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Effects of long-term participation in tennis on cognitive function in elderly individuals

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MASTERS THESIS

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Effects of long-term participation in tennis on cognitive function in elderly individuals

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Declaration

I declare that this thesis does not incorporate without acknowledge any material previously submitted for a degree or diploma in any university of higher education, and that to the best of my knowledge it does not contain any materials previously published or written by another person except where due reference is made in the text.

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ABSTRACT

Many studies have reported the relationship between exercise and cognition with conflicting results. This may be due to differences in intervention durations, session lengths, intensities, and type of exercise. It has been suggested that exercises requiring greater cognitive demand such as football, basketball and racquet sports, are protective against cognitive decline, compared to less cognitively demanding exercises such as swimming, cycling and running, however, research concerning exercise types are currently limited. The present study tested the hypothesis that elderly individuals who had been regularly playing tennis more than 10 years, would have greater cognitive function than those who had been performing walking, swimming and running.

Twenty tennis players, and 23 closed-skilled exercisers (walkers, swimmers or runners) were recruited. Individuals who were healthy but not involved in any structured or purposeful exercise served as the control group (n = 19). All participants were aged between 62 and 75 years old. Participants in the tennis group had been playing tennis at least twice per week for 10 years, and the closed-skilled exercisers had been walking, swimming or running at least twice a week for 2 years. Participants in all the three groups were closely matched for gender, education (13.6 ± 3.0 y), BMI (27.8 ± 4.3), social network diversity, cognitive activity, depression, total physical activity energy expenditure (4285.4 ± 2723.4 kcal), and physical function. Global cognitive function was determined by the Montreal Cognitive Assessment (MoCA). The cognitive function of inhibition function was assessed by a modified Flanker test, and the cognitive functions of processing speed (simple reaction and choice reaction time), working memory, and learning and memory were assessed by a computer-based Cogstate test (CogState Ltd, Melbourne, VIC, Australia). Physical function was measured by a modified version of the senior physical fitness tests including chair sit and reach, 8-ft up and go, grip

strength, chair stand and the 6-minute walk tests. These variables were compared between the groups by one-way ANOVAs followed by Tukey's post-hoc tests.

The tennis group had faster ($P<0.05$) simple (323.3 ± 44.3 ms) and choice reaction time (518.3 ± 60.6 ms) compared to the closed-skilled group (391.1 ± 75.4 ms, 578.6 ± 69.6 ms). There were no significant differences between the groups for other cognitive variables including the MoCA test score (tennis: 23.7 ± 1.9, closed-skill: 25.4 ± 3.6, control: 26.7 ± 2.3). No significant differences in any of the physical function tests were found between the three groups. However, the 6-minute walk test distance was weakly correlated ($r_s = .274$, $P<0.05$) with working memory for all participants combined.

The present study confirmed previous study findings that elderly tennis players had faster processing speeds as represented by faster reaction times. This may be explained by the demand in tennis to respond to unpredictable stimuli within a dynamic and externally-paced environment. However, results did not support the hypothesis that tennis players would have greater executive function and memory performance. Compared with the normal reference values of the MoCA and Cogstate tests for the same age groups, the cognitive performance of the participants in the present study was better. It may be that the tests used in the study were not sensitive enough to detect possible differences in cognitive function between groups. However, it is possible that the influence of exercise choice (e.g. tennis vs closed-skilled) on the cognitive functions is small for older adults who are physically active and relatively fit. Further study is necessary to increase the number of participants in each group, and include more detailed investigation of the daily activities (e.g., reading, playing the music instrument) other than the exercise activities that the present study focused on (i.e., tennis, walking, running, swimming). It is also interesting to investigate the effects of the level of tennis (e.g., social vs competitive) on cognitive function.

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Chapter 1. INTRODUCTION

1.1 Background

Dementia is a clinical syndrome elicited by neurodegeneration of the brain, commonly caused by underlying pathologies such as Alzheimer's disease, vascular dementia, frontotemporal dementia and Lewy body (Prince et al., 2013). Currently, more than 353,800 Australians are living with dementia, resulting in the greatest cause of disability in older Australians aged over 65 years (Australian Institute of Health and Welfare, 2012). This clinical syndrome is characterised by the loss of independence and the rapid deterioration of cognitive function (Prince et al., 2013). Cognitive function includes a wide array of cognitive or mental abilities (Rasmussen & Laumann, 2013) ranging from higher-order processes such as executive functioning (responsible for decision making, goal planning, and choice behaviour), to more basic lower-level processes, such as simple and choice reaction time (Coles & Tomporowski, 2008). However, the decline in cognitive function is not limited to those with dementia, but also evident in normal aging (Salthouse, 2009).

