez, 2007; Colcombe et al., 2004; Dustman et al., 1984; El-Naggar, 1986; Elsayed, Ismail, & Young, 1980; Hansen, Johnsen, Sollers, Stenvik, & Thayer, 2004; Hassmen & Koivula, 1997; Hawkins, Kramer, & Capaldi, 1992; Hill, Storandt, & Malley, 1993; Ismail & El-Naggar, 1981; Kramer et al., 2001; Marmeleira et al., 2009; Masley, Roetzheim, & Gualtieri, 2009; Muscari et al., 2010; Rikli & Edwards, 1991; Smiley-Oyen et al., 2008; Stacey, Kozma, & Stones, 1985; Stevenson & Topp, 1990; S. Stroth et al., 2009; Williams & Lord, 1997; Young, 1979). Although it seems as if the positive benefits of exercise are easily confirmed, several investigators have reported that exercise interventions resulted in

only marginal or no differential improvement in cognitive function (Blumenthal et al., 1991; Blumenthal & Madden, 1988; Emery & Gatz, 1990; Fabre, Chamari, Mucci, Masse-Biron, & Prefaut, 2002; Harma, Ilmarinen, Knauth, Rutenfranz, & Hanninen, 1988; Kamijo et al., 2007; Klusmann et al., 2010; Oken et al., 2006; Okumiya et al., 1996; Oswald, Gunzelmann, Rupprecht, & Hagen, 2006; Perri & Templer, 1984; Ruscheweyh et al., 2009; Taylor-Piliae et al., 2010; Whitehurst, 1991; Williamson et al., 2009).

As with epidemiological studies, intervention studies have their own strengths and weaknesses in design. A summary table of their characteristics is depicted in Table 2.

Nearly three quarters of the experimental studies summarised in Appendix B were focussed on older aged populations. Twenty-seven studies included individuals younger than 60, with fourteen including middle aged participants (Table 2). In Table 2, "age at baseline" characterises the number of studies having participants in each range. Multiple entries were allowed for studies with age ranges spanning more than one category. For studies not reporting the age range of participants, the mean age or minimum age (e.g. "65+) was used. Although cognitive decline disproportionately affects quality of life and activities of daily living in older individuals, it may be short-sighted to only investigate the benefits of physical activity at this late stage. Rather, finding ways of protecting cognitive function in earlier stages of adulthood (through building cognitive reserve) may act to ameliorate cognitive decline.

The age range of participants *within* each study also varied. Although the majority of studies chose a relatively narrow age range for their participants (i.e. 20 year range), some researchers chose to recruit from young adulthood through to older age for a single study (El-Naggar, 1986; Ismail & El-Naggar, 1981; Masley et al., 2009; Young, 1979). Masley et al. and Young tried to overcome this problem by including age as a covariate. However, El-Naggar and Ismail & El-Naggar treated their samples as homogeneous. The use of this wide age range makes the assumption that individuals from these disparate ages will adapt similarly to the exercise programs.

Recruiting and retaining participants in an exercise program is not easy. As indicated by the group sample sizes in Table 2, there was a large variability in the number of participants engaged in each intervention. Some studies had less than 10 participants in each of their experimental and control groups (Barry et al., 1966; Whitehurst, 1991). Other researchers retained over 100 participants across experimental and comparison groups (Hill et al., 1993; Klusmann et al., 2010; Kramer et al., 2001). Studies with very small sample sizes recruited from a limited pool may not have results which can be generalised to other similar-aged populations.

Table 2. Characteristics of Intervention Studies

Smallest *n* per group	No.	Age at Baseline (y)	No.[a]	Duration of Intervention	No.	Aerobic Exercise	No.	Comparison Group(s)	No.[a]	Domain(s) Assessed	No.[a]
≤10	3	≤20	4	≤1 mo	1	Mixed aerobic	15	No exercise	21	PM	21
>10 – 20	15	>20 – 40	9	>1 – 3 mo	13	Walk/jog	11	Stretch + tone	7	WM	16
>20 – 30	9	>40 – 60	14	>3 – 6 mo	15	Aerobic + strength	5	Mental / cognitive	6	EM	13
>30	11	>60 – 80	34	>6 – <12mo	2	Aquatics	3	Education	4	E	20
		>80	14	≥1 year	7	Exercycle	1	Strength + stretch	3	AK	2
						Aerobic + mental/ cognitive	1	Low intensity	1	VS	4
						Program NR	2	No comparison group	5	G	5

Note. No.= a count of the number of studies described by each characteristic subcategory, *n* = sample size, NR = not reported, PM = perceptual motor performance (tasks which assess information processing speed with a simple behavioural response), WM = working memory (tasks requiring short-term rehearsal and manipulation of information), EM = episodic memory (tests assessing declarative recall or recognition of verbal or visual information), E = executive function (tasks requiring strategy development, set shifting, reasoning, problem solving, verbal and visual fluency, interference control, response inhibition and/or conflict resolution), AK = acquired knowledge (tests of semantic knowledge, vocabulary, and general information), VS = visuospatial ability, G = global cognitive function composite score.

[a] Multiple choices were allowed for Age at Baseline, Comparison Group(s) and Domain(s) Assessed.

Despite a relatively large sample size in Kramer et al. (2001), 30% of the original recruited sample attrited and this is not an atypical rate. Attrition is a major challenge for exercise research. Are the participants who endure somehow different than those who attrite (i.e. motivation level, level of interest in personal health, involvement in other lifestyle behaviours) and are the results representative of the general population? Means of keeping participants motivated must be an integral part of the exercise programs.

Durations of the reported interventions were most often between 3 and 6 months. Fifteen studies reported interventions of 3-6 months, while 13 studies employed interventions lasting 1-3 months (Table 2). Fewer studies used programs which continued longer than 6 months probably due to the difficulty of keeping participants motivated.

Although the studies chosen for review all had an exercise intervention with an aerobic component, the nature of the aerobic exercise varied greatly. Aerobic activity varied from walking, exercycling, running, aquatics, calisthenics to Nordic walking. Walk/jog programs seemed to be popular particularly among studies using older aged participants – 11 studies used this medium (Table 2). Aquatics and exercycling were less popular (3 studies and 1 study, respectively) probably given the need for specialised facilities. Few researchers decided to utilise aerobic components alongside strength exercises (Okumiya et al., 1996; Taylor-Piliae et al., 2010) or with multi-tasking/coordination activities (Marmeleira et al., 2009).

Although intervention studies can be powerful because they can prescribe very specific types of activity and report their distinctive effects on cognitive function, the level of detail provided on these programs varied. Some studies used very clearly defined aerobic activity with intensity levels prescribed using a set percentage of maximal oxygen uptake (VO_{2max}) or maximal heart rate (HR_{max}) (Dustman et al., 1984; Kramer et al., 2001; Sanna Stroth et al., 2010). Other researchers used mixed aerobic programs which included combinations of aerobic, flexibility, muscle endurance and coordination exercises with very little detail on the program followed (Elsayed et al., 1980; Oswald et al., 2006). Having a variety of activities would be beneficial in keeping participants motivated and possibly reduce attrition. However, clear detail of programming would allow study replication and provide evidence for the nature of aerobic activity which is most effective for improving cognitive function.

Only a few studies have specifically studied the effect of aerobic exercise intensity on cognitive performance. Stevenson & Topp (1990) reported the effects of low intensity aerobic versus high intensity aerobic exercise. However, the two groups were said to show similar increases in aerobic fitness and composite memory scores. Ruscheweyh

et al. (2009) also reported on changes in memory resulting from participation in one of three interventions: Nordic walking (moderate intensity), stretching/toning (low intensity), and controls (no exercise). Although there was no effect of group assignment on word recall, increase in self-reported physical activity was associated with improved memory across the entire cohort. Further studies are needed to compare contrasting intensities of exercise against a control group for any conclusions to be made.

Another point of difference among the studies reviewed is the use of a control or comparison group. The powerful nature of intervention studies rests on being able to carefully control the experience of the experimental group and compare that to individuals not receiving the treatment. However, five of the reviewed studies only utilised a single group pre-post design with no control (Carral & Perez, 2007; El-Naggar, 1986; Elsayed et al., 1980; Stacey et al., 1985; Young, 1979) (Table 2 and Appendix B). Without a control group it cannot be concluded that any positive effects came from exercise alone, but may be due to practice effects or other nebulous effects from taking part in a research study (e.g. social interaction with other participants or the researcher).

Most control groups received no treatment (21 studies). Other studies employed comparison groups based on health education or “mental” activity programs. Providing a non-exercise group which still receives an intervention of some sort may allow the participants in both groups to receive similar amounts of attention/feedback. The difficulty is how to treat the comparison groups. One example is a study by Klusmann et al. (2010) who compared an aerobic training group with a computer training group and a non-trained control group. Results showed that both exercise and computer trained groups improved episodic memory compared to no change for controls. Given that the computer education course included so-called “memory tasks”, it is not surprising that memory function improved over time for this group. What is interesting, however, is that the physical activity also benefitted episodic memory for stories and for words. One might argue that any improvements in cognitive function may be due to the social interaction inherent in participating in either of the trained groups. However, the computer intervention was not a “social activity control group” but a cognitive training group. Thus, the results could indicate that the exercise and computer interventions benefitted memory through “stimulating and social” activities, or different aspects of exercise and computer education each contributed to improved memory function.

Other comparison groups were based on stretch/tone programs including flexibility exercises, Yoga, or Tai Chi. Many of the stretch/tone programs had intensity levels

prescribed to ensure participants kept below a threshold which would improve aerobic fitness. This design is useful for determining whether improvements in cognitive performance are a function of *any* physical movement or of aerobic activity in particular.

For ease of evaluation, neuropsychological instruments were again grouped into the following domains: PM (perceptual motor performance), WM (working memory), EM (episodic memory), E (executive functions), AK (acquired knowledge), VS (visuospatial ability), and G (global cognition score). The method of these groupings is outlined in the legends for Table 2 and Appendix B. Similar to the epidemiological literature reviewed in Section 1.3.1, there were a growing number of instruments used in a growing number of intervention studies in this field. Instruments assessing perceptual motor performance (tasks categorised as those which assess information processing speed with a simple behavioural response) were the most frequently assessed. Executive function, working memory and episodic memory were the next most popular domains studied.

Twenty-three different instruments were used to assess executive function, ten for working memory and another eleven designed to assess episodic memory (Appendix B). Interpretation is difficult enough with such a large number of instruments each with individual task requirements. However, there are also instances of studies using tests which are not detailed in the publication nor found in common texts of neuropsychological assessment (El-Naggar, 1986; Ismail & El-Naggar, 1981). Having clear protocols using validated tests is important to ensure the robustness of results in this field.

Similar to epidemiological studies, the large majority of instruments employed to assess executive function in intervention studies were speeded (e.g. Stroop, Trail Making, Eriksen Flanker, Task Switching). These tests might have been chosen for time-saving reasons or it might be that effects of exercise were only observed for executive control tasks under the added stress of speed. Future research should utilise non-speeded executive function tasks to further elucidate these effects.

1.3.2.1 Meta-analyses of intervention studies

There are no firm conclusions which can be drawn at this stage, as there is still disagreement in the literature regarding the benefits of an exercise program on specific cognitive processes. Inconsistencies in results may be due to a number of factors: differences in the physical activity type, time, and intensity; differences in the nature of the comparison group; duration of the intervention; neuropsychological tests utilised; and participant characteristics including high versus low physical function and demographics such as age, gender, cultural group, socioeconomic status, and

education level. As such, meta-analyses have been published in an attempt to quantify the effect of physical activity on domains of cognitive performance.

A meta-analysis by Colcombe & Kramer (2003) included effect sizes for eighteen randomised exercise intervention studies published between 1966 and 2001. Studies chosen for analysis were ones which compared outcomes of an aerobic exercise group and a control group for older adults aged between 55-80 years. Tasks were allocated to one of four categories: *speed* (i.e. requiring "low-level" neurological functioning such as simple reaction time), *visuospatial* (requiring the transforming or remembering of visual and spatial information), *controlled* (requiring some cognitive control such as choice reaction time), *executive* (requiring planning, inhibition and/or scheduling such as the Eriksen flanker task). Tasks were coded independently by two researchers and tasks could be coded into multiple categories. Although both groups improved between pretest and posttest, the control group's improvement was significantly less at about $^1/_8$ of a standard deviation than the exercise group's improvement ($^1/_2$ of a standard deviation). Training programs that were short (1-3 months) were as effective as those that were medium duration (4-6 months), but not as effective as longer programs (6+ months). Session times had to be at least 30 minutes in length to be beneficial. Colcombe & Kramer also reported that exercise had the greatest effect on *executive* processes compared to lesser effects for *speed* and or *visuospatial* tasks.

A more recent meta-analytic study has been conducted by Smith et al. (2010) of 29 studies representing data from 2,049 participants and 234 effect sizes. Studies chosen for analysis were selected according to the following inclusion criteria: randomised treatment allocation, mean age ≥ 18 years, duration of treatment > 1 month, inclusion of an aerobic exercise intervention group, training conducted under supervision, and inclusion of a non-aerobic control group. Studies were excluded if participants had been diagnosed with dementia or AD at baseline. Tasks were coded into the following categories: *attention and processing speed* (requiring sustained focus, selective concentration and rapid information processing), *executive function* (requiring planning, initiation, sequencing and monitoring of goal-directed behaviour), *working memory* (requiring short term storage and manipulation of information), and *declarative memory* (requiring retention, recollection and recognition of previously encountered information). Smith et al. reported more moderate but significant effects of exercise on *executive function, attention and processing speed* and *declarative memory.*

The discrepancy in the size of the effects between these meta-analyses is probably due to a number of differing methodological factors. Firstly, age inclusion criteria for participants differed. The participants in the meta-analysis by Smith et al. (2010) had a

mean age greater than 18 years. The actual age range of participants was 16-91 years. Combining all of these ages into effect size calculations may be problematic. Given that there are age-related declines in certain cognitive processes and that the effect sizes for each category were not adjusted for the relative ages of the participants, the combination of all ages into these calculations may not be appropriate. Colcombe and Kramer limited inclusion to those aged 55-80 years and further analysed overall effect size by age group (55-65 y, 66-70 y, and 71-80 y). This analysis is arguably more meaningful to describe benefits of exercise specific to each age group, but is of course less generalisable to other stages of adulthood.

Another reason for the discrepancy between effect sizes may be the inclusion of participants with varying co-morbid conditions. Colcombe and Kramer (2003) included clinical populations ranging from persons with depression or cardiopulmonary disorders through to individuals diagnosed with dementia or AD. Smith et al. (2010) included participants with conditions such as chronic fatigue, multiple sclerosis, fibromyalgia, hypertension and mild cognitive impairment. The inclusion of clinical populations in these analyses renders it impossible to generalise the findings to normal adult populations.

The differing effect sizes may also be related to the particular method of coding neuropsychological tests into categories or domains of cognition. Although Smith et al. (2010) provided a list of neuropsychological tests belonging to each domain, Colcombe and Kramer (2003) did not reference their method of coding.

In the end, these meta-analyses are based on several of the same studies. Thus, these meta-analyses do not resolve the inherent methodological problems of the studies on which they are based.

1.3.3 Summary of the literature for physical activity and cognition

Due to the varying types and quality of research designs, neuropsychological instruments and exercise interventions, the efficacy of aerobic activity for improving cognitive function is still in question. Research designs which compare exercise interventions against a control group are needed to allow hypotheses of causation to be tested.

Studies of participants who are of normal cognition during young and middle adulthood may be more generalisable and may contribute evidence for the possible prophylactic effects of exercise.

Further study of aerobic activity is needed. Detailed physical activity programs should be reported to allow an understanding of which aspects of exercise may be beneficial

to cognitive function. Future research should investigate the mode of aerobic activity which will best serve cognitive function by comparing programs with different workloads. This will provide the layperson with more specific guidelines for the use of aerobic activity to improve cognitive health.

Behavioural tests of cognitive function should be ones which have robust evidence to support their reliability and validity, have large standardisation samples, have ecological validity and which are supported for use by clinicians.

1.4 Mechanisms for building cognitive reserve

The potential for physical activity to improve cognitive function has instigated a growing number of studies investigating possible mechanisms through which physical activity may build cognitive reserve. Both direct neurophysiological adaptations and indirect pathways have been proposed as mediating factors.

1.4.1 Direct neurophysiological adaptations

The relationship between physical activity and enhanced cognitive function has been purported to be due to neurophysiological adaptations which putatively build brain reserve and cognitive reserve. Recent cross sectional, prospective and experimental studies have reported that physical activity engagement is associated with increased grey matter and white matter volumes particularly for frontal and temporal regions (Colcombe et al., 2006; Erickson et al., 2010; Rovio et al., 2010). Other investigations using ERP (event related potentials) and fMRI (functional magnetic resonance imaging) have suggested that differing patterns of neural activation between physically active and sedentary individuals may be reflected in more effective and efficient cognitive performance (Colcombe et al., 2004; Hillman, Belopolsky, Snook, Kramer, & McAuley, 2004; Kamijo, Takeda, & Hillman, 2011). These adaptations are thought to be largely driven by exercise-induced expression of a number of neurotrophic factors. One of these, brain-derived neurotrophic factor (BDNF), has been shown to promote neurogenesis and synaptogenesis (and slow neuronal apoptosis) while improving transmission properties at selective synapses (Cotman & Berchtold, 2002; Kim et al., 2010; Vaynman & Gomez-Pinilla, 2006; Vaynman, Ying, & Gomez-Pinilla, 2004).

1.4.2 Indirect mediators

Alongside direct mechanisms, a number of potential indirect factors have been proposed to mediate the effect of physical activity on cognitive performance including: “physical resources” (e.g. more effective sleep, greater energy, better appetite/nutrition, reduced pain, reduced medication usage); “disease states” (e.g. reduction of hypertension, diabetes, cardiovascular and cerebrovascular diseases), and

"mental resources" (e.g. reduced chronic stress, reduced depression, enhanced self-efficacy) (Spirduso, Poon, & Chodzko-Zajko, 2008). The current study aimed to further investigate the cardiovascular pathway which is depicted in the adapted cognitive reserve model shown in Figure 2.

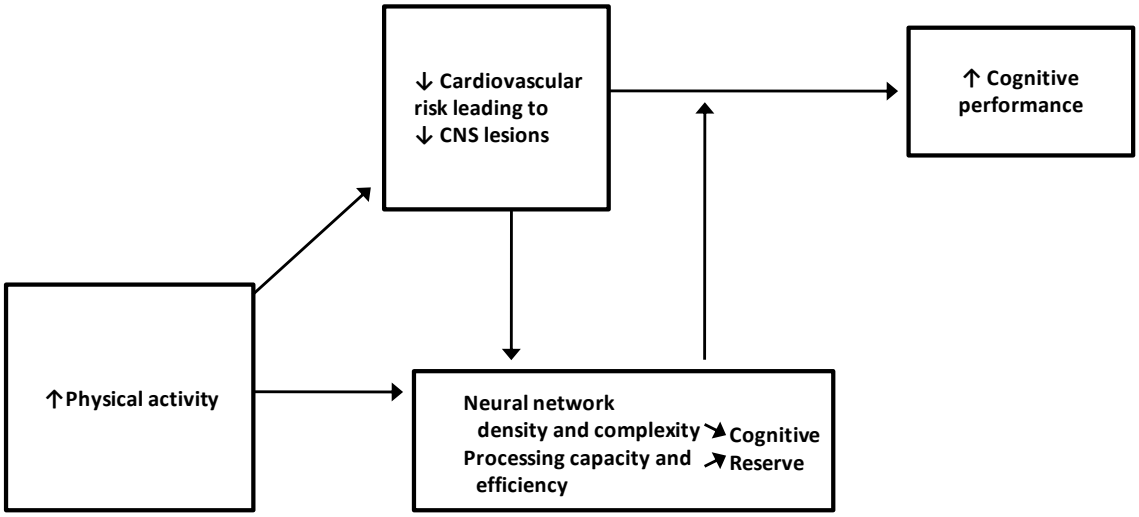

Figure 2. An adapted cognitive reserve model for physical activity.

1.4.2.1 Physical activity and cardiovascular adaptations

Cardiovascular disease has been estimated to account for a large proportion of New Zealand's burden of disease (approximately 35%) with the relative share of burden increasing with age (Ministry of Health NZ, 2001). Risk factors for cardiovascular disease are also those which impact on cerebrovascular, neuronal and white matter integrity with resulting effects on cognitive reserve and performance (Alagiakrishnan, McCracken, & Feldman, 2006; Deary et al., 2009; Taylor & MacQueen, 2007). It is thought that cardiovascular disease predisposes individuals to cognitive impairment through cerebral hypoperfusion due to atherosclerotic lesions, cerebral microvasculature damage, or even small infarcts due to emboli (Deary et al., 2009).

Optimising systolic and diastolic blood pressure, cholesterol profiles and blood glucose utilisation has been shown to be important for maintaining cognitive performance across perceptual motor, memory and executive function domains (Abbatecola et al., 2004; M. G. Dik et al., 2007; Hakamada-Taguchi, Uehara, Haebara, Negoro, & Toyo-oka, 2002; Knopman, Mosley, Catellier, & Coker, 2009; Reinprecht, Elmstahl, Janzon, &

Andre-Petersson, 2003). Therefore effective management of cardiovascular risk in New Zealanders may have flow-on effects for the cognitive health of the ageing population.

Substantive evidence exists to support the use of physical activity for reducing cardiovascular risk by controlling excess body weight, reducing blood pressure, improving cholesterol profiles, and maintaining blood glucose control (World Health Organization, 2004). Recent literature has posited that reducing sitting time by merely increasing habitual or non-exercise physical activity can reduce cardiovascular risk over and above the benefits conferred by other planned physical activity (Hamilton, Hamilton, & Zderic, 2007; Healy et al., 2008).

As physical activity reduces risk of vascular disease then it may also protect existing neurological integrity and afford the necessary perfusion to optimise further neurogenesis and/or synaptogenesis. In this way, physical activity effects on cognitive performance may be mediated by reductions in cardiovascular risk. And, more importantly, physical activity may selectively benefit the growing number of adults who have higher risk of cardiovascular disease.

1.5 The workplace as a vehicle for physical activity

Physical activity participation rates in New Zealand are low. According to the 2006/07 New Zealand Health Survey, only half of New Zealand adults meet the definition of being regularly physically active, that is participating in at least 30 minutes of physical activity per day on five or more days of the week (Ministry of Health NZ, 2008). One in seven adults (15%) are sedentary, reporting less than 30 minutes of activity per week (Ministry of Health NZ, 2008).

Limited adoption and maintenance of physical activity may be partially explained by a failure to alter the environments in which people live and work (S. L. Booth et al., 2001). The workplace could be an effective vehicle for improving physical activity levels particularly for middle aged adults who spend most of their daytime hours at work. By structuring the workplace to include opportunities for physical activity, common barriers to participation can be removed. A study of 1,232 physically inactive Australian adults aged between 18 to 78 years found that 50% of the sample felt “insufficient time” was the greatest barrier to physical activity participation (M. L. Booth, Bauman, Owen, & Gore, 1997). Over 30% of the respondents cited “wanting to exercise in a group”. Workplace physical activity programs can make participation convenient and easily accessible, with plenty of social support for activity.

A recent meta-analysis of the effectiveness of workplace interventions for increasing levels of physical activity was conducted by Conn, Hafdahl, Cooper, Brown, & Lusk

(2009). Including 71 reports and 24,520 participants, a significantly positive but modest effect size of 0.21 was observed in favour of the interventions on physical activity behaviour. Interventions provided for employees during and/or around work schedules were more effective than those provided outside of the workplace (Conn et al., 2009).

Workplace physical activity programs must be convenient, give maximum benefit for limited time away from the desk, be motivating and be supported by both employees and managers.

1.5.1 Physical activity programs

The Official 10,000 Steps® program is a popular pedometer-based walking program developed for use both in the community and in the workplace (Mummery, Schofield, Hinchliffe, Joyner, & Brown, 2006). Participants in this program are encouraged to increase habitual activity levels with a goal of 10,000 steps per day. Inherent to this program are team-based challenges for social support and an interactive website platform for setting individual and team goals. Pedometer-based programs are thought to be effective by allowing real-time feedback of accumulated steps. This feedback increases awareness of physical activity levels and is thought to motivate goal-setting for behaviour change throughout the day. The threshold of 10,000 steps per day has been considered to represent an "active" lifestyle (Tudor-Locke & Bassett, 2004). A systematic review of the effectiveness of pedometer interventions was recently conducted by Bravata et al. (2007). The authors reviewed 26 studies (eight randomised controlled trials, 18 observational studies) with a total of 2,767 participants (mean age = 49 y) involved in a pedometer-based program (mean duration of 18 weeks). Bravata et al. concluded that pedometer users increased physical activity levels by 26.9% over baseline and significantly decreased body mass index by 0.38 kg/m^2 and systolic blood pressure by 3.8 mmHg. Due to its well-developed formulaic workplace program, its focus on habitual low intensity activity (walking), and evidence supporting its use to improve indices of cardiovascular function, the 10,000 Steps® program was adopted for use in the main study. Further details on its protocol are provided in Chapter 3 (Section 3.3.4.1).

The second workplace program used in the main study was based on high intensity exercycling. The LifeSprints® program is a 30-minute high intensity intermittent exercycling program, developed by Australians Trapp, Chisholm & Boutcher (2007). The protocol is based on repeated shifts through sprint (8 sec) and recovery (12 sec) phases for a twenty minute duration (plus warm-up and cool-down periods). The LifeSprints® music track accompanies participants through the protocol with faster and slower rhythms guiding the shifts in speeded intervals. This protocol has been shown

to be effective for producing an acute physiological response characteristic of vigorous exercise with increased blood lactate and catecholamine levels (Trapp, Chisholm, & Boutcher, 2007). The intermittent nature also allows low-active individuals to exercise at a much higher intensity than could be sustained for steady-state exercise (McArdle, Katch, & Katch, 2006). The use of this protocol in a training program has been shown to be effective for producing significant increases in maximal oxygen uptake and decreases in total body mass, fat mass and central abdominal fat (Trapp, Chisholm, Freund, & Boutcher, 2008). The LifeSprints® protocol was chosen as the foundation for developing a workplace-based intervention as it is highly vigorous in nature, can be completed in 30 minutes, and has a formulaic program to follow. The pilot study was employed to test the feasibility of incorporating LifeSprints® into a workplace exercise program. Feedback from pilot study participants would be used to determine its utility and to further develop the program for use in the main study of the thesis.

1.6 Summary of literature and directions for research

Physical activity has been purported to be an accessible and effective way to build cognitive reserve and enhance cognitive performance, particularly in older age. There is a dearth of studies investigating the effect of physical activity on cognitive performance in middle age. Therefore good quality research is required, using robust neuropsychological instruments, to test domains of cognition which are most affected by ageing.

It is unclear whether the benefits to cognitive function result from having a more active lifestyle or whether one must engage in specific types of physical activity. Investigating which mode(s) of activity would most benefit cognitive performance would allow for the development of guidelines for laypeople and their health practitioners.

A number of mechanisms have been argued to mediate the effect of physical activity on cognitive function. Regular exercise may enhance cognitive performance through off-setting the damaging effects of cardiovascular risk.

Physical activity participation rates for New Zealand adults are low. A workplace model may provide a vehicle for improving the physical activity levels of working-aged New Zealanders.

Therefore, the primary aim of this thesis was to investigate the effects of two contrasting workplace physical activity programs on memory and executive function in middle aged individuals. The studies within provide an important contribution for understanding the effects of physical activity specific to middle age, with careful

attention to providing two very different aerobic exercise programs. The secondary aim was to determine whether cardiovascular function contributes to changes in cognitive function. This thesis provides a unique perspective by investigating whether cardiovascular risk level moderates the degree of change in cognitive performance.

Chapter 2. A feasibility study of a workplace exercycle program (Study 1)

2.1 Introduction

Based on a review of the existing literature (Chapter 1), there is sufficient evidence to suggest that physical activity may improve cognitive function. However, there were relatively fewer instances of studies based on middle age with insufficient detail on the nature of activity required to benefit cognitive performance. Furthermore, the mechanisms explaining the effects of physical activity on cognitive reserve and performance remain undetermined. Thus this thesis was designed to address these gaps in the current literature. Given that aerobic-type activity has been indicated for improving both cardiovascular health and cognitive performance, employing two contrasting types of aerobic activity may help to elucidate the nature of activity which would be most beneficial. The 10,000 Steps® program provided a well-developed intervention for improving habitual (walking) activity both in the community and the workplace. The LifeSprints® protocol, as described in Chapter 1 (Section 1.5.1), had the potential to provide a contrasting program to 10,000 Steps® by being highly vigorous in nature and by having a formulaic program to follow which could suit the workplace environment. However, prior to LifeSprints' inclusion in the main study with a large number of participants, the protocol needed to be tested for feasibility. It was important to determine how sedentary individuals would accept the vigorous nature of this protocol and their capacity to improve physical activity level over time. It was also necessary to ensure that participants would comply with incorporating the activity around working life. A small sample was deemed sufficient to meet the primary aim which was to determine the feasibility of the protocol for sedentary workers. Survey feedback from study participants was employed to determine the perceived utility of the protocol and to further develop the program for use in the main study of the thesis. This study also aimed to determine the effects of the program on indices of participant physical activity and cardiovascular health.

2.2 Research design

The feasibility study was a single group pre-post investigation. Primary outcome data on cardiovascular health factors were collected immediately prior to and again upon completion of the 6-week exercise intervention. Post-intervention, participant satisfaction with the program and recommendations for improvement were determined through survey responses to both Likert scale-based and open-ended questions.

2.3 Methods

2.3.1 Participants

Volunteers were recruited from Auckland University of Technology (AUT). To be deemed eligible for the study volunteers had to be aged over 40 years, in good general health, presently employed at AUT, and not meeting New Zealand recommended guidelines for physical activity (i.e. less than 30 minutes of moderate-vigorous activity most days of the week). Thirty individuals who volunteered were prescreened through a scripted phone interview. Prescreening information was recorded as shown in Appendix C. The demographic information collected included: gender, date of birth, ethnicity, occupation, smoking status and recreational drug use. Volunteers were asked to think about the previous month and report the average number of minutes per week they were involved in moderate-vigorous aerobic activity (i.e. whole body physical activity which consistently raised heart rate and caused sweating). The participants were then asked to describe these activities (including both leisure and occupational activities). A health history was taken including volunteers' use of prescribed medication. The exclusion criteria for Study 1 are shown in Table 3.

Table 3. Exclusion Criteria for Study 1

Exclusion criteria
• Regular engagement in moderate-vigorous activity for 30 minutes or more at least three days of the week
• History of chest pain or dizziness during exercise
• History of brain injury
• Medical diagnosis and/or treatment of: hypertension, neurological disease, psychological disorder, diabetes, infection, cardiovascular or respiratory disorders that would pose a risk during exercise, or any other existing chronic illness or injury which would preclude safe exercise participation
• Medications (prescribed or not) for the above conditions or steroid-based compounds
• Use of recreational drugs
• Uncorrected visual or hearing impairment

Five females who met the inclusion criteria were recruited for the study. Given budget limitations and a proof-of-concept-type design, a small sample was deemed sufficient to meet the aims of the study. Participants were all female non-smokers who identified themselves as either Pakeha or of European descent. The mean age of participants was 54.2 ± 6.1 years (range 45-61 y). Occupations of the volunteers included: lecturer (3), administrative support (1), and manager (1). All participants completed the physical activity intervention and posttest assessments.

2.3.2 Pretest measures - cardiovascular function

Dependent variables chosen to measure cardiovascular function are shown in Table 4. Body weight (kg) was determined using a Seca scale and height (m) employing a stadiometer. Blood pressure (BP) (mmHg) was measured after 10 minutes of quiet sitting using a mercury-column sphygmomanometer.

Table 4. Dependent Variables for Cardiovascular Function

Cardiovascular function variables: abbreviations and units	
BMI (kg/m^2)	Body Mass Index = weight (kg) / (height (m))^2
SBP (mmHg)	Systolic Blood Pressure
DBP (mmHg)	Diastolic Blood Pressure
TC:HDL [a]	Total Cholesterol: High Density Lipoprotein ratio
TRG [a] (mmol/L)	Triglycerides
GLU [a] (mmol/L)	Glucose

[a] Based on fasting whole blood capillary samples.

Finger-prick capillary blood samples were collected and analysed at the worksite using the Cholestech LDX® point-of-care analyser (Cholestech Corporation, Hayward, CA). On each day of testing an optics check was conducted with a dedicated calibration cassette. Participants were asked to ingest no food and have only water to drink after midnight the day of testing. The fingertip to be sampled was carefully wiped with alcohol to avoid contamination and to remove the presence of soaps/lotions which could falsely elevate sample triglycerides. The finger was pricked with a disposable lancet and the first drop of blood wiped with gauze to remove any excess tissue fluid from the sample. Using a heparin-coated capillary tube, 35 µl of capillary blood was collected. A disposable plunger was used to dispense the blood sample from the capillary tube into the testing well on a disposable Cholestech LDX® Lipid Profile-GLU cassette. The Cholestech LDX® analyser provided immediate on-site results which were made available to each participant.

2.3.3 Workplace physical activity intervention

The 6-week intervention employed was a high intensity intermittent exercycle protocol called LifeSprints® developed at the University of New South Wales (Trapp et al., 2007) (see Chapter 1, Section 1.5.1 for background on this protocol).

Exercycle sessions were 30 minutes in length and conducted three times per week at AUT University during the lunch hour. All exercycle classes were supervised by an

instructor who led each session, took attendance, provided information to participants on safe exercise practice, monitored participants and provided motivational prompts. Each session began with a warm-up period of 5 minutes of easy cycling (Cateye® EC1200 exercise bikes). Participants then performed 20 minutes of high intensity intermittent cycling, with alternating 8-second sprint and 12-second recovery phases. Volunteers were instructed to cycle as hard as possible during the sprint phase and then cycle as slowly as possible during the recovery phase. Participants were instructed to use the Rating of Perceived Exertion Scale and maintain perceived exertion between 13-15 ("somewhat hard" to "hard") overall. This exertion level has been reported to approximate 70 % HR_{max}, with exercise feeling difficult but still just able to carry on a conversation (McArdle et al., 2006). At the beginning of the training period, participants were able to start with as little as 5 minutes of this high intensity period of the workout and gradually increase that time to a maximum of 20 minutes. The volunteers finished each session with 5 minutes of cool-down consisting of slow cycling. At the completion of each session, the number of calories expended was recorded from the bike's digital display into personalised diaries.

2.3.4 Posttest measures

All pretest measures of cardiovascular function were repeated.

Participants completed a Participant Satisfaction Survey which consisted of both quantitative (Likert scale) and qualitative (open-ended) questions to assess the perceived advantages of the program and to identify any areas for improvement (Appendix D).

2.3.5 Data analysis

Program compliance was determined by calculating the percent of sessions attended. Change in workload across the sessions was determined using the percent change in calories expended during a session. Percent change in calories expended was calculated by comparing the mean caloric expenditure of the first three sessions to that of the final three sessions.

To determine if cardiovascular function improved postintervention, paired sample *t*-tests were used to analyse changes over time for the following dependent variables: BMI (kg/m^2), systolic and diastolic BP (mmHg), TC:HDL, TRG and GLU (mmol/L).

To determine the feasibility of using LifeSprints® in the main study, verbatim comments from the Participant Satisfaction Survey were collated for a qualitative analysis of satisfaction with the program. The number of respondents circling each choice was also determined for each scale-based question of the survey.

2.4 Results

2.4.1 Physical activity behaviour

Exercise session attendance rate averaged 70% (range 50-94%).

The mean caloric expenditure of an individual's first three sessions was calculated and compared with the mean of their final three sessions. Mean caloric expenditure improved on average by 42% (range 11-82%). A paired sample *t*-test confirmed the statistical significance of the change in physical activity level from pretest to posttest ($t_{(4)} = -3.700$, $p = .021$, two-tailed).

2.4.2 Cardiovascular function

At baseline, participants were within optimal ranges for fasting TC:HDL, triglycerides and glucose. Participant results alongside optimal ranges are shown in Table 5. Participants were slightly outside of the desirable ranges for BMI and blood pressure. The results of paired sample *t*-tests indicated no significant effect of the intervention on any of the cardiovascular variables analysed (all $p > .05$, two-tailed).

Table 5. Comparison of Pretest and Posttest Cardiovascular Measures

	Optimal range		Mean ± SD	$t_{(4)}$	*p*
BMI (kg/m^2)	18.5-25	Pre	27.9 ± 8.4		
		Post	27.6 ± 8.1	.884	.427
SBP (mmHg)	≤120	Pre	127.8 ± 9.0		
		Post	130.2 ± 5.3	-.528	.625
DBP (mmHg)	≤80	Pre	81.6 ± 9.1		
		Post	85.4 ± 5.1	-.993	.377
TC:HDL [a]	≤3.5	Pre	3.3 ± 0.9		
		Post	3.8 ± 1.2	-.473	.668
TRG[a] (mmol/L)	<1.7	Pre	0.9 ± 0.2		
		Post	1.0 ± 0.6	.026	.981
GLU[a] (mmol/L)	<5.6	Pre	5.4 ± 0.8		
		Post	5.4 ± 0.5	-.327	.765

Note. Dependent variables reported as mean ± standard deviation. Optimal ranges obtained from the Third Report of the National Cholesterol Education Program (NCEP) (National Institute of Health, 2001). *t* = paired samples *t*-test (two-tailed), BMI = body mass index, SBP = systolic blood pressure, DBP = diastolic blood pressure, TC:HDL = total cholesterol to high density lipoprotein ratio, TRG = triglycerides, GLU = glucose, Pre = pretest, Post = posttest.

[a] Based on fasting whole blood capillary samples.

2.4.3 Participant feedback

In response to Likert scale questions of the Participant Satisfaction Survey, all participants agreed that they had enjoyed the program (Table 6). All participants felt better about themselves and physically healthier for completing the program and 3 out of 5 participants agreed the program was convenient.

Table 6. Summary of Responses to Participant Satisfaction Survey

Question	**Number of responses**					
	Strongly Disagree (1)	Disagree (2)	Neither Agree/ Disagree (3)	Agree (4)	Strongly Agree (5)	Total
I feel better about myself for completing this program				2	3	5
I feel physically healthier for completing this program				1	4	5
This program was convenient to complete			2	2	1	5
I enjoyed participating in the program				3	2	5

Responses to open-ended questions indicated that participants enjoyed the group exercycling sessions, group camaraderie, short exercise sessions, instructor encouragement and support, ability to exercise at work in a dedicated space, commitment to a regular program, monitoring of progress and health, option of 3 out of 4 days to exercise, getting away from the desk and feeling “fitter” (see Appendix E for a summary of comments).

Participants disliked time away from the desk, time of the program (i.e. lunch hour), having less time to network with colleagues at lunch, at times having to do the hard physical exercise, uncomfortable bike seats and showering facilities.

Two participants reported no discomfort. Physical and psychological complaints included: minor muscle discomfort, fatigue, and concern about time absent from work.

Participants have made the following suggestions for improved satisfaction: more choice of times (including before and after work hours), a longer duration program (i.e. longer than 6 weeks), greater variety of music, and more ways to keep motivation levels high.

2.5 Discussion

LifeSprints® was used for the first time as a workplace intervention in this project. Given its vigorous nature, it was chosen as a protocol which could be further developed for use in the main study. For its development, it was deemed important to test the feasibility of incorporating the program into the workplace environment. It was also necessary to ensure that this program would be effective in increasing physical activity levels while still being enjoyable and motivating for participants.

Physical activity level was determined by recording the estimated caloric expenditure after each session from the digital bike display. Through the use of personalised diaries, participants could track their progress in workload over the course of the program. When comparing the means of the first three sessions to those of the final three sessions, caloric expenditure increased on average by forty-two percent. The range of change in expenditure was eleven to eighty-two percent. Two participants, despite reporting low activity at baseline, were able to complete the entire 30 minute protocol at the first session and achieved much higher caloric expenditures than the other volunteers. As such, with each session limited to 30 minutes, caloric expenditures would show relatively less improvement over time for the two high-performers. It is significant, however, that the other three participants were able to increase their caloric expenditures by thirty-two percent, sixty-seven percent, and eighty-two percent respectively over a short 6-week period. It is also important to note that these three participants were older (58.0 y vs. 48.5 y) and had BMIs in the overweight/obese categories (32.2 kg/m^2 vs. 21.4 kg/m^2). Therefore, this somewhat short, but intense, program was able to increase physical activity workload for participants, particularly those who may have been less “fit” to begin with.

It had been decided not to assess baseline “fitness” levels by measuring maximal oxygen uptake (VO_{2max}) for a number of reasons. Firstly, VO_{2max} is affected not only by “training state” but also by age, gender, heredity, body mass and composition, and exercise mode (McArdle et al., 2006). Therefore, baseline VO_{2max} would not necessarily confirm initial fitness levels. Secondly, the measurement of direct or predicted VO_{2max} requires considerable motivation on the part of sedentary participants to reach the necessary workloads (McArdle et al., 2006). Recruiting and keeping participants in the

study partly depended on having a non-threatening exercise environment – measuring VO_{2max} could be considered daunting to unfit or overweight individuals.

Improved physical activity level did not translate to improved cardiovascular function. There were no significant changes over time to any of the risk factors measured. Although somewhat disappointing for participants, these results were not unexpected from such a short duration exercise program. Adaptations to aerobic training usually occur with exercise performed at least three times per week for at least six weeks (McArdle et al., 2006). When the LifeSprints® protocol was utilised previously in a 15-week intervention, physiological adaptations were reported to have occurred. Trapp et al. (2008) reported that, compared to steady state exercise or no exercise, the LifeSprints® group demonstrated significant improvements in total body mass, fat mass, trunk fat and fasting insulin levels. Although the outcomes of interest were different than in the pilot study, it is expected that if the exercycle intervention were extended there would be similar changes in cardiovascular risk factors.

The absence of change in cardiovascular health over time could be due to not reaching a sufficient workload during exercise. A limitation of this study is that workload and/or heart rates were not recorded throughout the session. During steady-state exercise, $\%HR_{max}$ (% maximum heart rate) can be easily monitored. However, for the exercycle protocol, heart rates fluctuate concurrently with each of the 60 sprint and recovery cycles, making it difficult for participants to monitor. And, although the power (Watts) could be prescribed based on $\%VO_{2max}$, each sprint phase lasts only 8 seconds. As this limitation is difficult to overcome without changing the protocol, participants were instead instructed to cycle “as hard as possible” during the sprint phase and “as slowly as possible” during the recovery phase. They were given the additional instruction to determine their overall perception of exertion, using the Borg Rating of Perceived Exertion Scale level 13-15 (“somewhat hard” to “hard”). Evidence has shown that 13-15 on this scale is consistent with 70% HR_{max} – moderately vigorous activity (McArdle et al., 2006). A benefit of this method is that participants acquire the ability to monitor their own levels of exertion and fatigue instead of relying on technology.

The primary aim of this study was to determine the feasibility and acceptance of this protocol as a workplace intervention. To this end, the Participant Satisfaction Survey responses would be the most important evidence to further develop this program for the main study of the thesis. Participants reported that they enjoyed the exercycle protocol and felt better about themselves and their health for completing the program. Participants appreciated the ability to attend exercise sessions at their workplace and with their workmates. However, convenience was considered a short-coming of the intervention. Although participants were given the choice of 3 out of 4

weekdays to attend, all sessions were scheduled during the lunch hour. With such a small sample, it was preferable to have all participants attend at the same time for social support. Indeed, the group camaraderie contributed greatly to the success of the program. However, trying to fit exercise and lunch into the middle of a busy day was stressful for three of the volunteers. In response to this feedback, there will be more choice of session times available (e.g. before and after work) in the main study. Exercisers generally felt safe and supported by the exercise instructor and did not report any major physical or psychological complaints. For the main study, exercise sessions will continue to be supervised by an instructor. Participants also reported occasional boredom with the music track accompanying the protocol and therefore, for the main study, sessions will be accompanied by music videos projected onto a large screen with an embedded timer to guide speeded intervals. In order to keep motivation levels high and build social support, both individual- and team-based competitions will be developed for the program.

In summary, although there were a few recommendations for improvement, participants generally reported high satisfaction with the program at their worksite. With increased duration to 16 weeks and further development of the supporting features of the program, both enjoyment and physiological improvements are expected.

Chapter 3. Enhancing cognitive performance through physical activity (Study 2)

3.1 Introduction

Study 2 constituted the main study of the thesis. Evidence suggests that physical activity can improve cognitive reserve and cognitive performance. However, conclusions are largely based on older (and sometimes clinical populations) with varying quality of designs and robustness of neuropsychological instruments. As such, this study was undertaken to investigate the effect of physical activity on cognitive performance specific to middle aged individuals. Aspects of episodic memory and executive function were chosen for assessment as these cognitive domains have been shown to be sensitive to age-related changes through middle age. The neuropsychological instruments chosen to measure episodic recall and set shifting were robust measures with high reliability, large standardisation samples, ecological validity and clinical support.

Previous research in this area often provided insufficient detail on the nature of physical activity which benefitted cognitive function. There is certainly a gap in the current knowledge base for understanding the most effective type of activity and for providing evidence-based programs which elicit positive effects. Therefore, the primary aim was unique in that it sought to compare the effects of two highly contrasting physical activity programs (walking versus vigorous exercycling) against a control group (no exercise) on episodic recall and set shifting in middle age.

Underlying mechanisms which explain the effect of physical activity on cognitive reserve and function are still not fully understood. The secondary aim of the thesis was to investigate whether cardiovascular function moderates changes in cognitive function. This aim was designed not only to advance the knowledge on these mechanisms, but also to determine if risk level would determine the degree of cognitive change - a unique and important contribution to the cognitive reserve literature, particularly given the rising incidence of cardiovascular disease in ageing adults.

3.2 Research design

Volunteers meeting the study criteria participated in one of three 16-week interventions: pedometer (10,000 Steps® pedometer-based walking program), exercycle (vigorous cycling program), or control (no physical activity program). The study employed a repeated measures approach with quantitative data collection

methods. Participants underwent baseline and posttest measures of cognitive performance and cardiovascular risk.

The pedometer and exercycle interventions were developed as workplace programs. To ensure the integrity of each intervention and minimise "mixed messages" being received by participants, only one intervention took place at any one physical worksite. It was not possible to find one employer in Auckland which could provide both multiple sites and numbers of employees who would meet our strict entry criteria. Therefore, a quasi-experimental approach was employed to assign participants to either the pedometer or exercycle groups based on workplace site selection. Two employers participated in the pedometer program and four employers participated in the exercycle program. All four worksites in the exercycle group were within short walking distance of AUT North Shore Campus where the exercise sessions were held.

Employers generally wanted to be involved in this research study only if all of their employees participating had access to an exercise program. Thus, to ensure sufficient uptake and support from employers, it was decided not to randomly assign half of the participants to a control group. Being a doctoral study, the research design was limited by both budget and time constraints – as such it was also not possible to place control participants on a waiting list and offer them the opportunity to take part in a workplace exercise program on completion of the study. Given these constraints, it was decided that control group participants would be recruited from the community with the provisos that they meet all inclusion criteria, be employed and not be involved in any workplace heath programs.

3.3 Methods

3.3.1 Participants

To be eligible for the study volunteers had to be aged over 40 years, in good general health, employed and not meeting New Zealand recommended guidelines for physical activity (i.e. less than 30 minutes of moderate-vigorous activity most days of the week). Volunteers were prescreened through a scripted phone interview. The demographic information gathered included: gender, date of birth, ethnicity, years of formal education, occupation, smoking status and recreational drug use. Volunteers were asked to report the average minutes per week involved in moderate-vigorous aerobic activity (i.e. whole body physical activity which raised heart rate and caused sweating). The participants were then asked to describe these activities (including both leisure and occupational activities). A health history was taken including the volunteers' use of prescribed medication. Exclusion criteria were the same as for Study 1 (see Table 3 Section 2.3.1). An extra exclusion criterion was added for Study 2;

participants with a university degree were excluded. Individuals who have attained a university degree may perform better on standard neuropsychological tests given the training they have received. Therefore, this criterion was put in place to ensure that participants' cognitive performance would be more generalisable to New Zealand's middle aged population.

One hundred and fifty-eight volunteers were phone screened for eligibility. Figure 3 depicts the flow of participants through the study. Seventy-nine individuals were excluded for not meeting inclusion criteria. The investigator had originally intended to recruit thirty participants for each intervention group which would ensure sufficient power to detect significant differences among the groups. Unfortunately, given the strict entry criteria and limited pool of volunteers from participating employers who met the criteria, the sample sizes were smaller than ideal. The nature of the physical activity programs was such that all participants of one program had to begin the intervention at the same time. Thus, staggered recruitment was not possible. Given time and budget constraints inherent in a doctoral project, running another round of interventions would also not be feasible. Despite the accepted limitation of a sample size which was less than ideal and in the interest of advancing the knowledge in this area using a "real world" intervention, the pragmatic decision was made to progress with the recruited sample.

The seventy-nine volunteers were assigned to one of three intervention groups and completed pretest procedures. Of the initial twenty-nine participants assigned to the pedometer group, one person did not complete the intervention program due to an unrelated injury. Of the initial twenty-four exercycle participants, four did not complete the program (one due to change in work schedule, two due to unrelated injury/illness, and one no reason given). All twenty-six control participants maintained their involvement in the study throughout the 16-week intervention period. At posttest, six further pedometer participants were lost to follow-up (five due to change to night shifts, one no reason given). One exercycle participant was lost to follow-up due to unexpected overseas work commitments. Five control group participants did not complete posttesting (one due to unrelated illness and four no reason given). Therefore, the sample available for analysis included: pedometer group (n = 22), exercycle group (n = 19), and control group (n = 21). Baseline characteristics of the final sample are summarised in Table 7.

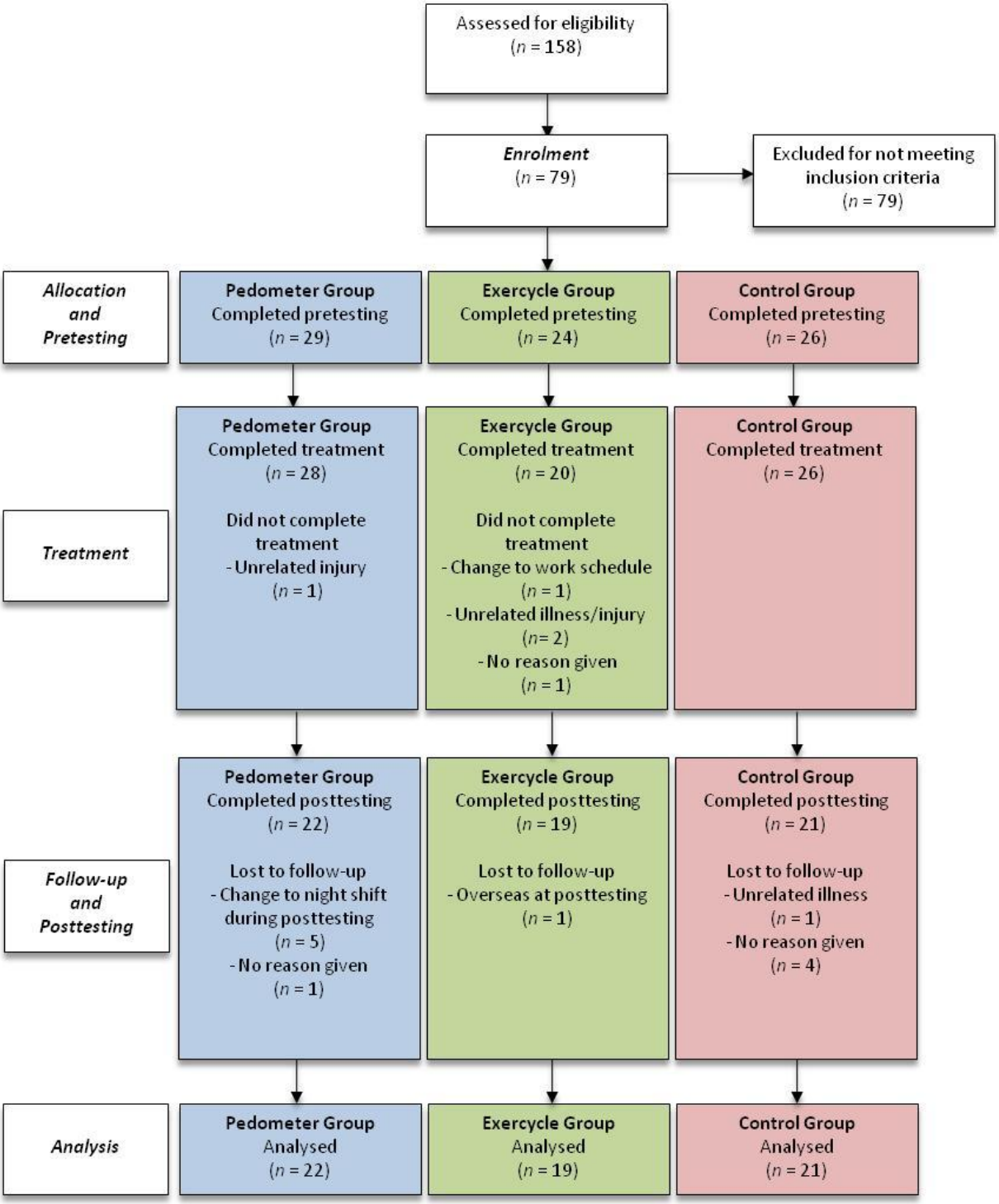

Figure 3. Flow diagram of participants throughout the study.

Table 7. Baseline Participant Characteristics

	Final sample (*N*=62)		
	Pedometer (*n*=22)	Exercycle (*n*=19)	Control (*n*=21)
Age (y)	51.9 ± 4.5	49.1 ± 7.9	53.0 ± 7.0
Education (y)	12.7 ± 1.9	12.7 ± 2.4	13.9 ± 2.2
WAIS VIQ[a]	107.5 ± 17.4	109.2 ± 14.5	113.3 ± 12.4
WAIS PIQ[b]	97.3 ± 16.3	98.9 ± 12.2	107.6 ± 13.1
WAIS FullIQ[c]	102.4 ± 15.6	104.1 ± 11.6	110.5 ± 9.2
Gender (% female)	82	95	76
Ethnicity (% total)			
-Pakeha/European	59	69	81
-Maori/Pacific	36	21	14
-Asian	5	5	0
-Indian	0	5	0
-Other	0	0	5

Note. Age, education, WAIS VIQ, PIQ and FullIQ are shown as mean ± SD.
[a] Estimated from Vocabulary subtest of the WAIS-III and adjusted for age. [b] Estimated from Block Design subtest of the WAIS-III and adjusted for age. [c] Calculated as the mean of VIQ and PIQ.

3.3.2 Measures of cognitive performance

Cognitive performance was assessed using a two-hour battery of standard neuropsychological tests routinely used for research and clinical purposes to assess cognitive functioning (Lezak, 1995; Mitrushina, Boone, Razani, & D'Elia, 2005). These tests operate by highly standardised protocols and have extensive normative data. Bashore, Osman, and Heffley (1989) have warned that failure to consider age-related slowing of response times in study designs using older individuals can result in extremely variable performance that does not accurately reflect the subjects' functional capacity. Therefore, the tests chosen for the current study were ones which did not depend on a speeded response, ameliorating any confounding effects of age-related slowing of response times. Primary outcome data were obtained for episodic recall and executive function (set shifting).

3.3.2.1 Cognitive performance - prescreening

The Wechsler Adult Intelligence Scale-III (WAIS-III) (Wechsler, 1997a) Vocabulary and Block Design subtests were employed as brief prescreening tools to ensure that recruited participants had no underlying cognitive impairment. The WAIS intelligence

scales are considered to be among the most reputable behavioural instruments for assessing cognitive potential (Kaufman & Lichtenberger, 1999). The WAIS-III Vocabulary subtest measures expressive word knowledge. For this test, the testee was shown a list of words. They were instructed to give the meaning of each word as the tester pointed to it. The Vocabulary subtest raw score was based on the accuracy of the definitions given. The WAIS-III Block Design subtest required subjects to arrange sets of blocks together in a way which matched patterns shown on accompanying cards. Nine possible patterns were presented, each increasing in difficulty. The Block Design subtest raw score was based on the accuracy of the design and the time to complete the pattern.