1.2 Significance of physical activity

Several lifestyle factors appear to reduce the rate of cognitive decline in aging, and one of the most important factors is the participation in physical activity (Bherer, Erickson, & Liu-Ambrose, 2013). Observational epidemiological studies have provided sufficient evidence to warrant the Physical Activity Guidelines Advisory and the American College of Sports Medicine to recommend involvement in physical activity to attenuate cognitive decline (Chodzko-Zajko et al., 2009; Physical Activity Guildlines Advisory Committee, 2018). However, physical activity is a generic term that ranges from taking the dog for walk or hanging up the washing, to more purposeful exercises such as running or performing resistance exercises. Exercise is defined as subcategory of physical activity that is planned, structured and repetitive with a purpose of either maintaining or improving one or more components of physical fitness (Caspersen, Powell, & Christenson, 1985). The benefits derived from exercise intervention programs have differed in their effects on cognition (Kramer & Erickson, 2007). The variation in outcomes may derive from differing program durations, session lengths, intensities and types of exercise.

1.3 Aerobic exercise and cognitive function

The most commonly researched type of exercise on cognitive function is aerobic exercise. Aerobic exercise aims at improving cardiovascular fitness through exercises such as running, walking, swimming and cycling (World Health Organization, 2010). Many cross-sectional studies have found that higher levels of cardiovascular fitness are positively associated with greater cognitive function (Colcombe et al., 2004; Dustman et al., 1990; Shay & Roth, 1992; Van Boxtel et al., 1997; Weinstein et al., 2012). Weinstein et al. (2012) found that cardiovascular fitness was associated with greater performance in tasks requiring executive function and spatial working memory. Similarly, Colcombe et al. (2004) placed older adults into either a high or low cardiovascular fitness group, and showed significantly greater performance in an executive function task in the high cardiovascular fitness group. Observational studies are in agreement, having shown cardiovascular fitness to have protective qualities against cognitive decline (Aichberger et al., 2010; Barnes, Yaffe, Satariano, & Tager, 2003; Burns et al., 2008; Yaffe, Barnes, Nevitt, Lui, & Covinsky, 2001). For example, baseline cardiovascular fitness measured by VO_2 peak, has been predictive of greater global cognitive function, executive function, verbal memory and verbal fluency, after a six year follow up (Barnes et al., 2003). However, observational studies pose several disadvantages, because individuals with greater cognitive function are more inclined to participate in aerobic exercise in later life (Hall, Smith, & Keele, 2001). In addition, lifestyle choices that often co-vary with exercise may have influence on the rate of cognitive decline (Churchill et al., 2002). Last but not least, cardiovascular fitness can be improved by other types of exercise other than aerobic exercise, such as aerobically demanding sports. To investigate whether a causal relationship exists between aerobic exercise and cognitive function, intervention studies are necessary (Hötting & Röder, 2013).

Many studies have since examined possible cognitive benefits of aerobic exercise interventions with mixed results. One of the earliest intervention studies found that aerobic exercise improved several cognitive functions (Dustman et al., 1984). The study assigned sedentary individuals aged between 55-70 years of age into either an aerobic exercise group (fast paced walking or slow jogging), a strength and flexibility group, or a sedentary control group. After 4-months, only the aerobic group showed improvements in memory, processing speed, and executive function. This finding has been contradicted by studies that have found no cognitive benefits from aerobic exercise (Blumenthal et al., 1989; Hassmén, Ceci, & Bäckman, 1992; Hill, Storandt, & Malley, 1993). For example, Blumenthal et al. (1989) investigated changes in cognitive function in healthy older adults over a 4-month intervention, where subjects were randomly assigned into an aerobic exercise group (cycling, walking and jogging), a yoga and flexibility group, or a control group. Over multiple measures for the cognitive domains of memory, processing speed, visual attention, and executive function, improvements in a particular group could not be identified, and suggested any changes were likely due to a practice effect rather than the influence of aerobic exercise. Several large meta-analysis studies investigating randomised controlled trials in cognitively normal elderly adults, have found little to no effect of aerobic exercise on cognitive function (Angevaren, Aufdemkampe, Verhaar, Aleman, & Vanhees, 2008; Young, Angevaren, Rusted, & Tabet, 2015). Angevaren et al. (2008) examined the effect of aerobic exercise versus no intervention and found a significant improvement in the cognitive domains of motor function such as finger-tapping (effect size 1.17), and auditory attention (effect size 0.50), although nine out of the eleven cognitive functions included in the meta-analysis yielded no benefits of aerobic exercise. Finally, a more recent meta-analysis by (Young et al., 2015) showed no significant benefits of aerobic exercise across all ten cognitive functions.