Subtest raw scores were translated to age-adjusted scaled scores based on normative data from 2,450 adults aged between 16-89 years (Wechsler, 1997a). Scaled scores have a mean of 10 and a standard deviation of 3.

Scaled scores were then transformed to a Vocabulary Index (used to represent Verbal IQ) and a Block Design Index (used to represent Performance IQ). Both Verbal IQ (VIQ) and Performance IQ (PIQ) have a mean of 100 and a standard deviation of 15. FullIQ was calculated as the mean of VIQ and PIQ. If a participant's FullIQ score fell more than two standard deviations below the normative mean, he/she was excluded from the study.

3.3.2.2 Cognitive performance - memory

The Wechsler Memory Scale Third Edition-Abbreviated (WMS-III-A) (Wechsler, 1997b) was employed to assess declarative episodic memory. The WMS-III-A is designed to provide a brief survey of auditory and visual memory abilities for immediate and delayed verbal recall (Wechsler, 1997b). The WMS-III-A was chosen for the study due to its highly standardised protocols, extensive normative data and low ceiling effects. The WMS-III-A is derived from a more comprehensive battery, the Wechsler Memory Scale-Third Edition which is much longer and provides very detailed measurements of specific memory abilities. The abbreviated format was chosen for this study as it would allow the researchers to determine whether changes in general memory indices were affected by physical activity in middle age. If these indices were found to be affected by exercise in the current study, then more extensive memory testing would be indicated for future study.

The WMS-III-A assesses auditory and visual memory abilities for immediate and delayed verbal recall using the Logical Memory (LM) and Family Picture (FP) subtests. For the LM subtest, the examinee listened to two different stories read by the examiner, and immediately after each story was asked to recall it from memory. The

examinee's score was based on the accuracy of his or her retelling of the stories. The record sheets were scored following a strict protocol. After a 25-35 minute delay the examinee was asked to recount each story again. Raw scores were determined for LM I (immediate recall) and LM II (delayed recall). For the FP subtest, the examinee was shown four different picture scenes. Each image was presented for ten seconds. Immediately after all four scenes had been displayed, the examinee was asked to remember which characters were in each scene, where they were positioned in the scene, and what they were doing. A strict protocol was followed by the tester for recording the testee's responses. After a 25-35 minute delay the testee was again asked to remember which characters were in each scene, where they were positioned in the scene, and what they were doing. Raw scores, based on the accuracy of recall, were determined for FP I (immediate recall) and FP II (delayed recall).

Raw scores for LM and FP I and II were translated to age-adjusted scaled scores based on normative data from 1,250 adults aged between 16-89 years (Wechsler, 1997b). Scaled scores have a mean of 10 and a standard deviation of 3.

3.3.2.3 Cognitive performance – executive function

Executive function (set shifting) was assessed using the Wisconsin Card Sorting Test (WCST) as first devised by Berg (1948) with further revisions described in Heaton, Chelune, Talley, Kay, & Curtiss (1993). The WCST was chosen for the current study as it is among the most frequently employed tests of frontal lobe executive function. Its validity has been supported by its clinical sensitivity to frontal lobe lesion and to normal age-related changes (Heaton et al., 1993; Rhodes, 2004; Stuss et al., 2000). Unlike many other measures of executive function, the WCST does not depend on a timed response and therefore is unlikely to be confounded by age-related changes in motor speed.

The WCST consists of four stimulus cards and 128 response cards that depict figures of varying forms (crosses, circles, triangles, or stars), colours (red, blue, yellow, or green) and numbers of figures (one, two, three, or four). Four stimulus cards were placed before the testee in left-to-right order: one red triangle, two green stars, three yellow crosses, and four blue circles. The testee was then handed a deck of 64 response cards and instructed to match each consecutive card from the deck with one of the four stimulus cards, whichever he or she thinks it matched. The testee was told only whether the response was right or wrong and was never told the correct sorting order (or category). Once the testee had made ten consecutive "correct" matches to the initial sorting principle (usually colour), the sorting principle was changed to form or number without warning. This required the testee to use the tester's feedback to develop a new sorting strategy. The WCST proceeded in this manner through up to six

shifts in set (sorting principle) among the three possible categories (colour, form and number).

The scores chosen as dependent variables were those which have been standardised for age and years of education (Heaton et al., 1993). Standardised scores have a mean of 100 and a standard deviation of 15. The most common error is a perseverative error, where the participant sorts according to a category no longer in effect. WCST scores and their abbreviations are listed with their descriptions in Table 8.

Table 8. Description of WCST Scores and their Abbreviations

WCST Score	**Description**
Perseverative Errors Score (**PE**)	Standard score based on the percent of total trials marked by errors which perseverated to previous category sorts. Higher scores represent fewer perseverative errors.
Nonperseverative Errors Score (**NPE**)	Standard score based on the percent of total trials marked by errors which did not perseverate to previous category sorts. Higher scores represent fewer of these errors.
Conceptual Level Responses Score (**CR**)	Standard score based on the percent of total trials marked by consecutive correct responses occurring in runs of three or more. Higher scores represent more conceptual level responses.

3.3.3 Measures of cardiovascular function

Assessment of cardiovascular function began by employing the measures and protocols used in Study 1 (i.e. BMI, SBP, DBP, TC:HDL, TRG and GLU) (see Table 4, Section 2.3.2.). A Framingham-based score sheet developed by D'Agostino et al. (2008) was used to obtain two additional scores for each participant based on direct measures listed in Table 4 - "CVD Risk (%)" (predicted 10-year risk of acquiring general cardiovascular disease) and "Heart Age (y)". D'Agostino and others (2008) derived these scores from a sex-specific multivariable risk factor algorithm incorporating the following covariates: gender, age, TC, HDL, systolic BP, antihypertensive medication use, current smoking status and diabetes status. Data were based on 8,491 Framingham participants aged 30 to 74 years (mean age = 49 y) with 4,522 women, all free of CVD at time of examination. CVD was defined as a composite of coronary heart disease (CHD) (coronary death, myocardial infarction, coronary insufficiency and angina), cerebrovascular events (ischaemic stroke, hemorrhagic stroke, and transient

ischaemic attack), peripheral artery disease (intermittent claudication), and heart failure. Scores for heart age truly represent "vascular age". Heart age was calculated by D'Agostino et al. (2008) as the age of a person with the same predicted CVD risk having risk factors in normal ranges.

Participants were given a written report of their health checks so that they were aware of their health status before beginning the intervention period of the study (Appendix F).

Participants were classified by cardiovascular (CV) risk level based on Framingham calculations for heart age. Participants were classified as high risk (Framingham heart age > chronological age) or low risk (heart age ≤ chronological age) independent of intervention group. Figure 4 depicts the relative differences between chronological age and heart age for participants in each of the categories.

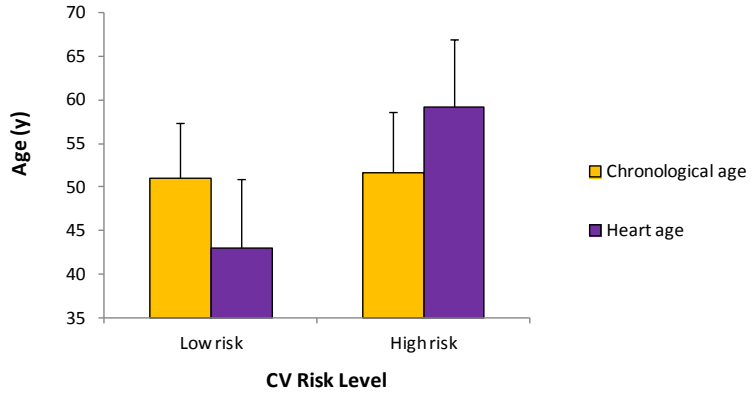

Figure 4. Chronological age versus heart age for low and high risk groups.
CV = cardiovascular.

The division of participants by comparing chronological age to Heart Age was chosen for a number of reasons. First, this index provided a composite measure of several known predictors of cardiovascular disease. Second, significant between-group differences were indicated for all of the relevant cardiovascular disease risk factors at baseline (all $p < .001$, two-tailed) (Table 9). Third, Heart Age could be compared to an individual's chronological age to provide an index of risk *relative* to age. Framingham's percent predicted risk of cardiovascular disease could have provided cut-off points for risk level (i.e. low risk < 10%, moderate risk 10-20%, severe risk > 20%). However, these percentage-based scores do not provide a measure of risk relative to an individual's age. As such, dividing along lines of percent risk would likely result in a comparison of older and younger individuals, rather than strictly high and low risk participants. Finally, it may have been preferable to split the sample into tertiles of risk and

compare the more extreme "lowest" and "highest" risk groups. However, given the strict exclusion of individuals who were on medications for cardiovascular disease, there were relatively few participants in a very high risk category. Therefore, the comparison of an individual's chronological age with Heart Age was decided to be the most informative determinant of relative risk which maximized inclusion of all participants for analysis.

Table 9. Cardiovascular Measures of Low and High Risk Groups at Baseline

		Cardiovascular Risk Level				
		Low Risk (n = 42)	High Risk (n = 19)	t		p
Age (y)	Pre	51.0 ± 6.4	51.7 ± 6.9	-0.405		.687
Heart Age (y)	Pre	43.0 ± 7.9	59.2 ± 7.8	-7.403	**	<.001
BMI (kg/m^2)	Pre	27.5 ± 4.7	31.5 ± 5.3	-2.949	**	.005
SBP (mmHg)	Pre	118.3 ± 10.1	129.3 ± 7.8	-4.229	**	<.001
DBP (mmHg)	Pre	73.4 ± 7.6	83.8 ± 5.4	-5.433	**	<.001
TC:HDL [a]	Pre	3.2 ± 0.9	4.7 ± 1.5	-4.027	**	<.001
TRG [a] (mmol/L)	Pre	1.0 ± 0.5	1.6 ± 0.7	-3.582	**	.001
GLU [a] (mmol/L)	Pre	4.9 ± 0.5	5.3 ± 0.7	-2.002	*	.050
Smoking Status (% Yes)		2.4%	21.1%			

Note. Dependent variables reported as mean ± standard deviation. t = independent samples t-test, SBP = systolic blood pressure, DBP = diastolic blood pressure, TC:HDL = total cholesterol to high density lipoprotein ratio, TRG = triglycerides, GLU = glucose, Pre = pretest.
[a] Based on fasting whole blood capillary samples.
* $p \leq .05$, ** $p < .01$.

3.3.4 Interventions

3.3.4.1 Pedometer program

Participants were instructed to increase habitual physical activity levels during a 16-week Official 10,000 Steps® pedometer-based program. The Official 10,000 Steps® program was adopted for the current study as it has already been developed for use as a workplace-driven team-based program utilising an interactive website platform for tracking physical activity (Mummery et al., 2006). Participants received a Yamax Digiwalker® pedometer (Yamax Corporation, Tokyo, Japan) and were instructed to wear the pedometer during all waking hours and to record the number of steps taken each day into a personalised diary provided to them. Volunteers were given a goal of reaching 10,000 steps per day and upon reaching 10,000 steps the goal was to "just do more". Participants were asked to form teams of four or five workmates to participate

in a virtual race around New Zealand. The Official 10,000 Steps® web-based program converts step counts to distance travelled around a New Zealand-based tour. Participants all had secure log-in access to the Official 10,000 Steps® webpage using aliases known only to the researcher and fellow team members to ensure that personal details would not be linked to physical activity data. The website provided information on the program and up-to-date calculations of team step counts and team distance (km) travelled around a New Zealand map. Each team chose a Step Captain who was responsible for recording weekly step counts on the website and providing leadership. All participants received weekly emails informing them of their team's progress around the race including tips for increasing physical activity levels.

3.3.4.2 Exercycle program

The exercycle protocol was based on the LifeSprints® program as described for Study 1 (Section 2.3.3) but extended in duration for 16 weeks. Participants were asked to attend a 30-minute exercycle class with their workmates three times per week at AUT University North Shore Campus. All exercycle classes were supervised by an instructor who led each session, took attendance, provided information to participants on safe exercise practice, monitored participants, provided motivational prompts and recorded the distance (km) each participant travelled. Participating workplaces were all within walking distance of the campus. Based on the participant feedback from the pilot study a greater number of session times were available during lunch hours and before and after work hours. Also, as a result of the Study 1 feedback, several changes to the program were made to increase participant motivation. Sessions were accompanied by a greater variety of music with accompanying videos projected onto a large screen. An embedded timer in one corner of the display guided the intermittent nature of the protocol and "counted down" the session. For each session attended, the distance (km) cycled was recorded into personalised diaries (see Appendix G for an exemplar page). Distance (km) was thought to be more meaningful for tracking progress and increasing motivation compared to caloric expenditure which was used in Study 1. As with the pedometer intervention, the exercycle program was adapted to be a team-based program to foster motivation and social support. Participants were asked to choose team-mates to form groups of four or five to compete in a virtual race around New Zealand. Weekly team distances were converted to distance around a New Zealand-based tour and plotted on a map (see Appendix H for an exemplar map). All participants received weekly emails informing them of their team's progress around the race and a map was displayed in the exercise room showing team locations.

3.3.4.3 Control group

Control group participants were asked to continue their usual physical activity throughout the 16-week intervention period.

3.3.5 Data analysis

Simple group statistics are shown as means ± standard deviations. All statistical significance levels were set at $p < .05$.

Pedometer participant compliance (%) was calculated by determining the percent of total weeks for which step counts were recorded. Percent change in step counts was calculated using the mean number of steps of the first three weeks and the mean number of steps of the final three weeks.

Exercycle participant attendance (% of total sessions attended) was determined. Percent change in distance travelled was calculated using the mean distance of the first three sessions and the mean distance of the final three sessions.

At pretesting, between-group one-way ANOVA with Bonferroni post-hoc analysis was employed to determine any baseline differences among groups (pedometer, exercycle, control) for cardiovascular function (BMI, SBP, DBP, TC:HDL, TRG, GLU), memory performance (LM I, FP I, LM II, FP II), and executive function performance (PE, NPE, CR).

To determine the effect of physical activity interventions on change in cognitive function and cardiovascular function over time, two-way repeated measures ANOVA was utilised with TIME (pretest, posttest) entered as the within-subjects factor and GROUP (pedometer, exercycle, control) entered as the between-subjects factor. Type III SPSS models were employed as these models are appropriate for unequal groups and are equivalent to weighted squares of means techniques. Bonferroni post hoc analysis further analysed between-group comparisons.

To assess the effect of *any* physical activity versus no activity on cardiovascular and cognitive function, participants from the exercycle and pedometer groups were combined into an *activity* group and compared with the control group. Two-way repeated measures ANOVA was used to determine the effects of physical activity engagement with TIME (pretest, posttest) entered as the within-subjects factor and ACTIVITY STATUS (activity, control) entered as the between-subjects factor.

To investigate the association between change in cardiovascular function variables and change in cognitive function variables, Pearson correlation statistics (two-tailed) were employed.

Individuals were classified as either low risk or high risk based upon baseline heart age. If heart age > chronological age, the individual was classified as high risk. If heart age ≤ chronological age, the individual was classified as low risk. The relative proportion of individuals classified as high risk in each group was cross-tabulated and tested using Fisher Exact Chi-square statistics (two-sided).

To determine any moderating effect of baseline cardiovascular risk level on changes in cognitive performance, all participants were combined and regrouped according to CV risk level. Collapsing across all groups, two-way repeated measures ANOVA was employed with TIME (pretest, posttest) entered as the within-subjects factor and CV RISK LEVEL (low risk, high risk) entered as the between-subjects factor.

Finally, to determine the interrelationship between physical activity and cardiovascular risk level on cognitive function, three-way ANOVA with repeated measures was conducted to test the interaction between TIME (pretest, posttest), ACTIVITY STATUS (activity, control), and CV RISK LEVEL (low risk, high risk) on memory and executive function scores.

3.4 Results

3.4.1 Physical activity behaviour

The compliance rate of pedometer participants was calculated as the percentage of total weeks for which step counts were recorded on the 10,000 Steps® website. Mean compliance rate was 94.7 ± 9.6% (range 63-100%). The change in physical activity behaviour was determined by comparing the mean weekly step count of the first three weeks of the intervention against the mean weekly steps of the final three weeks of the program. Weekly step counts increased on average by 10.8 ± 35.5% (range -37-113%).

Participants who completed the exercycle program had an average attendance rate of 75.4 ± 18.3% (range 39-98%). The change in physical activity behaviour was determined by comparing the mean distance (km) of the first three sessions of the intervention against the mean distance of the final three sessions of the program. Distance cycled during a session improved on average by 50.3 ± 18.7% (range 20-89%).

3.4.2 Physical activity programs and cognitive function

3.4.2.1 Physical activity programs and memory

Baseline memory function was compared among the experimental groups using a one-way ANOVA with the between-subjects factor entered as GROUP (pedometer,

exercycle, control) for the dependent variables: LM I (Logical Memory Immediate), FP I (Family Pictures Immediate), LM II (Logical Memory Delayed), and FP II (Family Pictures Delayed).

There were no significant differences among the intervention groups at baseline for any memory score (all $p > .05$) (Table 10). However, there was a trend for the control group to have a higher LM I mean score at pretesting (11.7 ± 2.8) than the pedometer (10.7 ± 2.5) and exercycle (9.7 ± 2.2) groups.

Table 10. Memory Performance by Intervention Group

		Group				
		Pedometer (*n*=22)	Exercycle (*n*=19)	Control (*n*=21)	*F*	*p*
Immediate memory						
LM I	Pre	10.7 ± 2.5	9.7 ± 2.2	11.7 ± 2.8	3.007[a]	.057
	Post	13.3 ± 3.1	12.9 ± 2.3	13.5 ± 2.8	1.649[b]	.201
FP I	Pre	9.9 ± 3.4	10.5 ± 2.3	11.0 ± 3.7	0.564[a]	.572
	Post	10.8 ± 3.4	10.8 ± 2.6	10.8 ± 3.1	0.927[b]	.402
Delayed memory						
LM II	Pre	11.0 ± 2.8	10.9 ± 1.6	12.5 ± 3.0	2.545[a]	.087
	Post	13.4 ± 2.8	13.1 ± 1.7	14.2 ± 2.4	0.678[b]	.512
FP II	Pre	10.2 ± 3.7	10.8 ± 2.3	11.5 ± 3.3	0.929[a]	.401
	Post	10.9 ± 3.5	11.1 ± 2.3	11.1 ± 3.6	1.122[b]	.332

Note. Dependent variables reported as mean ± standard deviation. Scores were standardised based on age. LM I = Logical Memory I, FP I = Family Pictures I, LM II = Logical Memory II, FP II = Family Pictures II, Pre = pretest, Post = posttest.
[a] *F* = one-way ANOVA among groups for baseline measures. [b]*F* = two-way repeated measures ANOVA of the interaction of TIME X GROUP.

Memory score changes over time were compared among the intervention groups using a two-way repeated measures ANOVA with TIME (pretest, posttest) entered as the within-subjects factor and GROUP (pedometer, exercycle, control) entered as the between-subjects factor. The dependent variables tested were LM I, LM II, FP I and FP II.

LM I scores increased on average from 10.7 ± 2.6 at pretesting to 13.2 ± 2.7 at posttesting ($F_{\text{TIME }(1, 59)} = 66.314$, $p < .001$). However, neither the main effect of GROUP ($F_{(2, 59)} = 1.406$, $p = .253$) nor the interaction was significant ($F_{(2, 59)} = 1.649$, $p = .201$) (Table 10 and Figure 5).

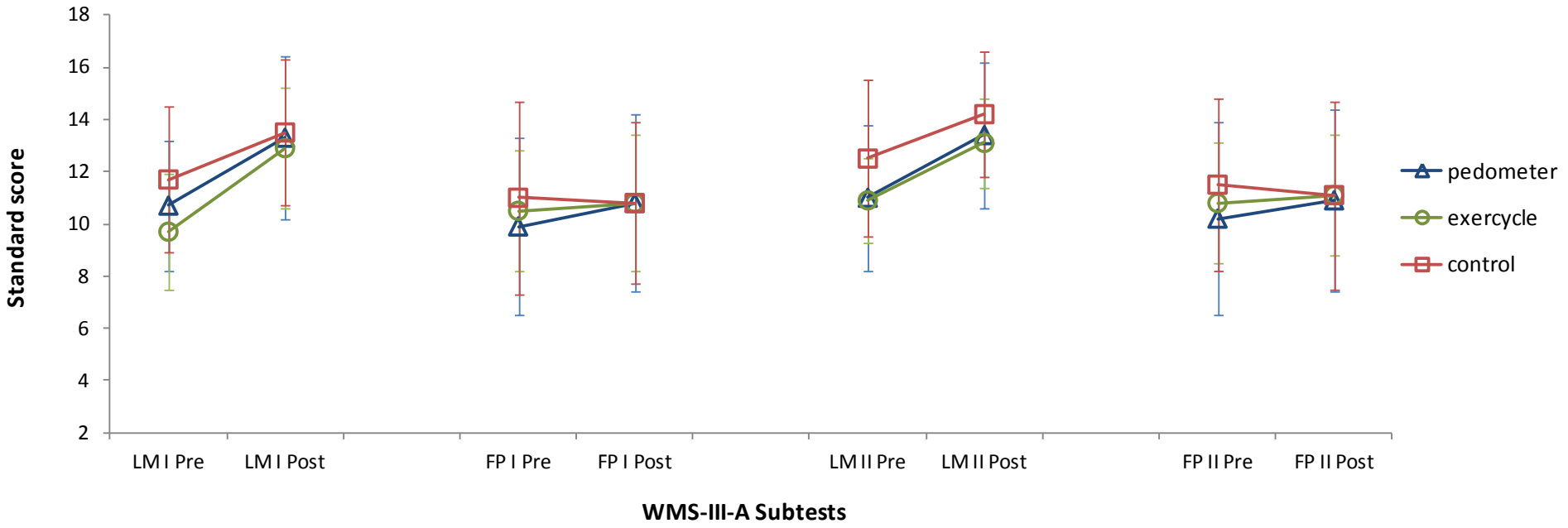

Figure 5. WMS-III-A scores by group from pretest to posttest.

Dependent variables reported as mean ± standard deviation. Memory scores were standardised based on age. LM I = Logical Memory I, FP I = Family Pictures I, LM II = Logical Memory II, FP II = Family Pictures II, Pre = pretest, Post = posttest.

Mean LM II scores significantly increased from 11.5 ± 2.6 at baseline to 13.6 ± 2.4 at posttesting ($F_{TIME\ (1, 59)} = 59.553$, $p < .001$). There was neither a significant main effect of GROUP ($F_{(2, 59)} = 2.204$, $p = .119$) nor a significant interaction of GROUP X TIME ($F_{(2, 59)} = 0.678$, $p = .512$).

For FP I and FP II scores, there were no significant main effects of TIME or GROUP and no significant interactions (all $p > .05$).

As reported in Section 3.4.1, participants *on average* tended to increase physical activity levels as a result of participation in the pedometer and exercycle interventions. However, the individual percent change in physical activity level varied widely within each group (i.e. range of -37-113% change in steps; range of 20-89% change in distance cycled). Given the varying "success" of the programs in terms of physical activity behaviour, it was therefore necessary to determine whether changes in memory performance depended on actual changes in physical activity levels rather than just mere participation. As such, Pearson correlation statistics were employed to test the association between change in physical activity and change in memory function within each intervention group.

For pedometer participants, change in physical activity level (i.e. mean weekly steps posttest – mean weekly steps pretest) was not significantly correlated with change in any memory score (i.e. memory score posttest – memory score pretest) (all $p > .05$, two-tailed) (Figure 6). See Appendix I for correlation statistics.

For the exercycle group, change in physical activity level (i.e. mean session distance posttest – mean session distance pretest) was also not correlated with change in any memory score (all $p > .05$, two-tailed).

3.4.2.2 Physical activity programs and executive function

Baseline scores for the WCST were compared among the intervention groups using a one-way ANOVA with the between-subjects factor entered as GROUP (pedometer, exercycle, control) for the dependent variables: PE (Perseverative Errors score), NPE (Nonperseverative Errors score), CR (Conceptual Level Responses score).

There were no significant differences among the intervention groups at baseline for any WCST score (all $p > .05$) (Table 11).

To determine the effect of group assignment on WCST scores over time, a 3 X 2 repeated measures ANOVA was conducted with GROUP (pedometer, exercycle, control) entered as the between-subjects factor and TIME (pretest, posttest) entered as the within-subjects factor. The dependent variables tested were PE, NPE, and CR.

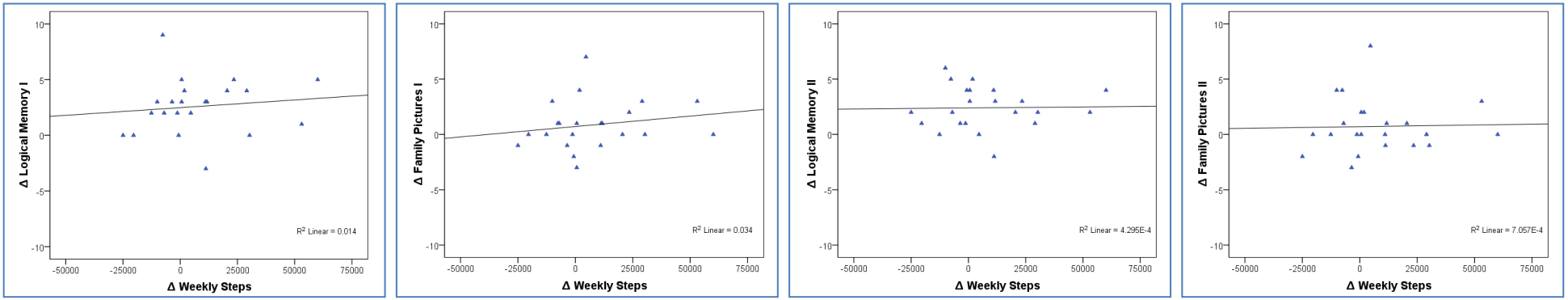

Figure 6. Scatterplots of change in physical activity level versus change in memory.

Δ = posttest – pretest. Positive values = improvement in physical activity and memory. Line of best fit is shown.

Table 11. Executive Function Performance by Intervention Group

		Group				
		Pedometer (*n*=21)	Exercycle (*n*=19)	Control (*n*=21)	*F*	*p*
PE	Pre	99.9 ± 16.6	102.3 ± 18.0	106.8 ± 11.7	1.064[a]	.352
	Post	104.3 ± 12.1	108.5 ± 17.1	104.9 ± 15.4	2.253[b]	.114
NPE	Pre	94.3 ± 16.3	99.2 ± 14.2	101.4 ± 15.2	1.182[a]	.314
	Post	97.9 ± 14.1	101.9 ± 18.8	103.5 ± 12.1	0.068[b]	.934
CR	Pre	93.8 ± 16.1	96.9 ± 15.2	101.4 ± 13.1	1.392[a]	.257
	Post	99.2 ± 12.9	102.6 ± 15.5	102.0 ± 12.9	1.727[b]	.187

Note. Dependent variables reported as mean ± standard deviation. Scores were standardised based on age and years of education. Higher scores indicate better performance. PE = Perseverative Errors, NPE = Nonperseverative Errors, CR = Conceptual Level Responses, Pre = pretest, Post = posttest.
[a] *F* = one-way ANOVA among groups for baseline measures. [b]*F* = two-way repeated measures ANOVA of the interaction of TIME X GROUP.

As depicted in Figure 7, there was a trend for the pedometer and exercycle groups to improve PE scores over time compared to a marginal decline for controls. Given these opposing trends, the main effects of TIME ($F_{(1, 58)} = 3.144$, $p = .081$) and GROUP were not significant ($F_{(2, 58)} = 0.451$, $p = .639$). Despite the trends, the interaction of GROUP X TIME ($F_{(2, 58)} = 2.253$, $p = .114$) did not reach statistical significance (Table 11 and Figure 7).

For NPE, there were no significant main effects of TIME or GROUP. The interaction effect was also not significant (all $p > .05$).

Overall, CR scores significantly increased from 97.4 ± 15.0 at pretesting to 101.2 ± 13.6 at posttesting ($F_{\text{TIME }(1, 58)} = 9.868$, $p = .003$). Neither the main effect of GROUP ($F_{(2, 58)} = 0.811$, $p = .450$) nor the interaction ($F_{(2, 58)} = 1.727$, $p = .187$) was statistically significant.

Despite no significant differential effects from participation in the physical activity programs compared to the control group, it was important to determine if executive function varied as a result of actual change in physical activity level over time. Therefore, Pearson correlation statistics were employed to test the association between change in physical activity level and change in WCST scores from pre- to posttesting.

Within the pedometer group, change in weekly step counts did not significantly correlate with change in any executive function score (all $p > .05$, two-tailed) (Figure 8).

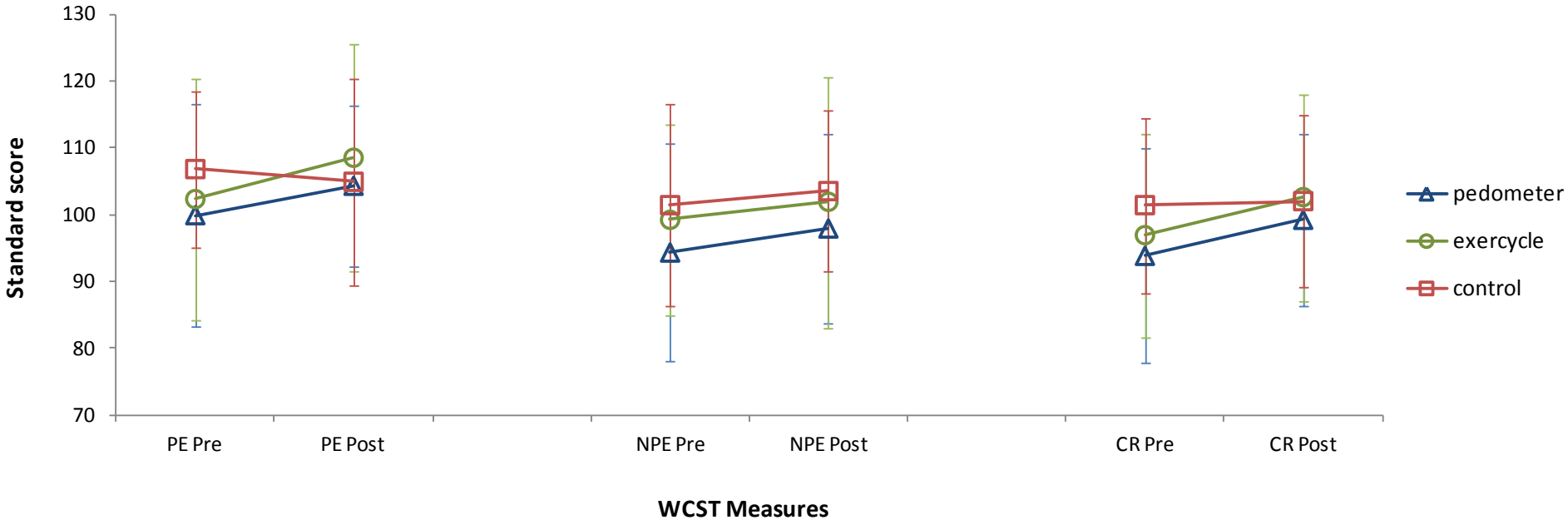

Figure 7. WCST scores by group from pretest to posttest.

Dependent variables reported as mean ± standard deviation. WCST scores were standardised based on age and years of education. Higher scores indicate better performance. PE = Perseverative Errors, NPE = Nonperseverative Errors, CR = Conceptual Level Responses, Pre = pretest, Post = posttest.

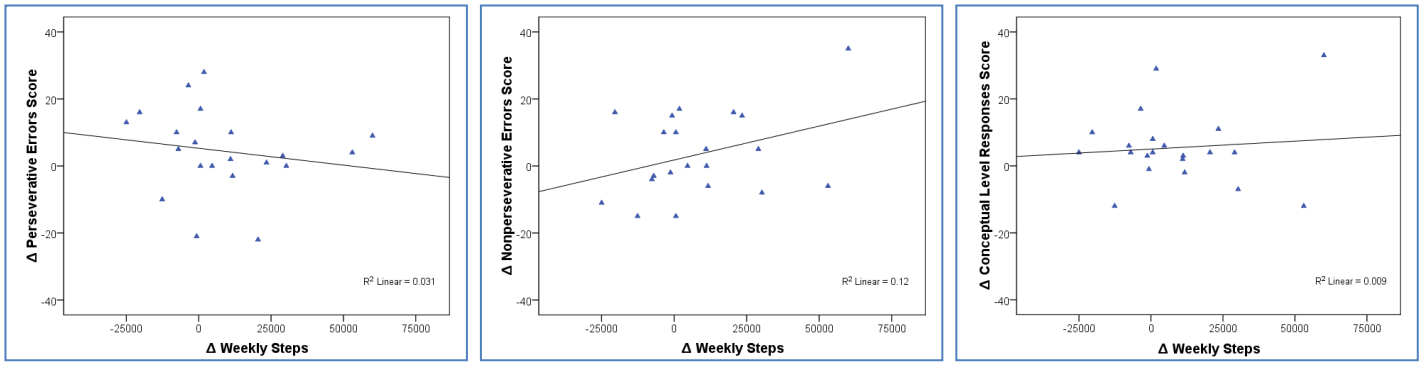

Figure 8. Scatterplots of change in physical activity level versus change in executive function.

Δ = posttest – pretest. Positive values = improvement in physical activity and executive function. Line of best fit is shown.

Appendix J displays the correlation statistics.

Within the exercycle group, change in exercycling distance was not correlated with change in any WCST measure ($p > .05$, two-tailed).

3.4.3 General activity and cognitive function

As reported in Section 3.4.2, the highly contrasting protocols of the pedometer and exercycle programs were not shown to differentially improve cognitive function with respect to each other or the control group. That is, the *intensity* of aerobic activity did not affect the degree of change in cognitive performance. However, it is important to determine whether *any* physical activity of any type can improve cognitive function in comparison to sedentary behaviour. As the pedometer and exercycle groups trended similarly over time with no statistically significant differences between them, these two groups were pooled into an activity group. This activity group was then compared against the control group for subsequent analyses of the effect of physical activity on cognitive function.

3.4.3.1 General activity and memory

Independent samples *t*-tests were used to compare baseline memory scores between the activity and control groups.

Baseline scores for LM I were significantly higher for the control group (11.7 ± 2.8) than the activity group (10.2 ± 2.4) ($t_{(60)} = -2.123$, $p = .038$, two-tailed) (Figure 9 and Table 12). LM II scores at pretest were also higher for the control group (12.5 ± 3.0) than the activity group (11.0 ± 2.3) ($t_{(60)} = -2.274$, $p = .027$).

A 2 X 2 repeated measures ANOVA was employed to determine the interaction of TIME (pretest, posttest) X ACTIVITY STATUS (activity, control) for memory scores.

LM I scores improved on average from 10.7 ± 2.6 at baseline to 13.2 ± 2.7 at posttesting ($F_{\text{TIME }(1, 60)} = 51.195$, $p < .001$) (Figure 9 and Table 12). The main effect of ACTIVITY STATUS was not significant ($F_{(1, 60)} = 2.052$, $p = .157$). The interaction effect for LM I more closely approached significance than when the physical activity interventions were considered separately ($F_{(1, 60)} = 2.660$, $p = .108$).

Participants tended to improve LM II scores over time (11.5 ± 2.6 pretest; 13.6 ± 2.4 posttest) ($F_{\text{TIME }(1, 60)} = 49.485$, $p < .001$). Across both testing sessions, the control participants scored significantly higher than the activity participants ($F_{\text{ACTIVITY STATUS }(1, 60)} = 4.390$, $p = .040$). The interaction effect was not significant ($F_{(1, 60)} = 1.157$, $p = 2.86$).

There were no significant main effects or interactions for FP I or FP II (all $p > .05$).

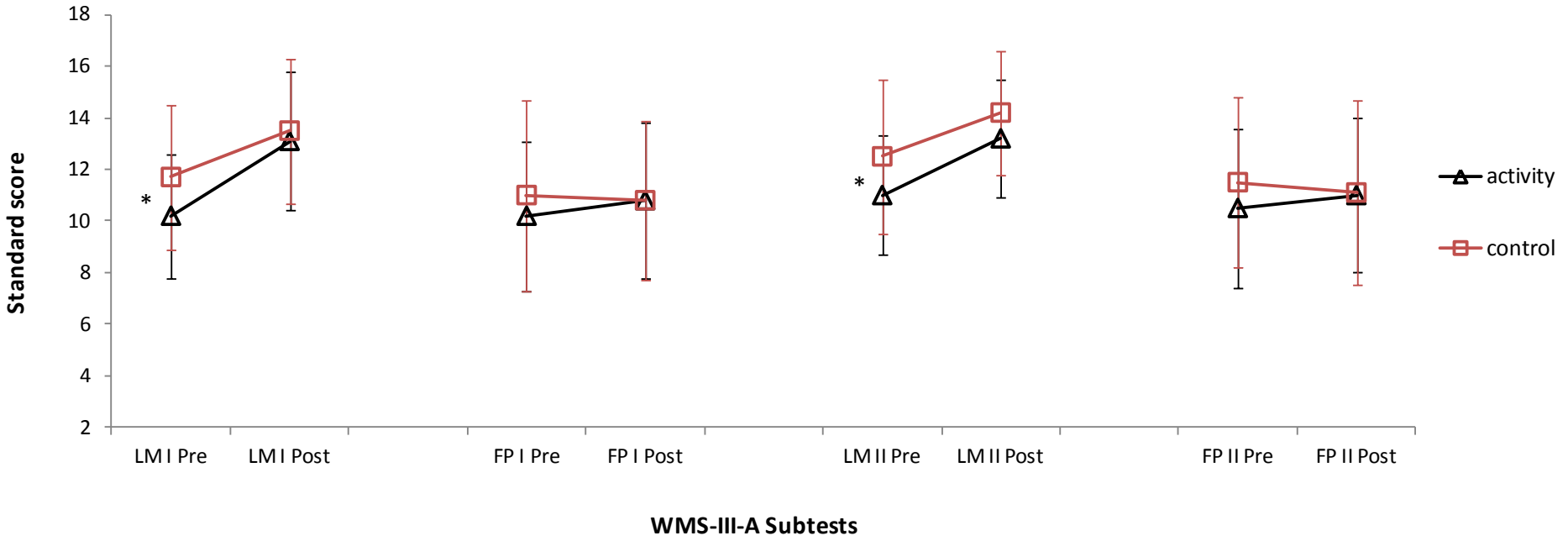

Figure 9. WMS-III-A scores by activity status from pretest to posttest.

Activity group = combined participants of pedometer and exercycle groups. Dependent variables reported as mean ± standard deviation. Memory scores were standardised based on age. LM I = Logical Memory I, FP I = Family Pictures I, LM II = Logical Memory II, FP II = Family Pictures II, Pre = pretest, Post = posttest.

* $p < .05$ for baseline differences for LM I and LM II, and group difference for LM II.

Table 12. Memory Performance by Activity Status

		Activity Status			
		Activity (*n*=41)	Control (*n*=21)	*t* / *F*	*p*
Immediate memory					
LM I	Pre	10.2 ± 2.4	11.7 ± 2.8	-2.123[a] *	.038
	Post	13.1 ± 2.7	13.5 ± 2.8	2.660[b]	.108
FP I	Pre	10.2 ± 2.9	11.0 ± 3.7	-0.909[a]	.367
	Post	10.8 ± 3.0	10.8 ± 3.1	1.480[b]	.228
Delayed memory					
LM II	Pre	11.0 ± 2.3	12.5 ± 3.0	-2.274[a] *	.027
	Post	13.2 ± 2.3	14.2 ± 2.4	1.157[b]	.286
FP II	Pre	10.5 ± 3.1	11.5 ± 3.3	-1.230[a]	.224
	Post	11.0 ± 3.0	11.1 ± 3.6	1.893[b]	.174

Note. Dependent variables reported as mean ± standard deviation. Memory scores were standardised based on age. LM I = Logical Memory I, FP I = Family Pictures I, LM II = Logical Memory II, FP II = Family Pictures II, Pre = pretest, Post = posttest.
[a] *t* = independent samples *t*-test for baseline scores. [b] *F* = two-way repeated measures ANOVA of the interaction of TIME X ACTIVITY STATUS.
* $p < .05$.

3.4.3.2 General activity and executive function

Independent samples *t*-tests were employed to compare baseline WCST scores between the activity group and the control group. There were no significant baseline differences (all $p > .05$) (Table 13 and Figure 10).

Table 13. Executive Function Performance by Activity Status

		Activity Status			
		Activity (*n*=40)	Control (*n*=21)	*t* / *F*	*p*
PE	Pre	101.0 ± 17.1	106.8 ± 11.7	-1.387[a]	.171
	Post	106.3 ± 14.7	104.9 ± 15.4	4.363[b] *	.041
NPE	Pre	96.7 ± 15.3	101.4 ± 15.2	-1.160[a]	.251
	Post	99.8 ± 16.4	103.5 ± 12.1	0.101[b]	.752
CR	Pre	95.3 ± 15.6	101.4 ± 13.1	-1.532[a]	.131
	Post	100.8 ± 14.1	102.0 ± 12.9	3.508[b]	.066

Note. Dependent variables reported as mean ± standard deviation. Scores were standardised based on age and years of education. Higher scores indicate better performance. PE = Perseverative Errors, NPE = Nonperseverative Errors, CR = Conceptual Level Responses, Pre = pretest, Post = posttest.
[a] *t* = independent samples *t*-test for baseline scores. [b] *F* = two-way repeated measures ANOVA of the interaction of TIME X ACTIVITY STATUS.
* $p < .05$.

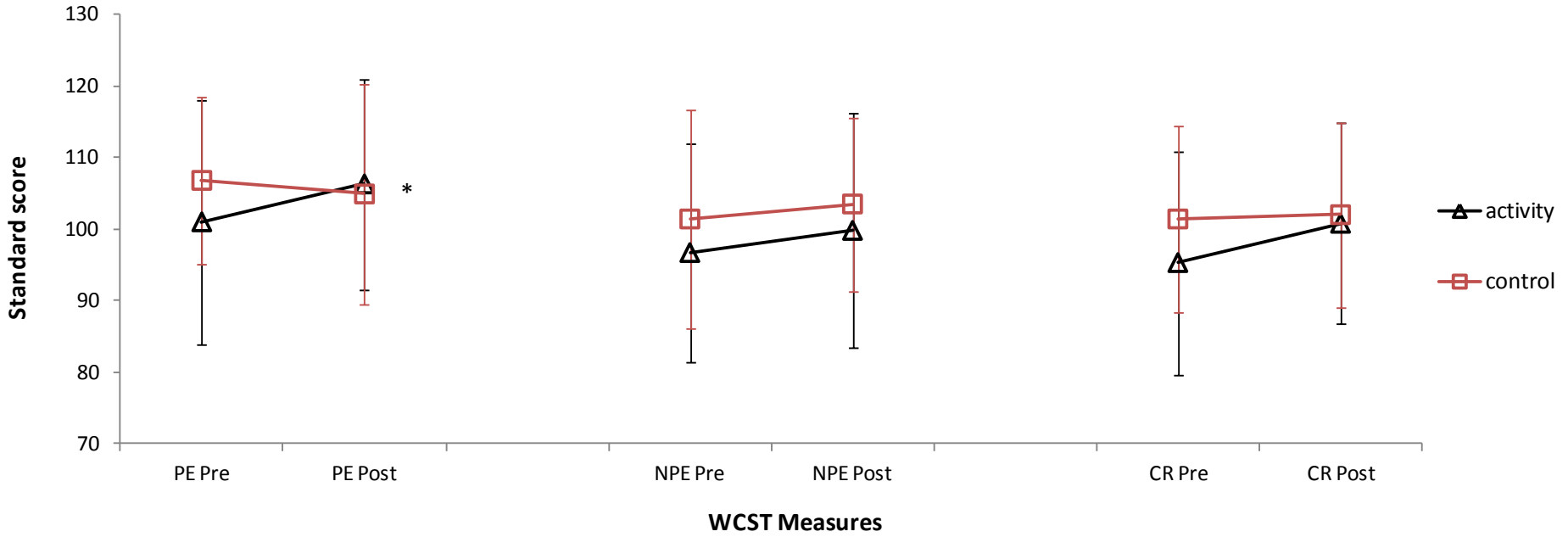

Figure 10. WCST scores by activity status from pretest to posttest.

Dependent variables reported as mean ± standard deviation. WCST scores were standardised based on age and years of education. Higher scores indicate better performance.
PE = Perseverative Errors, NPE = Nonperseverative Errors, CR = Conceptual Level Responses, Pre = pretest, Post = posttest.
*$p < .05$ represents a significant interaction of ACTIVITY STATUS X TIME.

To determine if any physical activity would result in differential improvement in WCST scores, a 2 X 2 repeated measures ANOVA was employed to determine the interaction of TIME (pretest, posttest) X ACTIVITY STATUS (activity, control).

As depicted in Figure 10, PE scores tended to improve for the activity group while declining slightly for control participants. Given these opposing trends, there were no significant main effects for TIME ($F_{(1, 59)} = 0.969$, $p = .329$) or ACTIVITY STATUS ($F_{(1, 59)} = 0.345$, $p = .559$). There was, however, a significant interaction effect ($F_{(1, 59)} = 4.363$, $p = .041$).

For NPE scores, there were no significant main effects of TIME or ACTIVITY STATUS and no interaction effect (all $p > .05$).

Overall CR scores tended to improve over time from a mean score of 97.4 ± 15.0 at pretest to a final score of 101.2 ± 13.6 at posttest ($F_{\text{TIME (1, 59)}} = 5.698$, $p = .020$). The main effect of ACTIVITY STATUS did not reach statistical significance ($F_{(1, 59)} = 1.034$, $p = .313$). There was a trend for the activity group to improve CR scores to a greater extent than controls with the interaction effect approaching statistical significance ($F_{\text{TIME X ACTIVITY STATUS (1, 59)}} = 3.508$, $p = .066$) (Table 13 and Figure 10).

3.4.4 Physical activity programs and cardiovascular function

In order to determine how the physical activity interventions affected cardiovascular function compared to sedentary behaviour, cardiovascular variables were measured at baseline and upon completion of the intervention period.

Baseline cardiovascular measures among the intervention groups were compared using a one-way ANOVA with the between-subjects factor entered as GROUP (pedometer, exercycle, control) for the dependent variables: BMI (body mass index), SBP (systolic blood pressure), DBP (diastolic blood pressure), TC:HDL (total cholesterol to high density lipoprotein ratio), TRG (triglycerides), GLU (glucose), and Heart Age.

The total study sample had an average BMI of 28.8 ± 5.17 kg/m^2, higher than the optimal range of 18.5-25 kg/m^2. There was a trend for BMI to be higher at baseline among the pedometer participants (30.9 ± 6.3 kg/m^2) compared to exercycle participants (27.6 ± 4.7 kg/m^2) and controls (27.6 ± 3.5 kg/m^2) ($F_{(2, 59)} = 3.060$, $p = .054$) (Table 14).

Baseline systolic blood pressure was significantly lower for participants in the control group (116.2 ± 8.6 mmHg) than those in the pedometer (124.9 ± 7.9 mmHg) and exercycle (124.2 ± 13.0 mmHg) groups ($F_{(2, 59)} = 4.924$, $p = .011$). Diastolic blood

pressure was also significantly lower in the control group (72.5 ± 7.8 mmHg) than in the pedometer group (78.6 ± 8.4 mmHg) ($F_{(2, 59)} = 3.985$, $p = .024$).

Table 14. Cardiovascular Function by Intervention Group

	Optimal range		Group: Pedometer (*n*=22)	Exercycle (*n* = 19)	Control (*n*=21)	*F*	*p*
BMI (kg/m^2)	18.5-25	Pre	30.9 ± 6.3	27.6 ± 4.7	27.6 ± 3.5	3.060[a]	.054
		Post	30.7 ± 6.2	27.8 ± 4.6	27.7 ± 3.6	0.970[b]	.385
SBP (mmHg)	≤120	Pre	124.9 ± 7.9	124.2 ± 13.0	116.2 ± 8.6	4.924[a]	* .011
		Post	118.2 ± 8.9	118.2 ± 8.3	115.2 ± 10.1	2.554[b]	.086
DBP (mmHg)	≤80	Pre	78.6 ± 8.4	78.6 ± 7.9	72.5 ± 7.8	3.985[a]	* .024
		Post	74.2 ± 5.7	73.0 ± 6.8	72.8 ± 7.7	2.946[b]	.060
TC:HDL[c]	≤3.5	Pre	3.5 ± 1.0	3.5 ± 1.1	4.2 ± 1.5	2.467[a]	.094
		Post	3.9 ± 1.2	3.6 ± 1.2	4.5 ± 2.0	0.889[b]	.417
TRG[c] (mmol/L)	<1.7	Pre	1.2 ± 0.6	1.2 ± 0.6	1.2 ± 0.7	0.015[a]	.985
		Post	1.1 ± 0.5	1.4 ± 0.8	1.4 ± 0.7	1.877[b]	.162
GLU[c] (mmol/L)	<5.6	Pre	5.1 ± 0.7	5.0 ± 0.6	5.1 ± 0.4	0.244[a]	.784
		Post	5.2 ± 0.6	5.1 ± 0.6	5.4 ± 0.4	4.750[b]	* .012
Heart Age[c] (y)	≤ age	Pre	49.4 ± 10.0	47.4 ± 11.5	47.9 ± 11.1	0.186[a]	.830
		Post	48.0 ± 10.3	43.6 ± 9.4	49.8 ± 11.7	3.613[b]	* .033

Note. Dependent variables reported as mean ± standard deviation. Optimal ranges obtained from the Third Report of the National Cholesterol Education Program (NCEP) (National Institute of Health, 2001). BMI = body mass index, SBP = systolic blood pressure, DBP = diastolic blood pressure, TC:HDL = total cholesterol to high density lipoprotein ratio, TRG = triglycerides, GLU = glucose, Pre = pretest, Post = posttest.

[a] *F* = one-way ANOVA among groups for baseline measures. [b]*F* = two-way repeated measures ANOVA of the interaction of TIME X GROUP. [c] Based on fasting whole blood capillary samples, *n* (control group) = 19).

*$p < .05$.

To investigate the effect of physical activity on cardiovascular health, a 3 X 2 repeated measures ANOVA tested the interaction of GROUP (pedometer, exercycle, control) and TIME (pretest, posttest) for all cardiovascular variables.

Overall, SBP improved (lowered) over time from pretesting (121.7 ± 10.6 mmHg) to posttesting (117.2 ± 9.1 mmHg) ($F_{\text{TIME}(1, 59)} = 15.756$, $p < .001$). There was a trend for the control group to have lower SBP readings compared to the pedometer and exercycle groups across both pretest and posttest ($F_{\text{GROUP}(2, 59)} = 3.129$, $p = .051$). SBP

tended to decrease towards optimal levels for pedometer (-6.7 mmHg) and exercycle (-6.0 mmHg) participants with little change for control participants (-1.0 mmHg). The interaction of GROUP and TIME approached statistical significance ($F_{(2, 59)} = 2.554$, $p = .086$) (Table 14).

Across all participants, DBP improved on average from baseline (76.5 ± 8.4 mmHg) to posttesting (73.4 ± 6.7 mmHg) ($F_{TIME\ (1, 59)} = 9.351$, $p = .003$). The main effect of GROUP was not significant ($F_{(2, 59)} = 2.235$, $p = .116$). DBP levels tended to decrease towards the optimal range for pedometer (-4.4 mmHg) and exercycle (-5.6 mmHg) subjects, while there was little change for controls (+0.3 mmHg). The interaction of GROUP and TIME approached significance ($F_{(2, 59)} = 2.946$, $p = .060$).

TC:HDL for the study sample was higher than the ideal value of 3.5, with values lying within a "borderline" range (ratio of 3.5-5). Over time, TC:HDL tended to increase from 3.7 ± 1.3 at pretest to 4.0 ± 1.5 at posttest ($F_{TIME\ (1, 57)} = 7.395$, $p = .009$). There was no significant effect of GROUP ($F_{(2, 57)} = 2.365$, $p = .103$) and no interaction ($F_{(2, 57)} = .889$, $p = .417$).

Although fasting blood glucose increased across all participants from a mean of 5.0 ± 0.6 mmol/L at baseline to 5.2 ± 0.6 mmol/L at posttesting, these values lie within a desirable range ($F_{TIME\ (1, 57)} = 22.363$, $p < .001$). The main effect of GROUP was not significant ($F_{(2, 57)} = 0.809$, $p = .450$). There seemed to be a trend for the control group to increase fasting blood glucose over time (+0.3 mmol/L) to a greater extent than pedometer and exercycle groups (both +0.1 mmol/L). There was a significant interaction of GROUP X TIME ($F_{(2, 57)} = 4.750$, $p = .012$), however, statistical significance did not remain after Bonferroni post hoc comparisons.

There was a trend for mean Heart Age to improve (i.e. decrease) from pretest to posttest for the pedometer participants (-1.4 y) and exercycle participants (-3.8 y), with a contrasting increase for controls (+1.9 y). Due to these opposing trends, there was no significant main effect of TIME ($F_{(1, 57)} = 1.646$, $p = .205$). The main effect of GROUP was not statistically significant ($F_{(2, 57)} = 0.675$, $p = .513$). Although the interaction of GROUP and TIME reached statistical significance ($F_{(2, 57)} = 3.613$, $p = .033$), significance did not survive Bonferroni post hoc analyses.

There were no main or interaction effects for BMI or TRG (all $p > .05$).

3.4.5 General activity and cardiovascular function

As reported in Section 3.4.4, the pedometer and exercycle programs did not significantly improve cardiovascular function compared to the control group. The results shown in Table 14, however, indicate trends for the pedometer and exercycle

groups to improve in a similar manner for certain cardiovascular parameters (i.e. SBP, DBP, GLU, Heart Age). Thus, to ascertain whether *any* physical activity was more effective in improving cardiovascular function compared to no activity, the two physical activity groups were pooled into an activity group and compared to controls.

As previously reported in Section 3.4.4, control participants had lower average baseline systolic blood pressure (116.2 ± 8.6 mmHg) than activity participants (124.6 ± 10.5 mmHg) at the pretest ($t_{(60)} = 3.154$, $p = .003$). See Appendix K for independent samples *t*-test statistics for comparison of baseline cardiovascular measures between activity and control groups. From pretesting to posttesting, systolic blood pressure improved overall from 121.7 ± 10.6 mmHg to 117.2 ± 9.1 mmHg ($F_{\text{TIME (1, 60)}} = 9.339$, p = .003). When the combined general activity group was compared against the control group, those involved in some form of activity decreased SBP significantly more than controls (-6.4 mmHg and -1.0 mmHg, respectively) ($F_{\text{TIME } x \text{ ACTIVITY STATUS (1, 60)}} = 5.110$, $p = .027$). See Appendix K for TIME X ACTIVITY STATUS interaction statistics for cardiovascular function variables.

Control participants had lower diastolic blood pressure than their active counterparts at baseline (72.5 ± 7.8 mmHg and 78.6 ± 8.1 mmHg, respectively) ($t_{(60)} = 2.847$, $p = .006$). DBP improved overall from 76.5 ± 8.4 mmHg to 73.4 ± 6.7 mmHg ($F_{\text{TIME (1, 60)}} = 4.381$, $p = .041$). However, the activity participants decreased DBP while controls showed little change over time (-4.9 mmHg and +0.3 mmHg, respectively) ($F_{\text{TIME X ACTIVITY STATUS (1, 60)}} = 5.744$, $p = .020$).

As previously reported in Section 3.4.4, GLU for the entire study sample was higher at posttest (5.2 ± 0.6 mmol/L) than pretest (5.0 ± 0.6 mmol/L) but still within an optimal range ($F_{\text{TIME (1, 58)}} = 29.900$, $p < .001$). Control participants increased fasting glucose from pre- to posttesting by 0.3 mmol/L while activity participants showed significantly less change (+0.1 mmol/L) ($F_{\text{TIME X ACTIVITY STATUS (1, 58)}} = 9.610$, $p = .003$).

Differences between activity and control groups were also strengthened for changes in Heart Age over time. Heart Age decreased for activity participants from 48.5 ± 10.7 y at baseline to 46.0 ± 10.0 y at posttest, while Heart Age increased for controls from 47.9 ± 11.1 y to 49.8 ± 11.7 y. The interaction of TIME X ACTIVITY STATUS was statistically significant ($F_{(1, 58)} = 5.785$, $p = .019$).

3.4.6 Cardiovascular function and cognitive function

The secondary aim of this study was to determine if and how changes in cognitive function co-vary with changes in cardiovascular function, *independent* of group assignment. Correlational analyses were employed to test the association between cardiovascular versus cognitive function changes.

3.4.6.1 Cardiovascular function and memory

Pearson correlation statistics tested the association between change in cardiovascular function measures (BMI, SBP, DBP, TC:HDL, TRG, GLU, Heart Age) and change in memory scores (LM I, FP I, LM II, FP II).

Improvement in systolic blood pressure from pretest to posttest (i.e. decreases or negative values) was significantly associated with improvement in Logical Memory I score (i.e. increases or positive values) (r = -.293, p = .021, two-tailed) (Figure 11). No other correlations were significant. Correlation matrices of all cardiovascular versus memory variables are reported in Table 15.

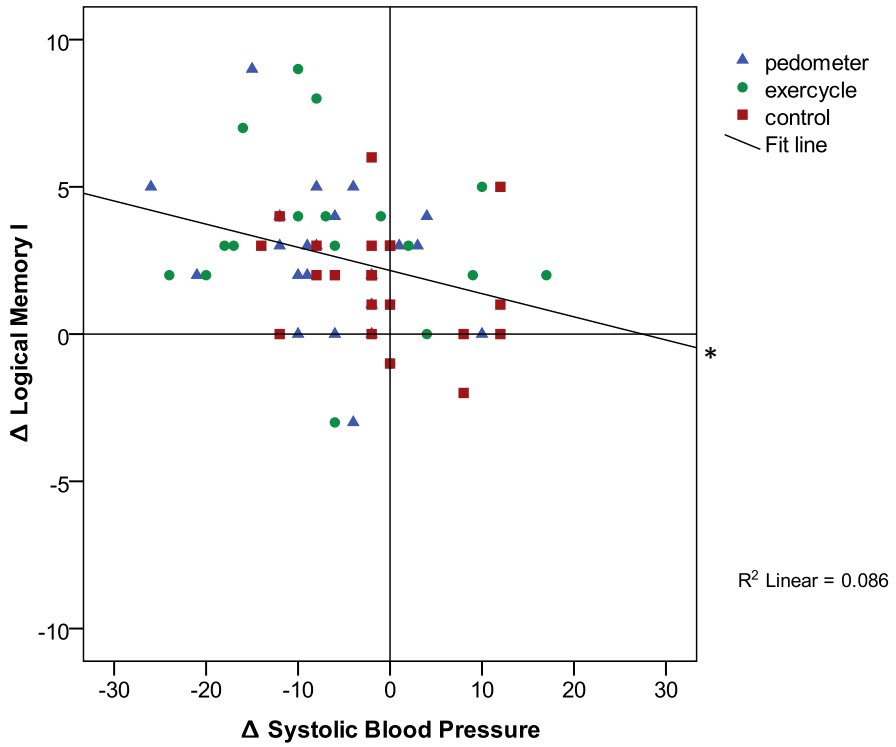

Figure 11. Scatterplot of change in Logical Memory I versus change in systolic blood pressure.

Δ = posttest – pretest. Improvement in systolic blood pressure = negative values. Improvement in Logical Memory I = positive values. Line of best fit is shown.

* p < .05 for correlation.

3.4.6.2 Cardiovascular function and executive function

To investigate how changes in cardiovascular measures (BMI, SBP, DBP, TC:HDL, TRG, GLU, Heart Age) related to changes in WCST scores (PE, NPE, CR) from pre- to posttesting, Pearson correlation statistics were again employed. No significant correlations were detected (Table 16).

Table 15. Correlation Coefficients of Change in Cardiovascular Function and Change in Memory

	Δ BMI		Δ SBP		Δ DBP		Δ TC:HDL		Δ TRG		Δ GLU		Δ Heart Age	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Δ LM I	.058	.653	-.293*	.021	-.057	.659	.154	.241	.139	.291	.146	.267	-.203	.119
Δ FP I	.124	.336	.054	.674	.078	.548	.058	.660	-.035	.792	-.137	.297	-.005	.969
Δ LM II	.017	.894	-.120	.353	-.012	.924	.005	.972	-.063	.633	.009	.947	-.005	.971
Δ FP II	.131	.312	.074	.566	.002	.986	.119	.365	.040	.760	-.181	.165	-.016	.902

Note. *r* = Pearson correlation coefficient, Δ = posttest – pretest differences, BMI = body mass index, SBP = systolic blood pressure, DBP = diastolic blood pressure, TC:HDL = total cholesterol to high density lipoprotein ratio, TRG = triglycerides, GLU = glucose, LM I = Logical Memory I, FP I = Family Pictures I, LM II = Logical Memory II, FP II = Family Pictures II. *n* = 62 for BMI, SBP, DBP. *n* = 60 for TC:HDL, TRG, GLU, Heart Age.
*$p < .05$, two-tailed.

Table 16. Correlation Coefficients of Change in Cardiovascular Function and Change in Executive Function

	Δ BMI		Δ SBP		Δ DBP		Δ TC:HDL		Δ TRG		Δ GLU		Δ Heart Age	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Δ PE	.000	.997	-.063	.627	-.144	.270	.053	.688	.065	.624	.036	.789	.058	.660
Δ NPE	-.130	.319	.115	.377	.148	.254	.022	.870	-.187	.157	-.080	.546	.113	.395
Δ CR	-.149	.251	.036	.780	-.050	.704	.120	.367	-.051	.701	-.048	.719	.077	.562

Note. *r* = Pearson correlation coefficient, Δ = posttest – pretest differences, BMI = body mass index, SBP = systolic blood pressure, DBP = diastolic blood pressure, TC:HDL = total cholesterol to high density lipoprotein ratio, TRG = triglycerides, GLU = glucose, PE = Perseverative Errors, NPE = Nonperseverative Errors, CR = Conceptual Level Responses. *n* = 61 for BMI, SBP, DBP. *n* = 59 for TC:HDL, TRG, GLU, Heart Age.

An exemplar scatterplot is depicted in Figure 12 between change in SBP and change in PE. PE was chosen for display as it is the most common WCST measure used to represent set shifting and it was shown to be positively affected by general activity in Section 3.4.3.2. In comparison to the significant negative relationship between SBP and LMI, decreases in SBP occurred with a more even distribution of positive and negative changes in PE score.

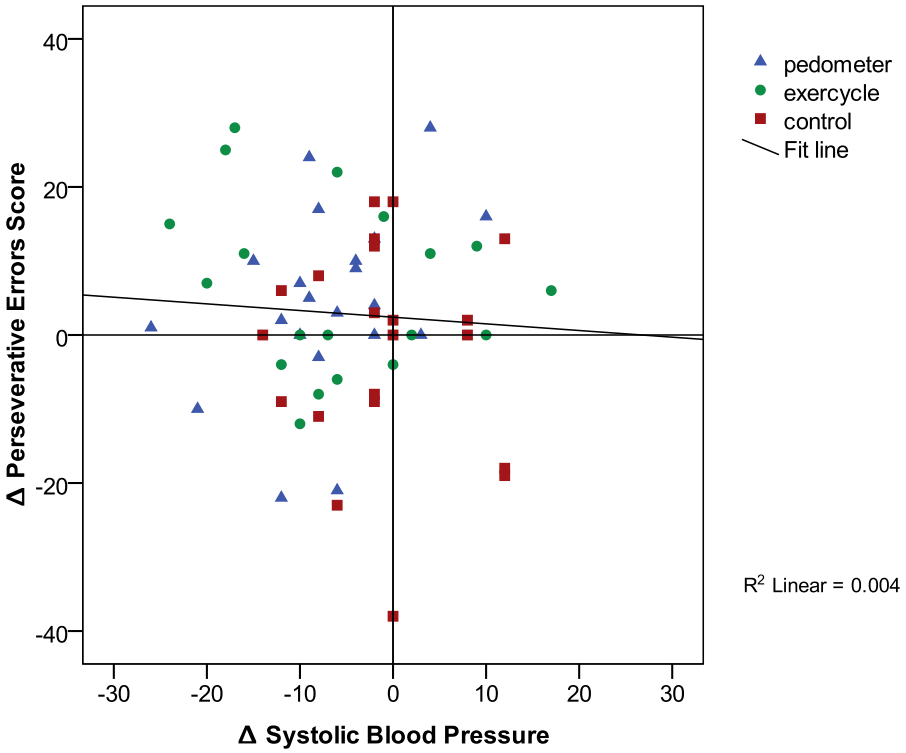

Figure 12. Scatterplot of change in Perseverative Errors Score versus change in systolic blood pressure.

Δ = posttest – pretest. Improvement in systolic blood pressure = negative values. Improvement in Perseverative Errors score = positive values. Line of best fit is shown.

3.4.7 Cardiovascular risk level and cognitive function

A secondary aim of the study was to determine if baseline cardiovascular risk level would modify the degree of change in cognitive function. That is, would individuals having low or high risk of cardiovascular disease be more labile to the effects of study participation? Therefore, all participants were combined and regrouped by baseline cardiovascular risk level using their Heart Age designation from a Framingham calculation as detailed in the Methods (Section 3.3.3). After baseline testing,

participants were classified as either low risk (Heart Age ≤ chronological age) or high risk (Heart Age > chronological age).

3.4.7.1 Cardiovascular risk level and memory

Independent samples *t*-tests were conducted to analyse the differences between cardiovascular risk level groups at baseline. There were no significant differences between low and high risk groups at baseline for any memory score (all $p > .05$, two-tailed) (Table 17 and Figure 13).

Table 17. Memory Performance by Cardiovascular Risk Level

		CV Risk Level				
		Low Risk (*n*=42)	High Risk (*n*=19)	*t* / *F*		*p*
Immediate memory						
LM I	Pre	10.7 ± 2.4	10.5 ± 2.8	0.267[a]		.791
	Post	12.9 ± 2.6	14.1 ± 2.8	4.343[b]	*	.042
FP I	Pre	10.4 ± 2.9	10.7 ± 3.8	-0.400[a]		.691
	Post	10.8 ± 3.1	10.7 ± 3.1	0.413[b]		.523
Delayed memory						
LM II	Pre	11.5 ± 2.6	11.4 ± 2.7	0.148[a]		.883
	Post	13.4 ± 2.5	13.9 ± 2.2	1.096[b]		.299
FP II	Pre	10.9 ± 3.0	10.7 ± 3.7	0.213[a]		.832
	Post	11.0 ± 3.2	11.1 ± 3.3	0.083[b]		.774

Note. Dependent variables reported as mean ± standard deviation. Memory scores were standardised based on age. CV = cardiovascular, LM I = Logical Memory I, FP I = Family Pictures I, LM II = Logical Memory II, FP II = Family Pictures II, Pre = pretest, Post=posttest.
[a] *t* = independent samples *t*-test for baseline scores. [b] *F* = two-way repeated measures ANOVA of the interaction of TIME X CV RISK LEVEL.
*$p < .05$.

To determine whether there was differential improvement in memory based on initial cardiovascular risk level, a 2 X 2 repeated measures ANOVA was conducted to test the interaction between CV RISK LEVEL (low risk, high risk) and TIME (pretest, posttest) across all participants.

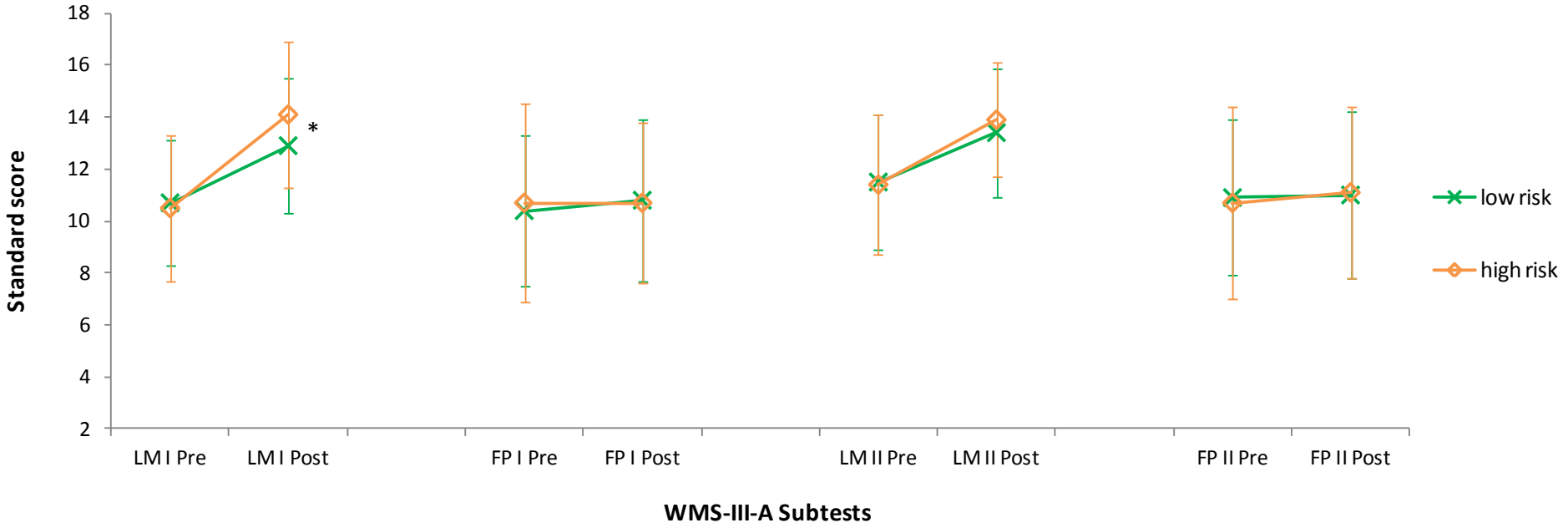

Figure 13. WMS-III-A scores by cardiovascular risk level from pretest to posttest.

Dependent variables reported as mean ± standard deviation. Memory scores were standardised based on age. LM I = Logical Memory I, FP I = Family Pictures I, LM II = Logical Memory II, FP II = Family Pictures II, Pre = pretest, Post = posttest.

* $p < .05$ for significant interaction of TIME X CV RISK LEVEL.

Regardless of risk classification, overall LM I scores increased over time by 2.5 standard points ($F_{\text{TIME (1, 59)}} = 76.134$, $p < .001$). There was no main effect for CV RISK LEVEL alone ($F_{(1, 59)} = 0.576$, $p = .451$). However, high risk participants showed a significantly greater improvement over time for LM I scores (+3.6 units) compared to low risk individuals (+2.2 units) ($F_{\text{TIME x CV RISK LEVEL (1, 59)}} = 4.343$, $p = .042$) (Table 17 and Figure 13).

The relationship between SBP (a significant determinant of cardiovascular risk) and LM I was shown previously in Figure 11. If this relationship is replotted with cases identified by CV risk level, high risk individuals seem to have a higher proportional representation in the upper left quadrant (decreases in systolic blood pressure and improvements in LM I) (Figure 14).

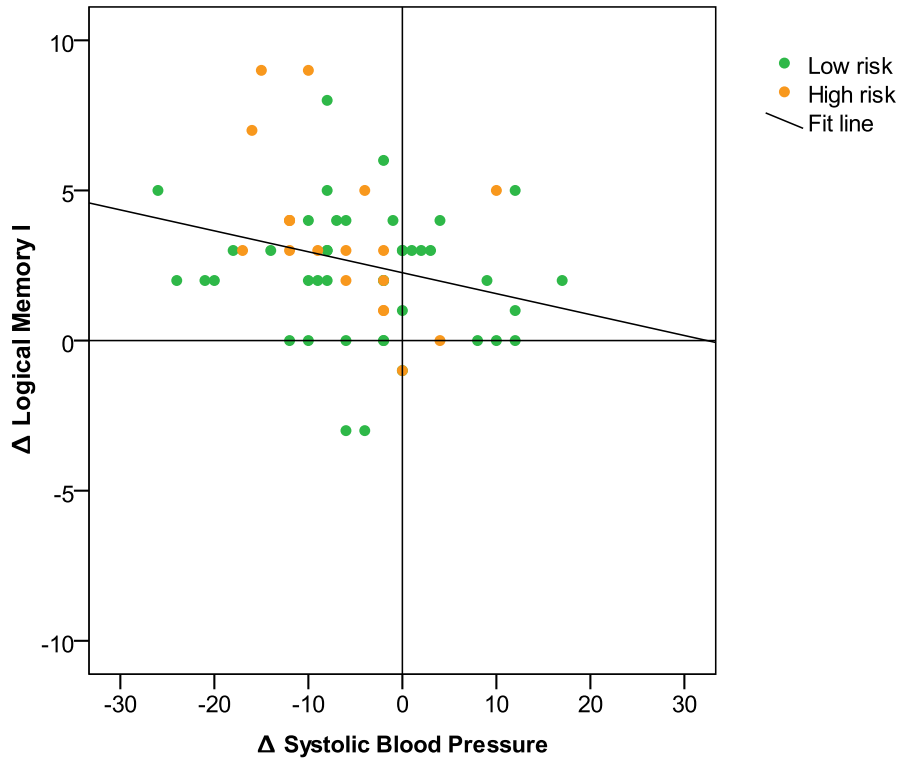

Figure 14. Scatterplot of change in LMI versus SBP with respect to risk level.
Δ = posttest – pretest. Improvement in systolic blood pressure = negative values. Improvement in Logical Memory I = positive values.

As such, correlations were tested between change in SBP and change in LM I within *each* of the CV risk level groups. The association between changes in SBP and LMI was much stronger for high risk individuals ($r = -.488$, $p = .034$, two-tailed) than for low risk individuals ($r = -.150$, $p = .341$, two-tailed) (Figure 15).

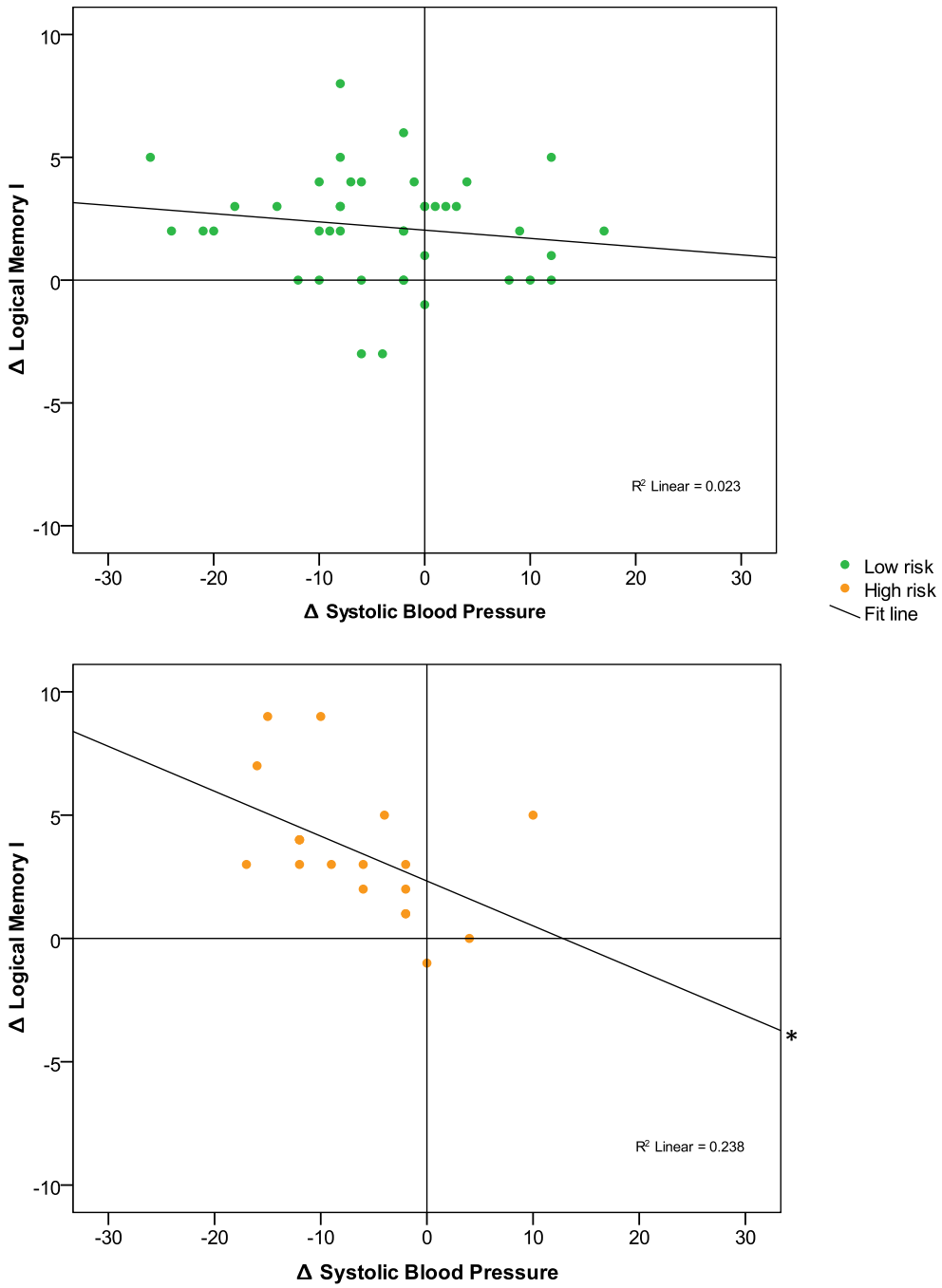

Figure 15. Scatterplots of change in Logical Memory I versus change in systolic blood pressure controlled by risk level.

Δ = posttest – pretest. Improvement in systolic blood pressure = negative values. Improvement in Logical Memory I = positive values. Line of best fit is shown.

* $p < .05$.

LM II increased from pretesting to posttesting (11.4 ± 2.6 and 13.6 ± 2.4, respectively) ($F_{\text{TIME (1, 59)}} = 60.901$, $p < .001$). There was neither a significant effect of CV RISK LEVEL alone ($F_{(1, 59)} = 0.090$, $p = .765$) nor a significant interaction ($F_{(1, 59)} = 1.096$, $p = .299$).

There were no significant main effects or interactions for FP I and FP II (all $p > .05$).

3.4.7.2 Cardiovascular risk level and executive function

Independent samples *t*-tests indicated that there were no significant differences between risk groups for baseline executive function (Table 18). However, there was a trend for the high risk group to have a higher PE score than the low risk group (108.1 ± 21.0 and 100.5 ± 12.1, respectively).

Table 18. Executive Function Performance by Cardiovascular Risk Level

		CV Risk Level			
		Low Risk (*n*=41)	High risk (*n*=19)	*t* / *F*	*p*
PE	Pre	100.5 ± 12.1	108.1 ± 21.0	-1.775[a]	.081
	Post	104.2 ± 12.7	109.1± 18.8	0.547[b]	.463
NPE	Pre	97.6 ± 14.3	98.8 ± 17.4	-0.301[a]	.765
	Post	100.8 ± 14.4	100.3 ± 15.9	0.244[b]	.623
CR	Pre	95.8 ± 12.7	99.8 ± 18.9	-0.957[a]	.343
	Post	100.3 ± 12.2	102.3 ± 16.4	0.545[b]	.463

Note. Dependent variables reported as mean ± standard deviation. Scores were standardised based on age and years of education. Higher scores indicate better performance. CV = cardiovascular, PE = Perseverative Errors, NPE = Nonperseverative Errors, CR = Conceptual Level Responses, Pre = pretest, Post = posttest.

[a] *t* = independent samples *t*-test for baseline scores. [b] *F* = two-way repeated measures ANOVA of the interaction of TIME X CV RISK LEVEL.

To determine whether baseline cardiovascular risk level affected the change in executive function, a 2 X 2 repeated measures ANOVA was conducted to test the interaction of CV RISK LEVEL (low risk, high risk) X TIME (pretest, posttest).

For PE and NPE, there were no significant main effects or interactions (all $p > .05$) (Table 18 and Figure 16).

CR scores tended to increase overall from pretesting (97.1 ± 14.9) to posttesting (101.0 ± 13.5) ($F_{\text{TIME (1, 58)}} = 6.406$, $p = .014$). However, the main effect of CV RISK LEVEL ($F_{(1, 58)} = 0.626$, $p = .432$) and the interaction effect ($F_{(1, 58)} = 0.545$, $p = .463$) were not significant.

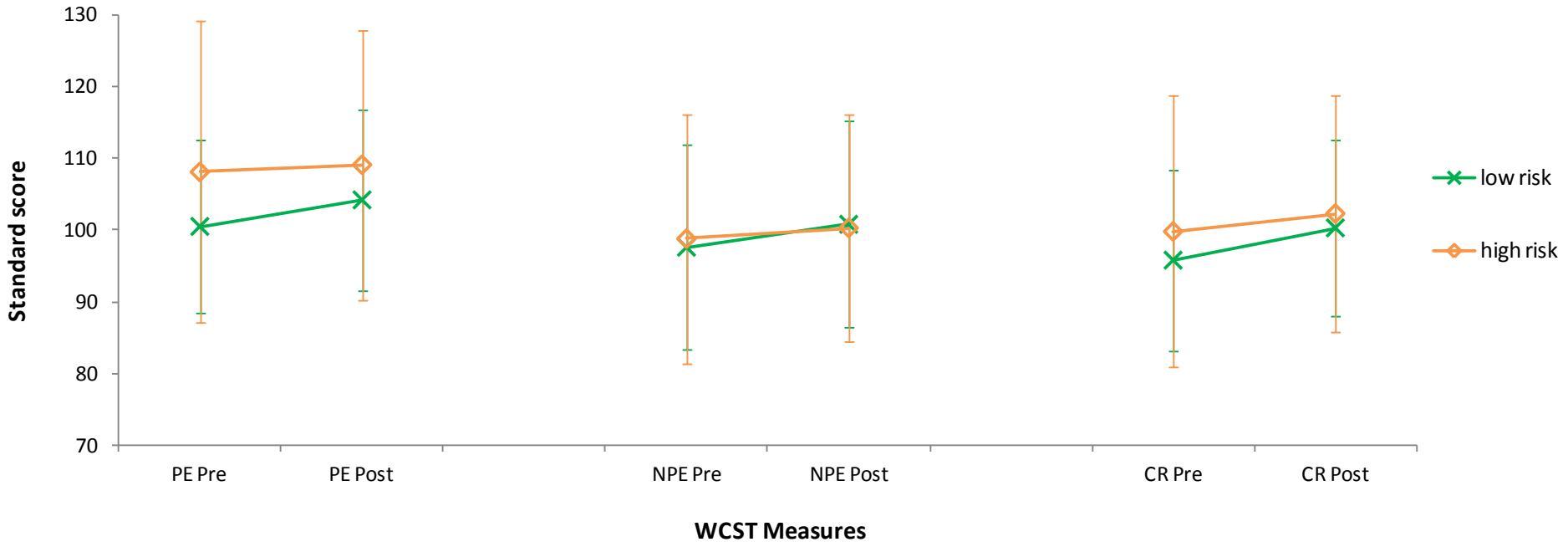

Figure 16. WCST scores by cardiovascular risk level from pretest to posttest.

WCST scores were standardised based on age and years of education. Higher scores indicate better performance. PE = Perseverative Errors, NPE = Nonperseverative Errors, CR = Conceptual Level Responses, Pre = pretest, Post=posttest.

3.4.8 Interactions between activity and cardiovascular risk on cognitive function

The results of this study have reported on the individual influences of physical activity and cardiovascular risk on changes in cognitive function. Final analyses were conducted to test how physical activity and cardiovascular risk interacted with respect to changes in memory and executive function.

It was decided to analyse these interactions with respect to *activity status*, not intervention group. As previously reported in Section 3.4.3, the effect of physical activity on cognitive function was stronger when the pedometer and exercycle groups were considered together and compared to the control (non-activity) group.

In order to illustrate the proportion of low and high risk participants belonging to each of the activity and control groups, a 2 X 2 cross-tabulation with Fisher Exact Chi-Square statistics was conducted. In the activity group, 34.1 % of participants were classified as high cardiovascular risk, while 25.0% of control participants were of high risk (Table 19). There was no significant difference in risk level classification between the activity and control groups (p = .564, two-sided).

Table 19. Cross-tabulation of Group and Risk Level.

			CV risk level		
			Low	High	Total
Activity Status	activity	Count	27	14	41
		% of activity status	65.9%	34.1%	100.0%
	control	Count	15	5	20
		% of activity status	75.0%	25.0%	100.0%
Total		Count	42	19	61
		% of activity status	68.9%	31.1%	100.0%

Note. CV = cardiovascular.

3.4.8.1 Interaction of activity and cardiovascular risk for memory

A 3-way ANOVA (2 X 2 X 2 repeated measures) was conducted with ACTIVITY STATUS (activity, control) and CV RISK LEVEL (low risk, high risk) entered as between-subject factors and TIME (pretest, posttest) entered as the within-subjects factor. Logical Memory I was chosen as the dependent variable of interest given that changes over time were found to be significantly affected by cardiovascular risk level.

There was a trend for the "activity+high risk" group to improve LM I score to a greater extent than the other groups with the three-way interaction approaching statistical significance ($F_{(1, 57)}$ = 2.359, p = .130) (Table 20 and Figure 17).

Table 20. Interaction of Activity Status X Risk Level X Time for Logical Memory I

		Activity		Control			
		Low CV Risk (*n*=27)	High CV Risk (*n*=14)	Low CV Risk (*n*=15)	High CV Risk (*n*=5)	*F*	*p*
LM I	Pre	10.4 ± 2.2	10.0 ± 2.7	11.3 ± 2.8	12.0 ± 2.5		
	Post	12.6 ± 2.6	14.1 ± 2.6	13.4 ± 2.6	13.8 ± 3.7	2.359	.130

Note. LM I scores reported as mean ± standard deviation. LM I was standardised based on age. CV = cardiovascular, LM I = Logical Memory I, Pre = pretest, Post = posttest, *F* = three-way repeated measures ANOVA interaction.

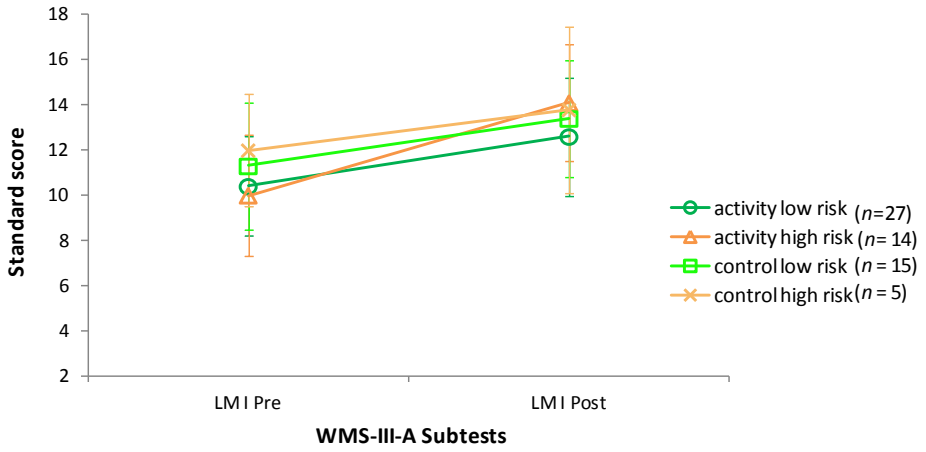

Figure 17. Interaction between activity status, risk level and time for LM I.
LM I was standardised based on age. LM I = Logical Memory I, Pre = pretest, Post = posttest.

3.4.8.2 Interaction of activity and cardiovascular risk for executive function

A 3-way ANOVA (2 X 2 X 2 repeated measures) was conducted with ACTIVITY STATUS (activity, control) and CV RISK LEVEL (low risk, high risk) entered as between-subject factors, and TIME (pretest, posttest) entered as the within-subjects factor.

PE and CR were chosen as the dependent variables of interest as these were affected by activity status to a greater extent than NPE. Participants in the "control+high risk" category showed a significant decline in PE and CR scores over time, while the other group combinations improved. There were significant interactions of TIME X ACTIVITY STATUS X CV RISK LEVEL for PE ($F_{(1, 56)} = 6.957$, $p = .011$) and CR ($F_{(1, 56)} = 4.652$, $p = .035$) (Table 21 and Figure 18).

Table 21. Interaction of Activity Status X Risk Level X Time for WCST Scores

		Activity		Control			
		Low CV Risk (*n*=26)	High CV Risk (*n*=14)	Low CV Risk (*n*=15)	High CV Risk (*n*=5)	*F*	p
PE	Pre	97.9 ± 12.7	106.9 ± 22.6	104.9 ± 9.8	111.4 ± 17.4		
	Post	102.4 ± 12.3	113.6 ± 16.2	107.3 ± 13.1	96.2 ± 21.3	6.957 *	.011
CR	Pre	93.5 ± 12.3	98.6 ± 20.5	99.9 ± 12.9	103.2 ± 14.8		
	Post	98.7 ± 12.9	104.8 ± 15.9	103.3 ± 10.6	95.2 ± 17.6	4.652 *	.035

Note. Dependent variables reported as mean ± standard deviation. PE and CR were standardised based on age and years of education. Higher scores indicate better performance. CV = cardiovascular, PE = Perseverative Errors, CR = Conceptual Level Responses, Pre = pretest, Post = posttest, *F* = three-way repeated measures ANOVA interaction.
* $p < .05$.

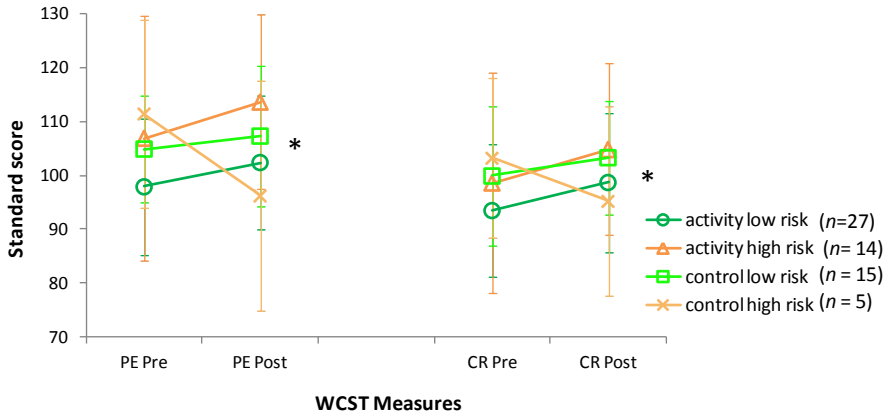

Figure 18. Interaction between activity status, risk level and time for PE and CR.
WCST scores were standardised based on age and years of education. Higher scores indicate better performance. PE = Perseverative Errors, CR = Conceptual Level Responses, Pre = pretest, Post = posttest.
* $p < .05$ represents a significant interaction of ACTIVITY STATUS X CV RISK LEVEL X TIME.

3.4.9 Summary of Results

The main study utilised a quasi-experimental design comparing the effects of monitored pedometer and exercycle programs against a control group on changes in memory and executive function in middle aged individuals. This study also undertook to investigate these changes in cognitive function with respect to participant cardiovascular function and risk of cardiovascular disease.

The pedometer and exercycle programs were successful in terms of overall high compliance and attendance rates. While average physical activity levels for the pedometer program (steps) and exercycle program (cycling distance) improved over

the duration of the study, there was a wide range in percent change in physical activity level achieved by the participants.

There was no significant effect of group assignment on memory performance. And, change in physical activity level (steps/cycling distance) was not related to change in any memory score. When the two physical activity groups were combined and compared against the control group, there was still no significant effect of activity on memory.

There was no significant effect of intervention group on executive function. Change in executive function measures were not predicted by change in physical activity level achieved over time. However, when the pedometer and exercycle groups were combined and analysed against the control group, Perseverative Errors scores improved to a greater extent for those involved in any activity compared to controls.

Compared to sedentary behaviour, involvement in any activity led to improvements in cardiovascular function, namely systolic and diastolic blood pressure and Heart Age, with maintenance of fasting glucose levels.

Regardless of group assignment, decreases in systolic blood pressure from pretest to posttest were associated with improvements in immediate logical memory over time. In contrast, executive function scores were not associated with changes in cardiovascular function.

Individuals with higher risk of cardiovascular disease demonstrated greater improvement in immediate logical memory compared to those of lower risk. In fact, the relationship between systolic blood pressure and immediate logical memory was significantly stronger for those of higher risk. Cardiovascular risk level did not, however, moderate the degree of change in any executive function score.

The interaction between activity status and cardiovascular risk level failed to reach statistical significance for immediate logical memory. There was a trend for “activity+high risk” participants to improve to a greater extent than other participant categories. The interaction was, however, statistically significant for both Perseverative Errors and Conceptual Level Responses scores, with “control+high risk” participants demonstrating declines in executive function compared to improvements for all other groups.

3.5 Discussion

The primary aim of this controlled intervention study was to compare the effects of two highly contrasting physical activity programs (walking versus vigorous exercycling) against a control group (no exercise) on memory and executive functioning in middle age. This research was based upon the concept of cognitive reserve which posits that healthy lifestyle choices such as physical activity can protect cognitive function against age-related decline through increased complexity and efficiency of neural networks (Scarmeas & Stern, 2003). Research outcomes from this study could provide further evidence for how this reserve may be built / accessed in normal middle aged individuals through behavioural assessments of memory and executive function. Detailed physical activity programs specially designed for their inclusion into workplace settings were employed to determine if the nature of physical activity would cause differential change in cognition.

The secondary aim was to investigate whether changes in cognitive performance would be related to changes in cardiovascular variables. This secondary aim would provide a unique contribution to the cognitive reserve literature by: determining if cardiovascular mechanisms provide a likely mediator for changes in cognitive performance; and more importantly, by investigating whether cardiovascular risk level influences how labile cognitive function is in middle age.

3.5.1 Physical activity and memory function

It has been suggested that physical activity can lead to improved memory function (Hassmen & Koivula, 1997; Hill et al., 1993; S. Stroth et al., 2009) through enhanced functioning of the hippocampal formation (Nithianantharajah, Hannan, Nithianantharajah, & Hannan, 2009). For the current study, behavioural measures of episodic memory were determined using the WMS-III-A Logical Memory and Family Pictures subtests. These tasks require the individual to recall not only content- but contextual-based information. These are comparable to memory tasks required in everyday living and are sensitive to age-related declines (Price, Said, & Haaland, 2004). Results showed that study participants improved performance on verbal memory scores (i.e. Logical Memory Immediate and Delayed) from pretest to posttest. However, there were no significant differential effects of physical activity intervention on changes in episodic recall – visual or auditory, immediate or delayed. Further analysis indicated that the change in physical activity level over time within each group (i.e. changes in steps or distance) did not predict the level of change in memory. That is, memory performance did not depend on “how hard” participants worked over the course of the exercise programs.

There was a trend, however, for the two physical activity groups to behave similarly from pretest to posttest for Logical Immediate Memory (LM I). Thus, the pedometer and exercycle group participants were combined into an "activity" group to determine if *any* physical activity program would lead to significantly greater improvement in LM I compared to the control group. The difference between the groups approached, but did not reach, statistical significance.

The majority of previous intervention studies have also reported no differential effects of physical activity intervention on episodic memory (Blumenthal et al., 1991; Fabre et al., 2002; Klusmann et al., 2010; Kramer et al., 2001; Masley et al., 2009; Oken et al., 2006; Perri & Templer, 1984; Ruscheweyh et al., 2009; Williamson et al., 2009).

Studies which have demonstrated positive effects of physical activity on episodic memory are fewer (Hassmen & Koivula, 1997; Hill et al., 1993; S. Stroth et al., 2009; Young, 1979). Of these, the most comparable study to this current project employing the Wechsler Memory Scale (WMS) is that by Hill et al. (1993). These investigators studied 121 individuals aged 60-73 years who were assigned to either an aerobic endurance group (walking/running) or a non-exercise control group. The WMS Logical Memory test (immediate recall) was conducted at baseline and after 9 months-1 year of exercise. Upon completion of the interventions, immediate memory scores had declined for controls but were maintained for exercisers (Hill et al., 1993). That is, exercisers did not improve over time but may have been protected against decline.

There are differences in design between this study and Hill et al. (1993) which may account for the discrepant results. Firstly, the age range of the cohort in Hill's study is much older. Declines for non-exercising controls may certainly be more precipitous for an older aged cohort than a middle aged one. This may more readily highlight any potential effects of physical activity engagement on memory.

Secondly, the group sample sizes were much larger for Hill et al. (1993). A major limitation of the current study is its sample size with relatively lower statistical power. A larger number of recruited participants in each group may have allowed the detection of significant differences between the activity group and controls for memory. The method of recruiting volunteers through specific workplaces limited the pool of participants meeting the strict study criteria. However, delivering the exercise programs at the worksite was seen as an important vehicle for working middle aged individuals to access well-designed programs with plenty of social support for activity. Certainly, commitment to the programs was high with 97% of pedometer participants and 83% of exercycle participants completing the activity interventions (Figure 3).

Despite a larger recruitment sample, Hill et al. (1993) still suffered the loss of 100 participants from the initial 229 people recruited for the study (i.e. a very high attrition rate of 47%). This attrition is most likely due to the relatively long intervention period imposed on their participants. A recent meta-analysis by Colcombe and Kramer (2003) reported that interventions continuing for at least 6 months provided the optimum benefit to cognitive function. However, the drawback to such a long intervention is that those who remain in the study may differ in important ways from those who withdraw. For the current project, it was decided to keep the intervention shorter and include a number of motivational features (i.e. team competitions) in order to maximise participant involvement. With an overall attrition rate of 22% for the current study, the generalisability of the results is more certain.

It could be argued that physical activity groups in the current study did not work as hard as those in Hill's study leading to differences in memory outcomes. However, increases in physical activity level within each group were not correlated with changes in memory performance.

Any improvements noted in verbal recall from pretest to posttest may have been a consequence of practice effects, however, these effects were considered negligible for a number of reasons. First the decision to employ a four-month intervention phase allowed a six-month gap between cognitive function pre- and posttesting in order to ameliorate any effects of practice. This time period is in accordance with typical follow-up times for repeat neuropsychological assessments in clinical practice. Second, the use of a control group should provide some evidence to indicate whether changes in cognitive performance over time are merely a result of practice. Although the control group did improve verbal memory scores over time (which might indicate a practice effect), they did not show any learning effect for visual memory or executive function scores (as discussed below in Section 3.5.2). As well, control group participants in effect received an intervention –they were part of a health promotion research study and more importantly, they were given a cardiovascular risk report at baseline. As such, some control group volunteers may have changed other health behaviours over the course of the intervention period. Evidence of this was indicated by 57% of the control group decreasing their systolic blood pressure and 21% decreasing their Heart Age. Given the relationship between systolic blood pressure and verbal memory (but not visual memory or executive function) over time (as discussed below in Section 3.5.4), it is suggested that enhanced verbal memory may have been a consequence of other cardiovascular effects of study participation.

3.5.2 Physical activity and executive function

Park and Reuter-Lorenz (2009) argue that the adult brain responds to challenge by engaging in continuous functional reorganisation, so-called "scaffolding" (the authors' analogue to Stern's cognitive reserve model). The authors purport that frontal cortex is the most versatile structure in the brain and scaffolding through compensatory circuits largely resides in this area (Park & Reuter-Lorenz, 2009). There is certainly prior evidence supporting the effects of physical activity on frontal-lobe mediated executive functions (Albinet et al., 2010; Barry et al., 1966; Colcombe et al., 2004; Dustman et al., 1984; Elsayed et al., 1980; Hawkins et al., 1992; Klusmann et al., 2010; Kramer et al., 2001; Masley et al., 2009; Smiley-Oyen et al., 2008; Young, 1979). And, a burgeoning number of human studies in this area have indicated that physical activity is associated with morphological changes (e.g. increased volumes of grey and white matter) and recruitment of compensatory circuits in frontal regions (Colcombe et al., 2006; Floel et al., 2010; Hillman et al., 2004; Rovio et al., 2010).

The WCST was chosen as the tool for providing behavioural measures of underlying frontal lobe function through a set shifting protocol. The WCST has the advantage of providing measures of specific sources of difficulty on the test (Heaton et al., 1993). Higher Perseverative Errors scores indicate less perseveration and greater ability to maintain a shift in set. Higher Nonperseverative Errors scores represent fewer errors which are not perseverative. Higher Conceptual Level Responses scores indicate greater ability to demonstrate understanding/learning of the shifts in set. The WCST has ecological validity and people generally enjoy playing the card game. The test does not depend on speeded responses which ameliorates the confounding effects of age-related slowing of reaction times.

There was no significant effect of group assignment on change in WCST scores from pretest to posttest. In addition, improvements in WCST scores were not dependant on how hard participants worked (i.e. percent change in steps/distance over time).

Previous studies have supported the use of physical activity to improve executive functions using a variety of neuropsychological instruments most of which were speeded (Albinet et al., 2010; Barry et al., 1966; Colcombe et al., 2004; Dustman et al., 1984; Elsayed et al., 1980; Hawkins et al., 1992; Klusmann et al., 2010; Kramer et al., 2001; Masley et al., 2009; Smiley-Oyen et al., 2008; Young, 1979). Only two other intervention studies summarised in Appendix B used the WCST. Albinet et al. (2010) studied the effects of an aerobic program compared to a stretching program conducted for 12 weeks using 24 individuals aged 65-78. The investigators concluded that aerobic exercise differentially improved executive performance through reduced number of total errors on the WCST (Albinet et al., 2010). The study by Smiley-Oyen et

al. (2008) investigated the effect of either aerobic or stretching 10-month programs on cognitive function of fifty-seven older adults aged 65-79 years. Despite the improvement for aerobic exercisers on the Stroop Interference task, there were no significant effects on WCST number of total and perseverative errors.

For the current study, the pedometer and exercycle participants were combined into an activity group and compared against the control group. It is important to note that there was a non-significant trend for the control group to have higher PE scores at baseline compared to those assigned to an activity intervention. One unfortunate but unavoidable limitation of this study was that participants were not randomly assigned to intervention groups. In order to motivate employers to uptake and support the study and its workplace-based activity programs, it was decided not to randomly assign half of their employees to a non-exercise control group. Thus, recruitment of the control group (from the community) differed from that of the physical activity participants (from participating worksites). Since the PE score is adjusted for age and education, differences in these variables would not account for the trend. However, there may be some other unidentified participant demographics which would account for the baseline differences between groups.

The change in executive function scores from pretest to posttest was compared between the activity group and the control group. Individuals in the activity group demonstrated a significant improvement in PE scores while control scores showed a marginal decline. Given the higher baseline PE scores for controls, however, by posttesting both the activity and control groups performed similarly. One of the following effects may account for this result.

The first is that individuals involved in a physical activity program improved set shifting ability over time with little or no change for controls. Given the literature supporting the beneficial effect of physical activity on executive function in older aged individuals, the results could indicate that this effect is also found in middle age. However, we are unable to definitively conclude that it was the physical activity alone which led to improved performance. Could there be some other nebulous effects of involvement in a group activity program (e.g. socialisation, attention from researchers/instructors, the "feel-good" factor, encouragement from colleagues/supervisors)? Could the motivational tools developed for the current study (i.e. individual and group competitions) be responsible? Did involvement in physical activity cause transference to other positive health behaviours (e.g. better food choices, less alcohol)? Is physical activity just a general marker of good health? And is it the reduction of cardiovascular risk which impacts most on brain health and cognitive function?

The differential effect of activity on executive function may also have been exaggerated by combining the activity groups and thus increasing the statistical power. However, combining these groups was thought to be a way of determining from the data whether involvement in any activity program would lead to improved set shifting. In order to compare these unequal-sized groups, the SPSS Type III ANOVA model was employed which is equivalent to a weighted-squares-of-means technique.

It must also be considered that there were other effects (e.g. practice effects) affecting all participants but which impacted less on control outcomes because this group was already performing at a higher level. However, control scores had not reached a "ceiling", so this explanation is less likely.

It should be emphasized here that understanding the effects of activity on executive function may be limited by the use of only one test (WCST) in this study to assess one aspect of executive function (set-shifting). The term executive function represents a broad construct often used to describe a number of higher order cognitive processes. Miyake and Friedman (2012) postulate that executive function represents not only general goal-directed behaviour, but more specifically can be divided into set-shifting and updating abilities. Both limited budget and scope of the project precluded the use of additional test measures. Clearly, further research is needed to confirm the effect of physical activity specific to other non-speeded executive processes.

3.5.3 Physical activity and cardiovascular function

Compared to the control group, involvement in neither the pedometer nor exercycle interventions led to statistically significant changes in cardiovascular measures. This result was surprising. It has been well documented that regular aerobic exercise results in beneficial effects on the following cardiovascular variables: body weight and composition, resting blood pressure, serum triglyceride and cholesterol profiles (American College of Sports Medicine, 2006; World Health Organization, 2004). Adaptations to aerobic exercise usually begin to be evident after six weeks of training (McArdle et al., 2006).

A meta-analysis recently conducted by Bravata et al. (2007) concluded that pedometer-based walking programs can be effective for reducing body mass index and systolic blood pressure in particular. A limitation of the current study is that step counts were recorded by participants which depended on their honesty and accuracy. It was not feasible for the investigator to visit all participants at the same time every week to record step counts. Having sealed pedometers opened weekly by investigators may have provided more accurate representations of participant physical activity level.

The use of the LifeSprints® protocol in another training study was shown to positively affect body mass and composition and insulin resistance (Trapp et al., 2008). A limitation of the current study could be that the intervention was completely workplace-based. It could be that the exercycle participants in the current study were active only for the scheduled workplace sessions, and attitudes toward physical activity did not extend to activity at home or other health behaviours (e.g. nutrition).

Despite the non-significant result comparing the interventions, there was certainly a trend for both physical activity groups to normalise blood pressure and maintain fasting glucose over time. When activity interventions were combined and compared to controls, beneficial effects of activity on systolic and diastolic blood pressure and on fasting glucose were more clearly indicated. Thus, involvement in any physical activity may have beneficial results in normalising cardiovascular factors.

3.5.4 Cardiovascular function and memory function

A growing body of evidence has shown that elevated cardiovascular risk is associated with cerebral atrophy, white matter lesions, disturbed cerebral perfusion, reduced cerebral metabolism and impaired cognitive function (Richard, Ligthart, Moll van Charante, & van Gool, 2010; Rogers, Meyer, & Mortel, 1990; Stanek et al., 2011; Taylor & MacQueen, 2007). The hippocampus is particularly vulnerable to changes in blood flow and hippocampal dysfunction typically begins during the fourth decade of life accelerated by vascular disease (W. Wu et al., 2008). While most of these at-risk individuals would not show notable impairment on standard neuropsychological testing, persistent heightened risk will contribute to their heightened morbidity with ageing (Taylor & MacQueen, 2007). Previous studies have also indicated that reducing risk can enhance cognitive performance (Alagiakrishnan et al., 2006; Richard et al., 2010; Stanek et al., 2011). This research is also supported by the concept of brain reserve which purports that factors leading to higher functional neural networks (with sufficient perfusion and metabolism) would lead to improved cognitive performance (Richards et al., 2007).

The current study reported that Logical Memory I and II increased over time across the cohort, with physical activity behaviour not sufficient to fully explain the improvements in verbal memory. Although practice/learning effects were possible, these effects were not indicated for Family Pictures (visual memory). It is possible that some other factors were responsible for mediating these changes in Logical Memory. Given the association between cardiovascular risk and hippocampal-based functions in previous literature, further analyses on memory changes were conducted.

Correlational analyses tested whether changes in memory function were associated with changes in cardiovascular indices, independent of the intervention. Decreases in systolic blood pressure were significantly correlated with increases in Logical Memory I from pretesting to posttesting. That is, lowering systolic blood pressure was associated with improved immediate logical memory. The current study provided detailed cardiovascular risk reports to participants prior to the intervention period. This information alone may have motivated participants, regardless of the intervention, to lower their systolic blood pressure with resulting changes in memory functioning. This finding is supported by other studies which have demonstrated the benefits of lower systolic blood pressure levels in mid life (even within normotensive ranges) on cognitive performance (Hakamada-Taguchi et al., 2002; Richard et al., 2010).

The above results led the investigator to surmise that if cardiovascular factors played a role in memory function then individual baseline risk level may influence how memory scores would change over time. All participants were combined (collapsing across intervention groups) and classified as either low risk or high risk. There were no baseline differences between risk groups on pretest memory scores. However, high risk individuals improved Logical Memory I scores to a significantly greater extent than low risk individuals regardless of the intervention. At first this result may seem contrary to logic. Why would high risk individuals be more likely to improve their memory over time? A clearer picture emerges, however, when that result is considered in light of another finding - the relationship between decreased systolic blood pressure and improved immediate logical memory was significantly stronger for those of higher risk. That is, for high risk individuals, decreasing (i.e. normalising) systolic blood pressure had a greater impact on memory function than for those who were already of low vascular risk. For high risk participants, it is possible that by reducing systolic blood pressure, regular and sufficient hippocampal blood supply was improved, leading to significantly greater improvement in memory function. Unfortunately, investigations of changes in blood supply were well beyond the scope of the current project, but future imaging studies may provide further support for this idea.

An unexpected outcome was that there was no significant difference between the risk level groups for immediate logical memory at baseline. It has been suggested, however, that early hippocampal dysfunction due to vascular disease and inconsistent perfusion may not be detected on common behavioural tests (Taylor & MacQueen, 2007; W. Wu et al., 2008). Stern (2006) purports that individuals experiencing impairment may engage or recruit compensatory neural networks to return performance to a “normal” level . Increased recruitment of prefrontal structures during episodic memory retrieval in older individuals has been suggested to provide

evidence of compensation for impairment (Grady, 2007; Madden et al., 1999). The results of the current study show that at baseline there was a strong trend for high risk individuals to demonstrate higher executive function (i.e. higher Perseverative Errors score) than low risk persons. If high risk participants were regularly activating prefrontal networks to support memory retrieval, these individuals may have built strong pathways for cognitive control resulting in relatively higher executive function ability. At this stage, we are unable to determine whether any compensation has taken place and its presence is purely speculative. Further research utilising fMRI and ERP studies are required to compare differences in neural activation patterns between high and low risk subjects at baseline and after interventions.

To get a complete picture of how effects of physical activity engagement and cardiovascular risk level may be linked over time, a three-way ANOVA was employed. The dependent variable chosen was Logical Memory I due to its previous association with cardiovascular risk. The three-way interaction closely approached, but did not reach, statistical significance. There was a trend, however, for high risk individuals involved in activity to improve immediate logical memory to a greater extent than the other group combinations.

A recent longitudinal study of women with high vascular risk reported that higher physical activity engagement was associated with slower decline for verbal memory, and with less consistent effects for executive function (Vercambre, Grodstein, Manson, Stampfer, & Kang, 2011). Therefore, it appears that individuals of high vascular risk can achieve benefit from physical activity.

However, research has not been conducted which investigates whether cognitive function in high vascular risk individuals will be more labile than that in lower risk persons. Only one other study by Smith et al. (2011) showed that physical activity (PA) selectively improved memory-related brain activation for high risk individuals (in this case, APOE-ε4 allele carriers) compared to high PA/low risk, low PA/high risk, or low PA/low risk. Further research in this area is needed to determine if cognitive function can be selectively improved for high risk groups.

3.5.5 Cardiovascular function and executive function

The reduction of cardiovascular risk may ensure frontal lobe integrity and function in the same way as that for hippocampal-based memory. However, results of the current study did not demonstrate any significant associations between change in WCST measures and change in cardiovascular risk variables.

Contrary to the results for episodic memory, changes in WCST scores were not moderated by baseline cardiovascular risk level. However, there was a trend for high

risk participants to show a higher Perseverative Errors score at baseline. As discussed in the previous section, if the higher PE score is real, it may be a reflection of underlying compensatory processes for any risk-related dysfunction in other regions.

To determine if physical activity engagement and cardiovascular risk level interacted to affect executive function over time, a three-way ANOVA was employed. The dependent variables were Perseverative Errors and Conceptual Level Responses standard scores. These measures were chosen as they had previously been shown to be more affected by physical activity status than Nonperseverative Errors. These interactions were statistically significant for both WCST measures. Participants in the control group, who were classified as high risk, showed greater declines in PE and CR scores compared to small improvements for the other combination groups. It appears that individuals who were already of high risk and did not undergo an intervention fared worse than all other participants. A word of caution is required however. The "control+high risk" group only represented five participants and the variability around the means for this group was large. Given there was no association between WCST scores and cardiovascular measures and that there was no main effect of CV risk level on WCST scores, conclusions cannot be made with confidence on this interaction.

Conclusions and future directions

Despite the highly contrasting physical activity programs developed and implemented for this study, pedometer walking and exercycling did not differ in their effects on cognitive function and cardiovascular health outcomes. However, when walking and exercycling participants were combined, involvement in any activity program (compared to controls) resulted in significant improvements in aspects of executive function, mainly the ability to maintain a shift in set. Although it is does not appear to be the level of physical activity or exact exercise prescription which promotes such changes, there may be other influences at play which need to be further investigated. Other extraneous effects of involvement in group activity such as social support, reduced levels of stress and awareness of personal wellbeing may well be responsible for the changes that were noted. Future studies should aim to demonstrate which aspects of physical activity programming may be influencing these effects. Future research should also be aimed at further exploiting the changes in non-speeded executive function tasks which are ecologically valid. Such results can then be more easily extended to describe the effects on other daily living or workplace tasks.

Although the intervention programs did not significantly affect memory performance, this study was able to identify an important role of cardiovascular function specific to hippocampal-dependent processes. Improvements in systolic blood pressure were particularly beneficial for verbal memory performance and for individuals who were identified as being high risk. Future research could provide further evidence by recruiting equal numbers of high risk and low risk participants and then assigning half of each classification into intervention/control groups. This would require prescreening on the basis of cardiovascular risk testing or recruitment through GP referral processes. The challenge ahead is to be able to recruit sufficient numbers of individuals who are of higher risk but on no medication and who are able to safely participate in exercise. Future research in this area is exciting but relies on the collaboration of investigators who utilise ERP, imaging, behavioural measures, and physiological testing to fully understand the interplay between cardiovascular risk and neural correlates of cognition in middle age.

“It is important to realise that even a very modest effect of treatment aimed at a specific risk factor can have a major impact at population level if the risk factor is highly prevalent, the so-called prevention paradox” (Richard et al., 2010, p. 287). Certainly given the rising incidence of cardiovascular disturbances in progressively younger stages of adulthood, improving levels of risk among individuals may have great impact on the cognitive health of our ageing population. Multi-faceted programs (i.e. activity, nutrition, education) which focus on reduction of cardiovascular risk may

significantly improve the cognitive health and productivity of the ageing New Zealand population, leading to reduced burden of disease.

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Appendix A. Epidemiological Studies

Table A1. Epidemiological Studies Investigating the Association of Physical Activity and Cognitive Function

Study ID	*n* final	Baseline mean age (range) y	Design	Nature of self-report physical activity	Mean follow-up (y)	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
Abbott 2004	2257	76.9 (71-93)	Prospective	Distance walked per day	7	Clinical diagnosis of total dementia, AD, vascular dementia	Walking distance was associated with reduced risk of total dementia and AD. No association between distance walked and risk of vascular dementia.
Almeida 2006	601	77.5 (Range NR)	Prospective	Involvement in vigorous and non-vigorous activity during the week	4.8	MMSE (**G**)	Only vigorous activity associated with preserved cognitive function (MMSE ≥ 24) at follow-up.
Andel 2008	3134	48.1 (Range NR)	Prospective	4-point scale based on type of exercise from ages 25-50	31.4	Clinical diagnosis of dementia, AD	Case control analysis: light and regular exercise reduced risk of dementia and AD compared to hardly any exercise. Co-twin analysis: no significant results.
Angevaren 2007	1858	56.4 (45-70)	Cross sectional	Total time/week, estimated intensity (METs/week), number of activities	n/a	Verbal Learning (Dutch) (**EM**), Concept Shifting Task A, B (**PM**) and C (**E**), Stroop Colour (**PM**) and Interference (**E**), Letter Digit Substitution (**PM**), Word	No significant association between exercise time and cognition. Greater intensity and variety of activity related to higher **PM**, **EM**, and **E** scores.

Study ID	*n* final	Baseline mean age (range) y	Design	Nature of self-report physical activity	Mean follow-up (y)	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
						Fluency (**E**)	
Bixby 2007	120	78.9 (65-92)	Cross sectional	Composite score based on time and intensity of weekly physical activities	n/a	Stroop Colour (**PM**), Word (**PM**) and Interference (**E**)	Higher physical activity was associated with higher executive function but not perceptual motor performance.
Buchman 2008	521	82.3 (Range NR)	Cross sectional	Accelerometer plus self-report of time spent in activity/week	n/a	Battery of 19 cognitive tests. Global cognition score (**G**) and subscale composite scores for "semantic memory" (**AK, E**), "episodic memory" (**EM)**, "working memory" (**WM)**, "perceptual motor speed" (**PM**), "visuospatial ability" (**VS**, **E**).	No association between self-report activity and cognition. Higher actual activity (actical) associated with higher scores for **G** composite and individual subscales.
Bugg 2006	35	72.5 (61-88)	Cross sectional	Classed as active or sedentary based on time and intensity of daily living and exercise activities	n/a	Simple Reaction Time (**PM**), Working Memory Test (**WM**)	**WM** scores decreased from morning to evening in the sedentary group, while performance was maintained from morning to evening for active people.

Study ID	*n* final	Baseline mean age (range) y	Design	Nature of self-report physical activity	Mean follow-up (y)	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
							No significant associations with **PM**.
Carlson 2008	294	44.7 (Range NR)	Prospective	Participation in four physical activities: outdoor, sports, gardening, home improvement	28-36	Clinical diagnosis of dementia	Midlife physical activity did not modify dementia risk.
Cassidy 2004	270	74.6 (70-92)	Cross sectional	Three or more hours of physical activity/week (active), fewer than 3h/week (inactive)	n/a	Cambridge Cognitive Examination for Mental Disorders of the Elderly composite score (**G**)	No association between physical activity and global cognition score.
Chang 2010	4945	51 (Range NR)	Prospective	Classed by hours per week of physical activity (none, ≤ 5h, > 5h)	26	Battery of 9 cognitive tests with composite scores for “speed of processing” (**PM**), “memory” (**EM**), “executive function” (**E**, **WM**). Clinical diagnosis of dementia.	Both physical activity groups had higher performance scores across all three composites compared to no activity. Group with ≤ 5 hours less likely to have dementia than no activity group.
Christensen 1993	116	"Younger" (PhD students) "Older" (70+)	Cross sectional	Overall physical activity score calculated from time and intensity of daily and exercise activities per day	n/a	Ten cognitive tests loaded on to three factors: “fluid IQ”, “crystallized IQ” and “memory”	Higher physical activity was associated with higher fluid IQ in older subjects. No association between physical activity and crystallized IQ or memory for either age group.

Study ID	*n* final	Baseline mean age (range) y	Design	Nature of self-report physical activity	Mean follow-up (y)	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
Clarkson-Smith 1989	124	69.7 (Range NR)	Cross sectional	Classed as high exercise or low exercise based on weekly time engaged in different types of activities	n/a	Vocabulary (**AK**), Letter Sets (**WM**), Digit Span (**WM**), Reading Span (**WM**), Simple and Choice Reaction Time (**PM**), Common Word Analogies (**E**), Advanced Progressive Matrices (**E**), Letter Series Completion (**E**)	High exercise was associated with higher scores for **AK**, **E**, **WM** (except for Digit Span) and **PM**.
Dik 2003	1241	74.9 (62-85)	Retrospective	Categorised as: no, low, moderate or high physical activity based on time per week engaged in vigorous physical activity between the ages of 15-25 years	n/a	MMSE (**G**), Alphabet Coding (**PM**)	Men engaged in low to moderate physical activity in early life had higher **PM** scores in older age compared to no or high exercise groups. Physical activity was not related to **G**.
Eggermont 2009	544	78.2 (70-97)	Cross sectional	Quartiles based on time engaged in physical activities per week weighted by intensity of each activity	n/a	Letter Fluency (**E**), Category Fluency (**E**), Trail Making A (**PM**) and B (**E**), Clock-in-a-box (**G**), Hopkins Verbal Learning Test (**EM**)	Compared to least active, 3rd quartile had higher scores for Clock test (**G**), Category Fluency (**E**), Trail Making A (**PM**) and B (**E**), and top quartile had higher scores for Trail Making A (**PM**) and Category Fluency (**E**).
Emery	6979	44.3	Cross	Average daily time spent walking	n/a	Simple and Choice Reaction Time (**PM**), Incidental	Compared to low walking, moderate-high walking was associated with a more

Study ID	*n* final	Baseline mean age (range) y	Design	Nature of self-report physical activity	Mean follow-up (y)	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
1995		(18-94)	sectional			Memory (**EM**), Spatial Reasoning (**E**)	gradual age-related slowing of **PM**. Walking not related to **EM** or **E** scores.
Etgen 2010	3903	67.7 (55+)	Cross sectional	Categorised as: no, moderate or high activity based on number of days/week involved in strenuous activity	n/a	Short Blessed Test (**G**)	Baseline physical activity predicted higher **G** scores at baseline and two years later.
	3369	67.5	Prospective		2.2		
Flicker 2005	618	77.4 (74-83)	Prospective	Engaged in vigorous or non-vigorous exercise (Yes/ No)	4.8	MMSE (**G**)	Men engaging in vigorous exercise had higher **G** scores than those who did not.
Gallucci 2009	668	84.1 (70+)	Cross sectional	Walked and/or gardened every day (Yes /No)	n/a	MMSE (**G**)	Physical activity was associated with higher **G** scores.
Geda 2010	1324	Mean NR (76-86)	Cross sectional	Time and intensity of exercise within 1 year (late-life) and retrospectively at age 50-65 y (midlife)	n/a	Clinical diagnosis of cognitive impairment	Any moderate exercise at midlife or late life was related to reduced risk of MCI. Light physical activity (3-4 times/wk) in late life reduced risk of MCI.
Hillman 2006	241	"Younger" 25.5 (15-39)	Cross sectional	Rank ordered based on number of times per week physically active to cause sweating	n/a	Eriksen Flanker (**PM**, **E**), Digit Symbol (**PM**), Information (**AK**),	Higher physical activity was associated with faster reaction times for congruent (**PM**) and incongruent (**E**) Flanker tasks.

Study ID	*n* final	Baseline mean age (range) y	Design	Nature of self-report physical activity	Mean follow-up (y)	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
		"Older" 49.6 (40-71)				Similarities (**E**), Vocabulary (**AK**), Arithmetic (**WM**), Letter Number Sequencing (**WM**), Block Design (**VS**), Matrix Reasoning (**E**), Picture Completion (**E**)	Higher physical activity was associated with greater response accuracy for incongruent (**E**) Flanker task in the older group. No association of physical activity with other tests.
Huang 2009	681	93.5 (90-108)	Cross sectional	Habit of exercising almost every day classified as: "never", "in the past", "current"	n/a	MMSE (**G**)	Men with a habit of current exercise had higher cognitive function scores than those without habit.
Kareholt 2011	1643	57.4 (46-75)	Prospective	Participation in sports, gardening and/or dancing activities	22.8	MMSE (**G**)	Physical activity related to higher **G** scores for women.
Lam 2009	782	72.1 (60-79)	Cross sectional	Physical exercise practised for no years, <5 years or >5 years categorized as stretching (SE), aerobic (AE), or mind-body (MB) exercise	n/a	MMSE (**G**), Digit and Visual Span (**WM**), Category Fluency (**E**), List Learning 10 min Delayed Recall (**EM**)	Physical exercise > 5 years compared to no exercise had higher **E** scores. AE and MB exercising for > 5 years had higher scores for **G**, **EM**, Visual Backward Span (**WM**) and **E** compared to SE. No difference between MB and AE.
Landi 2007	363	85.9 (80+)	Retrospective	Participation in light-moderate and high intensity physical activity at 20-40 y, 41-60 y, and during the	n/a	Cognitive Performance Scale (**G**)	People with a history of higher intensity activity (regardless of age period) had

Study ID	*n* final	Baseline mean age (range) y	Design	Nature of self-report physical activity	Mean follow-up (y)	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
				last year			reduced risk of cognitive impairment.
Larson 2006	1740	74.4 (65+)	Prospective	Classed into: exercised <3 times/week or exercised ≥3 times/week	6.2	Clinical diagnosis of dementia, AD	Participants who exercised ≥ 3 times/ week had lower incidence of dementia or AD than those who exercised <3 times/week.
Laurin 2001	4615	Mean NR (65+)	Prospective	Composite score of "no", "low", "moderate" or "high" activity based on intensity of exercise	5	Clinical diagnosis of CIND, AD, dementia, vascular dementia	Among women a significant trend for reduced risk of CIND, AD and dementia with higher physical activity levels.
Lee 2009	537	73 (65+)	Prospective	Physical activity classed as "yes" (i.e. moderate activity 30 minutes X ≥5 times/week or vigorous activity 20 minutes X ≥ 3 times/week) or "no" if did not meet guidelines	2	MMSE (Korean) (**G**)	Physical activity was associated with higher **G** scores.
Lindwall 2008	813	75.1 (60-96)	Cross sectional	Grouped according to current status and change over the past year for participation in light and strenuous exercise	n/a	Word Recall (**EM**), Recognition of Position (**EM**), Vocabulary (**AK**), Digit Cancellation (**PM**), Digit Span (**WM**), Comparing Figures (**PM**), MMSE (**G**)	Men engaged in any light exercise (but not strenuous) scored higher than non-exercisers for **EM**, **AK**, **WM**, and **PM** (Digit Cancellation only). Men previously active in light exercise had lower **G** scores compared to those

Study ID	*n* final	Baseline mean age (range) y	Design	Nature of self-report physical activity	Mean follow-up (y)	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
							consistently active.
Lytle 2004	1146	76.8 (65+)	Cross sectional	Classed as “high”, “low” or “no” exercise based on type, frequency and duration of exercise	n/a	MMSE (**G**)	No association between baseline exercise and baseline **G** score.
	929	76.2	Prospective		2		High baseline exercise was associated with less decline of **G** at follow-up.
Middleton 2010	9344	71.6 (65+)	Retrospective	Classed as “active” or “inactive” based on participation in exercise at teenage, age 30, age 50 and late life (current)	n/a	Modified MMSE (**G**)	Active women at any life stage had higher **G** scores and less risk of cognitive impairment. Women inactive as teens but active at 30 and 50 had reduced risk compared to consistently inactive.
Middleton 2008	5376	74.3 (65+)	Prospective	Classed as "high" or "low/no” exercise based on intensity of weekly physical activities	5	Modified MMSE (**G**)	High exercisers had more frequent stable/improved **G** scores over time compared to low/no exercisers.
Newson 2006	96	63.3 (18-92)	Cross sectional	Composite score based on time/week and effort (scaled 1 to 20) spent on 10 physical activities	n/a	Visual Imagery Simple (**VS**) and Complex (**VS**, **WM**)	Physical activity level related to better **VS** and **WM** performance, particularly for older adults.
Perrot 2009	64	"Younger" 24.2 (20-30)	Cross sectional	Classed as "active" (> 4hr activity /week) or "inactive" (<2 hr/week)	n/a	Letter Sets Test (**E**), Figure Classification (**E**), Raven	For older adults, active subjects scored higher for all **E** tests than inactive. Younger active were not significantly

Study ID	*n* final	Baseline mean age (range) y	Design	Nature of self-report physical activity	Mean follow-up (y)	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
		"Older" 66.4 (60-75)		Also confirmed by MET-hr/week		Progressive Matrices (**E**)	different from younger inactive on any **E** test.
Podewils 2005	3373	74.8 (65+)	Prospective	Grouped into quartiles of weekly energy expenditure based on type, frequency and duration of activities Activity index based on number of activities.	5.4	Clinical diagnosis of all-cause dementia, AD, vascular dementia	Higher energy expenditure was associated with reduced risk of AD. Higher number of activities reduced risk for total dementia, AD and vascular dementia.
Powell 1971	48	50.2 (range NR)	Cross sectional	Classed as: "Exercisers" (running program for 3 years) or "Nonexercisers" (mainly sedentary)	n/a	Culture Fair Test (**E**)	No significant differences among groups.
Psaltopoulou 2008	732	Mean NR (60+)	Prospective	Estimated energy expenditure/day based on time involved in certain occupational and leisure activities	8 (median)	MMSE (**G**)	Physical activity positively related to **G**.
Rasmussen 2006	416	73.2 (Range NR)	Cross sectional	Classed as: “exercise” or “no exercise”	n/a	Blessed Test (**G**)	Exercisers had lower risk of cognitive impairment.
Ravaglia 2008	749	73.2 (65+)	Prospective	Grouped into tertiles based on weekly energy expenditure for different types of activities	3.9	Clinical diagnosis of dementia, AD, vascular dementia	Highest tertile of moderate and total physical activity lowered risk of dementia (but not AD).

Study ID	*n* final	Baseline mean age (range) y	Design	Nature of self-report physical activity	Mean follow-up (y)	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
							Upper tertiles of walking, moderate and total physical activity associated with reduced risk of vascular dementia.
Rebok 2001	24	71.2 (58-81)	Cross sectional	Type, time and intensity of activities (all participants already active)	n/a	Names and Faces (**EM**), Word List (**EM**), Digit Symbol (**PM**), Vocabulary (**AK**)	Time exercising was related to better performance on Word List (**EM**).
Richards 2003	1919	36 (all 36)	Prospective	Classed as: “no activity”, “1-4 activities” or “5+ activities” per month	7, 17	Word List Recall (**EM**)	Any exercise at 36 years was associated with higher **EM** scores at 43 years and slower rates of decline in **EM** between 43 and 53 years.
Rovio 2005	1251	50.6 (39-64)	Prospective	Classed as: "active" (at least 2 times /week) or "sedentary" (less than 2 times/week)	21	Clinical diagnosis of dementia, AD	Being active in mid life was associated with lower risk of dementia and AD.
Sabia 2009	5123	44.1 (35-55)	Prospective Cross sectional	Classed into "high" or "low" High activity was > 2.5 h/wk of moderate or > 1 h/wk of vigorous activity	11, 17 n/a	Composite score for **E** based on: Alice Heim, Phonemic Fluency, Semantic Fluency. Score for **EM** (Word Recall)	Low levels of activity at 11 and 17 years follow-up was associated with poor **E** function at the 17 year follow-up. Low activity at 17 years related to lower **EM**.

Study ID	*n* final	Baseline mean age (range) y	Design	Nature of self-report physical activity	Mean follow-up (y)	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
Schuit 2001	347	74.6 (65-84)	Cross sectional Prospective	Time per day engaged in physical activity	n/a 3	MMSE (Dutch) (**G**)	Prevalence of cognitive impairment higher among inactive (≤ 30 min/day) compared to more active at baseline. Change in activity over 3 year period significantly associated with change in **G** score.
Stewart 2003	207	64 (55-75)	Prospective	Involvement in regular physical activity over last year that caused sweating or increased heart rate (yes/no)	3	MMSE (orientation)(**G**), Word List Recall and Recognition (**EM**), Trail Making A (**PM**)	Vigorous baseline activity moderated age-associated declines in **EM** and **PM**.
Sturman 2005	4055	73.5 (65+)	Prospective	Hours of physical activity/week	6.4	Composite score for (**G**) based on: East Boston Immediate and Delayed Verbal Recall (**EM**), MMSE (**G**), Symbol Digit (**PM**)	Physical activity was associated with a slower rate of cognitive decline at follow-up, but lost significance after adjusting for cognitive activities.
Sumic 2007	64	88.5 (85+)	Prospective	Classed as: "low" (≤4 hours/week) or "high" (>4 hours/week) exercisers Number of blocks walked daily	4.7	MMSE (**G**), Clinical Dementia Rating Scale (**G**)	Women who exercised more than 4 hours/week had a lower risk of cognitive impairment. No association between distance walked and cognitive impairment.

Study ID	*n* final	Baseline mean age (range) y	Design	Nature of self-report physical activity	Mean follow-up (y)	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
Taafe 2008	2263	76.6 (71-92)	Prospective	Tertiles of physical activity based on estimated energy expenditure of daily activities	6.1	Clinical diagnosis of incident dementia, AD, vascular dementia	For men with low physical function, moderate or high physical activity reduced risk of dementia and AD (but not vascular dementia). No exercise effect for men with moderate / high physical function.
van Boxtel 1996	80	67.2 (55+)	Cross sectional	Composite score based on estimated daily energy expenditure of household, sport and leisure activities	n/a	Word Learning Task (**EM**), Concept Shifting Task A and B (**PM**) and C (**E**), Letter Digit (**PM**), Stroop Word (**PM**) and Interference (**E**), Category Fluency (**E**), National Adult Reading Test (Dutch) (**AK**)	Significant interaction of age and activity on Concept Shifting C and Stroop Interference (**E**) and on Letter Digit (**PM**). No other effects.
van Gelder 2004	295	74.9 (range NR)	Prospective	Minutes of physical activity per day Mean intensity of activity classed into quartiles.	10	MMSE (**G**)	Lowest quartile of intensity at baseline was associated with greater rate of cognitive decline. Decrease in physical activity duration or intensity over 10 years was associated with greater cognitive decline than stable physical activity levels.

Study ID	*n* final	Baseline mean age (range) y	Design	Nature of self-report physical activity	Mean follow-up (y)	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
Verghese 2006	437	79.2 (75-85)	Prospective	Composite score based on weekly participation in number of physical activities	5.6	Clinical diagnosis of aMCI, incident dementia	Physical activity did not affect risk of aMCI or dementia.
Weuve 2004	16466	74.2 (70-81)	Cross sectional Prospective	Estimated energy expenditure based on time/week engaged in specific physical activities "Baseline expenditure" based on mean of 5 reports over 8-15 years Quartiles of walking caloric expenditures.	n/a 1.8	Telephone Interview for Cognitive Status (**G**), East Boston Test (**EM**), Word Recall (**EM**), Category Fluency (**E**), Digit Span Backwards (**WM**)	Higher total physical activity was associated with higher baseline scores for all measures. Higher level of walking activity associated with all measures except **EM**. Higher baseline physical activity was associated with less cognitive decline for all measures except **E**.
Woo 2003	107	"Younger" 19.0 (Range NR) "Older" 71.0 (Range NR)	Cross sectional	Classed as: "low" or "high" exercisers based on participation in certain types of physical activities	n/a	Category Superiority Effect (Verbal and Pictorial) (**EM**), Kaufman Brief Intelligence Test Verbal (**AK**) and Matrices (**E**)	No effects of exercise on Kaufman Tests. For the younger group, high exercise improved memory with category support. In older adults, high exercise was related to similar performance for Verbal versus Pictorial recall (low exercisers performed more poorly with words than with pictures).

Study ID	*n* final	Baseline mean age (range) y	Design	Nature of self-report physical activity	Mean follow-up (y)	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
Wu 2011	2119	73.3 (65+)	Cross sectional	Leisure time physical activity classed as: "no", "low" or "moderate-vigorous" based on estimated energy expenditures /week	n/a	MMSE (**G**)	Higher physical activity was associated with reduced risk of cognitive impairment.

Note. AD = Alzheimer Disease, NR=not reported, MMSE = Mini Mental Status Examination, METs = metabolic equivalents, MCI = mild cognitive impairment, aMCI = amnestic form of mild cognitive impairment, CIND=cognitive impairment-no dementia.

†Executive Function (**E**) refers to tasks requiring the following processes: strategy development, set shifting, reasoning, problem solving, verbal and visual fluency, interference control, response inhibition and conflict resolution. Working memory (**WM**) refers to tasks requiring short-term rehearsal and manipulation of information. Episodic Memory (**EM**) refers to tests which assess declarative recall or recognition of verbal or visual information. **VS** refers to tasks assessing visuospatial ability. Perceptual motor performance (**PM**) includes all tasks which assess information processing speed with a simple behavioural response. **AK** refers to tasks assessing acquired knowledge and includes tests of semantic knowledge, vocabulary, and general information.Tests providing an overall measure of global cognitive function are coded as **G** (e.g. Mini Mental Status Examination or MMSE).

*Reported cognitive outcomes are statistically significant at $p < .05$.

Appendix B. Intervention Studies

Table B1. Intervention Studies Investigating the Effect of Physical Activity on Cognitive Function

Study ID	*n* final	Baseline mean age (range) y	Conditions	Duration of intervention	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
Albinet 2010	24	70.7 (65-78)	Aerobic (mixed), stretching	12 weeks	Wisconsin Card Sorting Test (**E**)	Aerobic group improved **E** performance.
Barry 1966	13	70.8 (55-83)	Exercise (aerobic, balance, flexibility, abdominal muscle endurance), control (no exercise)	3 months	Card Sorting (**PM**), Simple Reaction Time (**PM**), Raven's Progressive Matrices (**E**), Short-Term Retention (**WM**), Simple Addition (**WM**), Imaging (Phonemic Fluency) (**E**)	Experimental group improved on Imaging (**E**) and Card Sorting (**PM**). No significant changes for control group.
Blumenthal 1991	97	67.1 (60-83)	Aerobic (mixed), non-aerobic yoga, waiting list (control) Semi-crossover design	Up to 14 months	Randt Short Story (**EM**), Digit Span Forward and Backward (**WM**), Benton Visual Retention (**EM**), Selective Reminding (**EM**), Digit Symbol (**PM**), Trail Making B (**E**), 2 and 7 Test (**PM**), Non-Verbal Fluency (**E**), Stroop Interference (**E**)	There was no consistent effect of group assignment on cognitive outcomes.

Study ID	*n* final	Baseline mean age (range) y	Conditions	Duration of intervention	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
Blumenthal 1988	28	43.3 (30-58)	Aerobic (walk/jog), anaerobic (strength and flexibility)	12 weeks	Memory Search Test (**WM**)	Type of exercise training did not differentially affect **WM**.
Carral 2007	56	68.4 (65+)	Aquatics plus strength, aquatics plus calisthenics	5 months	MMSE (Spanish) (**G**)	Both groups improved general cognitive function score over time.
Colcombe 2004	29	65.6 (58-77)	Aerobic (walking), stretching and toning	6 months	Flanker Task Interference (**E**)	**E** improved over time (i.e. less interference) for the aerobic exercise group but not for the stretching and toning group.
Dustman 1984	43	60.1 (51-70)	Aerobic (walk/jog), strength and flexibility, control (no exercise)	4 months	Culture Fair (**E**), Digit Span Forward and Backward (**WM**), Digit Symbol (**PM**), Dots Estimation (**VS**), Simple Reaction Time (**PM**), Stroop Interference (**E**)	The aerobic exercise group improved over time for measures of **PM**, **VS**, and **E** (Stroop). Strength and flexibility group improved **VS** score. Control group improved Culture Fair score.
el-Naggar 1986	30	Mean NR (25-65)	All volunteers participated in a mixed aerobic program	4 months	Successive Numbers (**WM**), Digit Span (**WM**), Trail Making (**PM**), Space Relations (**VS**), Culture Fair (Classification and Conditions) (**E**)	Successive Numbers and Digit Span (**WM**) scores improved over time for all.
Elsayed	36	"Younger" 34.8	All volunteers participated in	4 months	Culture Fair (**E**), Cattell Sixteen	Participants scored higher at posttest than pretest for two of the four **E**

Study ID	*n* final	Baseline mean age (range) y	Conditions	Duration of intervention	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
1980		"Older" 52.9 (24-68)	a mixed aerobic program		Personality Factor (**AK**)	subtests.
Emery 1990	38	72 (61-86)	Aerobic (mixed), social activity, waiting list	12 weeks	Digit Span (**WM**), Digit Symbol (**PM**)	No significant changes over time to **WM** or **PM** scores regardless of group assignment.
Fabre 2002	32	65.9 (60-76)	Aerobic (walk/jog), mental training, combined aerobic and mental training, control (non-trained)	2 months	Full Wechsler Memory Scale (**WM**, **EM**, **AK**)	Verbal **EM** subtests (Paired Associates, Logical Memory Immediate) improved over time for all three trained groups. Total memory (sum of all subtests) improved more for combined aerobic and mental training than for other trained groups. Control group showed no significant changes.
Hansen 2004	36	19.1 (18-22)	Naval officers assigned either to aerobic (program NR) for 4 extra weeks or detraining (rest)	4 weeks	Composite Scores of: "Non-Executive" (Simple Reaction Time **PM** and Choice Reaction Time **PM**) and "Executive" (Serial Pattern Matching 1 and 2 **WM**), 2-Back Test (**WM**)	Trained group improved reaction time and accuracy for "executive" tasks (**WM**) on the posttest compared to the pretest. Detrained group improved reaction times for "non-executive" tasks (**PM**) on the posttest compared to the pretest.

Study ID	*n* final	Baseline mean age (range) y	Conditions	Duration of intervention	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
Harma 1988	72	35 (20-49)	Aerobic (mixed), control (no exercise)	4 months	Search and Memory Test (**WM**)	No significant differences between groups on changes to **WM** performance across day/night shifts.
Hassmen 1997	40	66 (55-75)	Exercise (walking), control group (mental tasks)	3 months	Word List Recall (**EM**), Face Recognition (**EM**), Simple and Choice Reaction Time (**PM**), Digit Span (**WM**)	All participants improved **PM** score over time. Male exercisers and male controls improved for word recall compared to female groups. Male exercisers improved face recognition over time compared to controls and females. Female exercisers improved **WM** compared to males and controls.
Hawkins 1992	36	68.2 (63-82)	Exercise (aquatics), control (weekly health newsletters)	10 weeks	Attentional Flexibility (**E**), Attentional Time Sharing (**E**)	Exercisers improved more than non-exercisers for **E** tasks requiring response to either alternating or simultaneous auditory and visual stimuli.
Hill 1993	121	64 (60-73)	Aerobic (walk/jog), control (no exercise)	1 year, could exit at 9 months if VO2 plateaued	Logical Memory Immediate (**EM**), Digit Symbol (**PM**), Crossing Off (**PM**)	After 1 year **EM** performance decreased for the control group but was maintained for the exercise group.

Study ID	*n* final	Baseline mean age (range) y	Conditions	Duration of intervention	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
Ismail 1981	48	42 (24-68)	Aerobic (mixed), control (no exercise)	4 months	Verbal Reasoning (**E**), Successive Numbers (**WM**), Digit Span (**WM**), Trail Making A (**PM**) and B (**E**), Space Relations (**VS**), Culture Fair (**E**).	Exercisers improved performance for Successive Numbers (**WM**). No significant changes over time for controls.
Kamijo 2007	26	73 (62-88)	Aerobic (walking), control (no exercise)	12 weeks	Response Compatibility (**PM** & **E**)	No significant effect of group assignment on behavioural measures.
Klusmann 2010	230	73.6 (70-93)	Aerobic and strength, computer course, control (no training)	6 months	Rivermead Story Recall (**EM**), Selective Reminding Test (**EM**), Trail Making B/A (**E**), Stroop Interference (**E**), Verbal Fluency (**E**)	Exercise and computer groups improved Story Recall (**EM**) with no change for controls. Exercise and computer groups maintained Selective Reminding (**EM**) and Trail Making (**E**) scores over time while controls declined.
Kramer 2001	124	66.6 (60-75)	Aerobic (walking), anaerobic (stretching and toning)	6 months	Visual Search (**PM**), Task Switching (**PM**, **E**), Response Compatibility (**PM**, **E**), Simple and Choice Reaction Time (**PM**), Stopping (**E**), Spatial Attention (**PM**, **E**), Rey Auditory Verbal Learning Test (**EM**), Self Ordered Pointing (**WM**), n-Back Spatial (**WM**), n-Back Verbal (**WM**), Face recognition (**EM**),	Exercise group improved over time compared to control group for Stopping (**E**), Task Switching trial time (**E**), Response Incompatible trial time (**E**).

Study ID	*n* final	Baseline mean age (range) y	Conditions	Duration of intervention	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
					Digit Digit and Digit Symbol (**PM**), Digit Span (Forward and Backward) (**WM**)	
Marmeleira 2009	32	68.3 (60-82)	Exercise (aerobic and physical tasks which demand perception and cognition), control (no program)	12 weeks	Simple and Choice Reaction Time (**PM**), Dual Task (Simple Reaction Time + addition) (**WM**), Trail Making B (**E**), Stroop Interference (**E**)	**PM** movement and response times, and Dual Task (**WM**) reaction and response times improved for exercise group over time compared to controls.
Masley 2009	91	47.3 (18-70)	Moderate aerobic program NR (3-4 days/week), frequent aerobic exercise (5-7 days/week), control (usual activity)	10 weeks	Composite scores for: "Memory" (Rey Auditory and Visual Learning **EM**), "Psychomotor Speed"(Finger-Tap, Symbol Digit **PM**), "Information Processing Speed" (Stroop **PM**, **E**), "Cognitive Flexibility" (Shifting Attention **E**, Stroop **PM**, **E**), "Complex Attention" (Continuous Performance **PM**, Shifting Attention **E**, Stroop **PM**, **E**).	Cognitive flexibility score improved over time with greater exercise frequency.
Muscari 2010	120	69.2 (65-74)	Aerobic (mixed), control (educational materials)	12 months	MMSE (**G**)	Control group significantly decreased **G** scores over time. Exercisers more likely to maintain or improve **G** score.

Study ID	*n* final	Baseline mean age (range) y	Conditions	Duration of intervention	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
Oken 2006	118	72.1 (65-85)	Aerobic (walking), yoga, control (wait list)	6 months	Stroop Interference (**E**), Covert Orienting (**E**), Intra Extra Dimensional Set Shift (**E**), Word List (**EM**), Letter Number Sequencing (**WM**)	No effect of group assignment on cognitive function.
Okumiya 1996	42	78.8 (75-87)	Aerobic and strength, control (no exercise)	6 months	MMSE (Japanese) (**G**), Visuospatial Cognitive Performance (**PM**)	No effect of group assignment on cognition.
Oswald 2006	309	79.5 (75-93)	Physical training (mixed aerobic), cognitive training (fluid abilities), psychoeducational training (coping skills), combined psychoeducational and physical, combined cognitive and physical, control (no training)	1 year	Global composite score (**G**) based on 14 tests assessing **AK**, **PM**, **WM**, **EM**, and **E**	Physical training alone did not improve global cognitive function. Only psychoeducational, cognitive, and combined training groups improved cognition.
Perri 1984	42	65.5 (60-79)	Aerobic (mixed), control (no exercise)	14 weeks	Rey Auditory Verbal Learning (**EM**)	No significant changes to **EM** for either group.
Rikli 1991	34	70 (57-85)	Aerobic (mixed), control (hobby class)	3 years	Simple and Choice Reaction Time (**PM**)	Exercisers improved **PM** score over time.

Study ID	*n* final	Baseline mean age (range) y	Conditions	Duration of intervention	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
Ruscheweyh 2009	62	60.2 (50-72)	Medium intensity aerobic (Nordic walking), low intensity stretching and toning, control (no exercise)	6 months	Auditory Verbal Learning Test (German) (**EM**)	No significant effect of group assignment on **EM**. Increases in total physical activity associated with improved **EM** across entire cohort.
Smiley-Oyen 2008	57	70.2 (65-79)	Aerobic (mixed), strength and flexibility	10 months	Simple and Choice Reaction Time (**PM**), Stroop Word and Colour (**PM**) and Interference (**E**), Incompatible Choice Reaction Time (**E**), Go/No Go (**E**), Wisconsin Card Sorting Test (**E**)	Aerobic exercise group improved only for Stroop Interference (**E**) compared to strength and flexibility training.
Stacey 1985	50	60.2 (50+)	New members, existing members of fitness club (all in exercise intervention: aerobic, flexing, balancing, swimming)	6 months	Simple Reaction Time Ruler Drop (**PM**), Digit Symbol (**PM**)	All exercisers improved **PM** scores over time. No between group differences.
Stevenson 1990	72	63.9 (60-81)	Low intensity, moderate intensity (both mixed aerobics and both led to similar increases in fitness)	9 months	Strub and Black Mental Status tests (NR) reduced to composite scores for: “attention /concentration”, “memory”, “higher cognitive function”	All composite scores improved over time for all participants. No significant effect of exercise intensity.
Stroth 2009	26	19.7 (17-29)	Aerobic (jogging, running), control (no exercise)	6 weeks	Visual and Verbal Immediate Memory Test Street Map and Building (**EM**), d2	Exercisers improved visual memory (**EM**) over time compared to controls.

Study ID	*n* final	Baseline mean age (range) y	Conditions	Duration of intervention	Neuropsychological instruments (Domain ID) †	Main reported outcomes*
					Test of Attention (**PM**)	
Taylor-Piliae 2010	115	69 (60-84)	Western exercise (aerobic, strength and flexibility), Tai Chi, control (healthy aging classes)	6 months	Semantic Fluency (**E**), Digit Span (**WM**)	Tai Chi participants improved **WM** more than western exercisers and controls.
Whitehurst 1991	14	65.8 (61-73)	Aerobic (cycling) or control (no exercise)	8 weeks	Simple and Choice Reaction Time (**PM**)	No significant effect of exercise on **PM**.
Williams 1997	149	71.7 (60+)	Exercise (aerobic, coordination, strengthening, flexibility), control (no exercise)	12 months	Simple Reaction Time (**PM**), Digit Span Forward and Backward (**WM**), Picture Arrangement (**E**), Cattell's Matrices (**E**)	Exercisers improved **WM** and **PM** scores over time compared to controls.
Williamson 2009	92	77.4 (70-89)	Exercise (moderate intensity aerobic, strength, balance and flexibility), health education	12 months	Digit Symbol (**PM**), Stroop Interference (**E**), Modified MMSE (**G**), Rey Auditory Verbal Learning Test (**EM**)	No significant differences between groups.
Young 1979	32	40.4 (23-62)	All participants in aerobic exercise program (mixed)	10 weeks	Digit Symbol (**PM**), Block Design (**VS**), Trail Making (**PM**, **E**), Crossing Off (**PM**), Visual Reproduction (**EM**), Associate Learning (**EM**)	Regardless of sex or age, there was significant improvement on **PM**, **E**, **VS**, and **EM** (Associate Learning).

Note. NR = not reported, MMSE = Mini Mental Status Examination.
†Executive Function (**E**) refers to tasks requiring the following processes: strategy development, set shifting, reasoning, problem solving, verbal and visual fluency, interference control, response inhibition and conflict resolution. Working memory (**WM**) refers to tasks requiring short-term rehearsal and manipulation of information. Episodic Memory (**EM**) refers to tests which assess declarative recall or recognition of verbal or visual information. **VS** refers to tasks assessing visuospatial ability. Perceptual-motor performance (**PM**) includes all tasks which assess information processing speed with a simple behavioural response. **AK** refers to tasks assessing acquired knowledge and includes tests of semantic knowledge, vocabulary, general information. Tests providing an overall measure of global cognitive function are coded as **G** (e.g. MMSE).
*Reported cognitive outcomes are statistically significant at $p < .05$.

Appendix C. Prescreen Recording Sheet

Healthy Body, Healthy Mind

Pre-Screen Interview Recording Sheet

Name _____

Address _____ Phone _____

_____ Email _____

_____

Gender (circle one): M / F

Date of Birth: _____ Education (last year completed): _____

Ethnicity: _____ Occupation: _____

1. Thinking over the last month, how many minutes each week are you involved in moderate to vigorous physical activity (physical activity which raises your heart rate and makes you sweat)? _____

2. What types of physical activities are these?

_____

_____

3. Are you a smoker? Y / N

On average, how many cigarettes do you smoke each day? _____

4. Have you been diagnosed or treated by a health professional for any of the following conditions? *(If yes, ask for further medical history and medications prescribed and place details in the space provided).*

a) Cardiovascular condition (incl. high cholesterol, high blood pressure, history of heart attack, stroke)	Y / N
b) Diabetes	Y / N
c) Neurological disorder	Y / N
d) Brain injury	Y / N

e) Psychological disorder	Y / N
f) Respiratory condition (incl. asthma)	Y / N
g) Current active infection	Y / N
h) Visual impairment (corrected or uncorrected)	Y / N
i) Hearing impairment (corrected or uncorrected)	Y / N
j) Recent musculoskeletal injury	Y / N
k) Any other existing chronic illness	Y / N

5. Are you currently taking any medications? Y / N

If yes, which medications are you taking and what are they for?

_____

_____

_____

Any recreational drugs? Y / N

6. Have you experienced any chest pain or dizziness during exercise? Y / N
If yes, describe the circumstances.

_____

_____

_____

Recruited? Yes / No
Group Assignment: 10,000 Steps / MELTDOWN / Control

Appendix D. Participant Satisfaction Survey

Participant Satisfaction Survey

I feel better about myself for completing this program.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree/ disagree	Agree	Strongly agree

I feel physically healthier for completing this program.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree/ disagree	Agree	Strongly agree

This program was convenient to complete.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree/ disagree	Agree	Strongly agree

I enjoyed participating in the program.

1	2	3	4	5
Strongly disagree	Disagree	Neither agree/ disagree	Agree	Strongly agree

What aspects of the program did you like?

What aspects of the program did you dislike?

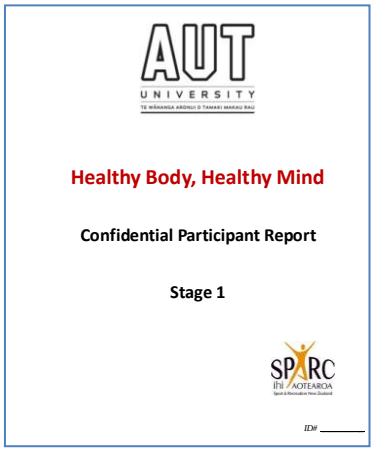
Figure D1. Questions from the Participant Satisfaction Survey for Study 1.

Appendix E. Summary Comments from Participant Satisfaction Survey

Table E1. Summary responses to open-ended questions of the Participant Satisfaction Survey

General comments (number of responses)
What aspects of the program did you like?
• Group exercise, group camaraderie, social support, more motivating than exercising alone (5)
• Maximum result for minimum time, only 30 minutes long (2)
• Supportive and motivating instructor (4)
• Cardiovascular checks before and after the program (2)
• Having program at work in a separate space (1)
• Having exercise "scheduled" (1)
• Ability to track progress (1)
• Feeling fitter (1)
• Option of days available for program attendance (1)
• Exercycling (1)
• Getting away from my desk (1)
• Feeling good after having done the exercise (1)
What aspects of the program did you dislike?
• Difficulty getting away from my desk three times per week (3)
• Missing lunch hour and time to interact with colleagues (3)
• The uncomfortable bike seats (1)
• At times feeling unmotivated to do the hard physical work (1)
• Shower facilities not cleaned to standard (1)
Did you experience any physical or psychological discomforts associated with the program? If YES, please indicate what these were.
• No (2)
• Muscle discomfort (3)
• Fatigue by the end of the day (1)
• Concerns about time away from the desk (1)
How could the program be improved or changed to suit your individual needs?
• More flexibility with times available (i.e. before and after work) (3)
• Longer duration (2)
• More variety in music (2)
• Something else to keep motivation or interest (2)

Appendix F. Health Check Report



AUT UNIVERSITY

Healthy Body, Healthy Mind

Confidential Participant Report

Stage 1

SPARC IHI AOTEAROA

ID# _____

Your other cardiovascular risk factors

Your blood was analysed under fasting conditions on _____

Total Cholesterol (mmol/L)	
Your result	**Classification**
	High (>6.22)
	Borderline (5.18-6.19)
	Optimal <5.18

HDL "Good" Cholesterol (mmol/L)	
Your result	**Classification**
	Protective (>1.55)
	Too Low (<1.03)

Colour Code
Very High Risk
High Risk
Could be better
Good
Great!

Fasting Blood Glucose (sugar) (mmol/L)	
Your result	**Classification**
	High (possible diabetes) (>7.0)
	Impaired (5.6-6.9)
	Optimal (3.9-5.6)

Your current estimated risk of cardiovascular disease

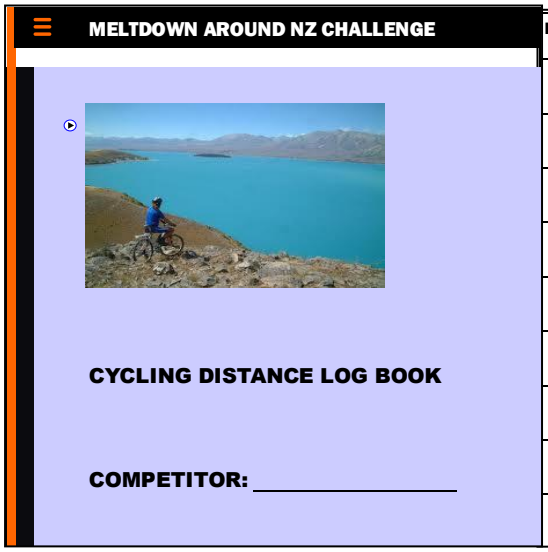
- Over the past 60 years and in cooperation with thousands of participants, researchers from The Framingham Heart Study have been working to identifying the common factors or characteristics that contribute to cardiovascular disease (CVD).
- Using a calculation from the Framingham study, we can estimate your risk of cardiovascular disease from your health screen data.
- Based upon your results your estimated 10-year risk of cardiovascular disease is _____.
- Although your chronological age is _____ your "heart age" has been estimated as _____.

IMPORTANT:

These predictions are based on only one test occasion and any abnormal results or concerns you have should be brought to the attention of your health practitioner.

Figure F1. Pages from the Health Report Booklet.

Appendix G. Exercycle Distance Diary



Date Attended	Distance Cycled	Comments

Figure G1. Pages from the exercycle diary.

Appendix H. Exercycle Tour Map and Weekly Progress

Royal Tour Itinerary

Overview

Start Auckland / Finish Queenstown

Distance: 2447 km

In 2002, the Prime Minister of New Zealand, Helen Clark, spent five days in the company of Peter Greenberg, Chief Correspondent for the Travel Channel. She showed Peter her view of New Zealand, which at times had him slightly terrified. This itinerary follows a similar path to that taken by the pair, experiencing the same activities, and adding a few more in along the way.

Tour Highlights:

- Auckland City
- Waikato Water Features
- Waitomo Caves
- Whakarewarewa
- Lake Taupo
- Trout Fishing, Turangi
- Mt Ruapehu
- Mangaweka Gorge
- Kapiti Coast
- The Windy Capital City!
- Biking Break—Cook Strait Ferry
- Picton
- Beachside Nelson
- Abel Tasman Park
- Westport
- Gold Mining in Greymouth
- Franz Josef Glacier
- Fox Glacier
- Haast Pass
- Warbirds in Wanaka
- Skiing in Queenstown
- Lake Te Anau
- Milford Sound
- Destination Queenstown!

Figure H1. Exercycle tour outline.

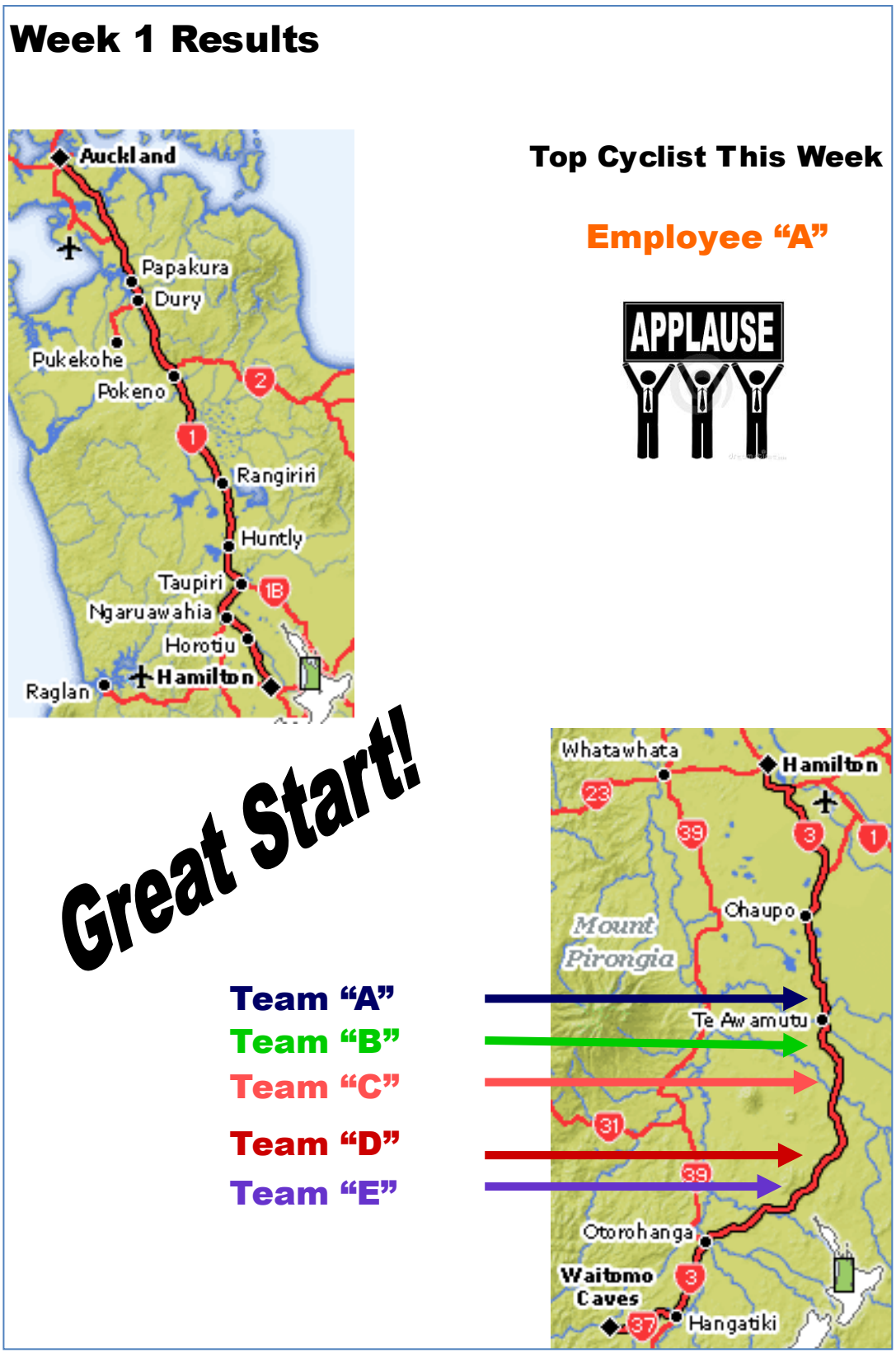


Figure H2. Exemplar exercycle progress map.

Appendix I. Correlation of Change in Physical Activity Level and Change in Memory Performance

Table I1. Correlations of Change in Pedometer Steps and Change in Memory

	Δ Steps	
	r	*p*
Δ LM I	.120	.594
Δ FP I	.185	.411
Δ LM II	.021	.927
Δ FP II	.027	.907

Note. *r* = Pearson correlation coefficient (two-tailed), Δ = posttest – pretest differences, Steps = average weekly pedometer steps, LM I = Logical Memory I, FP I = Family Pictures I, LM II = Logical Memory II, FP II = Family Pictures II.
Pedometer participants only (*n* = 22).

Table I2. Correlations of Change in Distance and Change in Memory

	Δ Distance	
	r	*p*
Δ LM I	.078	.752
Δ FP I	.052	.832
Δ LM II	-.001	.996
Δ FP II	.092	.707

Note. *r* = Pearson correlation coefficient (two-tailed), Δ = posttest – pretest differences, Distance = average session distance, LM I = Logical Memory I, FP I = Family Pictures I, LM II = Logical Memory II, FP II = Family Pictures II.
Exercycle participants only (*n* = 19).

Appendix J. Correlation of Change in Physical Activity Level and Change in Executive Function Performance

Table J1. Correlations of Change in Steps and Change in Executive Function

	Δ Steps	
	r	*p*
Δ PE	-.175	.447
Δ NPE	.346	.125
Δ CR	.094	.687

Note. *r* = Pearson correlation coefficient (two-tailed), Δ = posttest – pretest differences, Steps = average weekly pedometer steps, PE = Perseverative Errors, NPE = Nonperseverative Errors, CR = Conceptual Level Responses.
Pedometer participants only (*n* = 21).

Table J2. Correlations of Change in Distance and Change in Executive Function

	Δ Distance	
	r	*p*
Δ PE	.220	.365
Δ NPE	-.145	.552
Δ CR	.029	.908

Note. *r* = Pearson correlation coefficient (two-tailed), Δ = posttest – pretest differences, Distance = average session distance, PE = Perseverative Errors, NPE = Nonperseverative Errors, CR = Conceptual Level Responses.
Exercycle participants only (*n* = 19).

Appendix K. Cardiovascular Measures by Activity Status

Table K1. Cardiovascular Measures by Activity Status

		Activity status			
		Activity (*n*=41)	Control (*n*=21)	*t* / *F*	*p*
BMI (kg/m^2)	Pre	29.4 ± 5.8	27.6 ± 3.5	1.526[a]	.132
	Post	29.3 ± 5.6	27.7 ± 3.6	0.344[b]	.560
SBP (mmHg)	Pre	124.6 ± 10.5	116.2 ± 8.6	3.154[a] **	.003
	Post	118.2 ± 8.5	115.2 ± 10.1	5.110[b] *	.027
DBP (mmHg)	Pre	78.6 ± 8.1	72.5 ± 7.8	2.847[a] **	.006
	Post	73.7 ± 6.2	72.8 ± 7.7	5.744[b] *	.020
TC:HDL [c]	Pre	3.5 ± 1.0	4.2 ± 1.5	-2.240[a] *	.029
	Post	3.7 ± 1.2	4.5 ± 2.0	0.050[b]	.824
TRG[c] (mmol/L)	Pre	1.2 ± 0.6	1.2 ± 0.7	-.177[a]	.860
	Post	1.2 ± 0.7	1.4 ± 0.7	1.019[b]	.317
GLU[c] (mmol/L)	Pre	5.0 ± 0.7	5.1 ± 0.4	-.274[a]	.785
	Post	5.1 ± 0.6	5.4 ± 0.4	9.610[b] **	.003
Heart Age[c] (y)	Pre	48.5 ± 10.7	47.9 ± 11.1	.180[a]	.858
	Post	46.0 ± 10.0	49.8 ± 11.7	5.785[b] *	.019

Note. Dependent variables reported as mean ± standard deviation. BMI = body mass index, SBP = systolic blood pressure, DBP = diastolic blood pressure, TC:HDL = total cholesterol to high density lipoprotein ratio, TRG = triglycerides, GLU = glucose, Pre = pretest, Post = posttest.
[a] *t* = independent samples *t*-test (two-tailed) among groups for baseline measures. [b]*F* = two-way repeated measures ANOVA of the interaction of TIME X ACTIVITY STATUS.[c] Based on fasting whole blood capillary samples, control group (*n* = 19).
*$p < .05$.

Curriculum Vitae

Judy Thomas

Education

2008- PhD Candidate (Applied Science)
AUT University, Auckland
1997 Master of Science (Kinesiology - Exercise Biochemistry)
University of Western Ontario, London, Canada
1995 Bachelor of Human Kinetics (Honours)
University of Windsor, Windsor, Canada

Teaching Experience

Jan 2007-Dec 2011 Part-Time Lecturer/Tutor
AUT University
Lecturer - Human Anatomy & Physiology I, Oral Biology & Pathology, Physical Activity & Health (Workplace Health Promotion), Introductory Biology
Tutor - Human Anatomy & Physiology I, IIA, IIC

Apr 2005-Dec 2006 Lecturer
New Zealand College of Massage
Bachelor of Health Sciences – Anatomy & Physiology I
Diploma of Therapeutic Massage – Anatomy & Physiology I
Certificate of Relaxation Massage – Introduction to Anatomy & Physiology

Awards and Grants

2011 Winner – AUT 3 Minute Thesis Competition
2008-2011 AUT Vice-Chancellor's Doctoral Scholarship
2008-2011 SPARC NZ Project Grant
1995-1997 Natural Sciences & Engineering Research Council Scholarship (Canada)

Other Academic Activities

Ad hoc journal reviews for Health Promotion International

Professional Organizations

Society for Psychophysiological Research—Student Member

Publications

Conference Proceedings (peer reviewed)

Thomas, J. A. & Gaeta, H. (2011). Are memory and executive function moderated by cardiovascular risk? [Poster Session Abstract]. *Psychophysiology*, 48: S25.

Manuscripts (peer reviewed)

Thomas, J. A. and Noble, E. G. (1999). Heat shock does not attenuate low-frequency fatigue. *Canadian Journal of Physiology and Pharmacology*, 77(1), 64-70.