In an attempt to provide an explanation for the variation in cognitive outcomes following aerobic exercise, several hypotheses have been proposed. One such hypothesis is the “cardiovascular hypothesis” which states that cognitive function changes are mediated by increases in cardiovascular fitness (Kramer et al., 1999). Although, a meta-analysis that found aerobic exercise improved cognitive function, concluded that an increase in cardiovascular fitness was not a prerequisite (Smiley-Oyen, Lowry, Francois, Kohut, & Ekkekakis, 2008). Furthermore, meta-analyses that have reported improved cardiovascular fitness following aerobic exercise, did not find a concomitant increase in cognitive function (Angevaren et al., 2008; Young et al., 2015). These findings suggest that if aerobic exercise could improve cognitive function, it was possibly due to physiological or psychological mechanisms other than cardiovascular fitness (Etnier, Nowell, Landers, & Sibley, 2006).

A second hypothesis proposed by Kramer et al. (1999) is the “selective improvement hypothesis”, which suggests the mixed findings may be due to certain cognitive functions being more responsive to exercise than others. This hypothesis was supported by the findings of their 6-months training study (Kramer et al., 1999). They demonstrated that only cognitive tasks that relied on executive function were improved by aerobic exercise, whereas more simple processes that were reliant on processing speed, showed no improvement. The “selective improvement hypothesis” was partially supported by Dustman et al. (1984) who found that aerobic exercise improved not only executive function, but also processing speed. Many studies have found conflicting data that did not support this hypothesis (Blumenthal et al., 1989; Fabre, Chamari, Mucci, Masse-Biron, & Prefaut, 2002; Legault et al., 2011; Moul, Goldman, & Warren, 1995; Oken et al., 2006). For example, Legault et al. (2011) found no change in executive function in the elderly following 4-months of aerobic exercise (walking or cycling). Oken et al. (2006)

compared aerobic exercise to yoga, and a control group, and found no improvements of processing speed, memory or executive function. As only a few studies have found benefits exclusive to executive function, it is possible that aerobic exercise does not specifically help to improve executive function (Diamond, 2015; Diamond & Ling, 2016).The inconsistent cognitive outcomes following aerobic exercise also appears to be evident in other types of physical exercise.

1.4 Resistance training and cognitive function

To date the focus has predominantly been on aerobic exercise, however emerging research suggests that other types of physical exercise may play a role in preserving cognitive function in older adults. A meta-analysis by Colcombe and Kramer (2003) found that a combination of training modalities (e.g. aerobic exercise and resistance training) may have a greater benefit to cognitive function than aerobic exercise alone (effect size 0.59 and 0.41, respectively). A previous study assessed changes in the cognitive functions of memory and processing speed in elderly participants following 8 weeks of resistance training, and 1 year after cessation of the intervention (Peig-Chiello, Perrig, Ehrsam, Staehelin, & Krings, 1998). Immediately following the intervention, significant improvements to short-term as well as long-term memory were seen in the resistance training group, but not in the sedentary control group. Moreover, the resistance training group maintained greater memory performance 1-year post the intervention. This finding was supported in a subsequent study which showed significant benefits to memory following 24-weeks of resistance training (Cassilhas et al., 2007). Regardless of either moderate intensity (50% 1RM) or high intensity (80% 1RM) resistance training, the cognitive functions of short-term and long-term memory and verbal reasoning were significantly improved when compared to the control group. Only the high intensity group showed additional improvements to attention. However, no changes were found to working memory (Cassilhas et al., 2007). It appears that relatively short intervention periods and lower intensities are adequate to elicit changes to short-term and long-term memory, although the positive outcomes of resistance training on short-term and long-term memory do not appear to extend to working memory (Cassilhas et al., 2007; Lachman, Neupert, Bertrand, & Jette, 2006; Liu-Ambrose et al., 2010; Liu-Ambrose et al., 2008). Working memory differs from short-term memory as it additionally requires active manipulation of maintained information, a process for which executive function is responsible (Engle, Tuholski, Laughlin, & Conway, 1999). For example, Brown, Liu-Ambrose, Tate, and Lord (2009) reported that 6-months of resistance training performed twice weekly, resulted in significant improvements to processing speed and long-term memory, but not working memory.

The effects of resistance training on tasks requiring executive function have been investigated in few studies. Kimura et al. (2010) examined the effects of a 12-week resistance training intervention in elderly participants, on the executive function task of task-switching. Although mental health significantly improved, no improvements to task-switching were found. More positive outcomes have been found in executive function tasks after 6-months of resistance training or longer. Using a 6-months home-based strength program, Liu-Ambrose et al. (2008) demonstrated a 12% improvement in inhibition function performance in the resistance training group, in comparison to the sedentary control group. However, no significant improvements were seen in task-switching or working memory. Subsequent studies supported this finding of improved inhibition function, but not task-switching or working memory (Liu-Ambrose et al., 2010). In the study, elderly participants were assigned to a resistance training group, either once weekly or twice weekly, or to a balance and toning control group. In contrast to their previous study, 6-months of resistance training was found to be insufficient in improving any components of executive function (inhibition function, task-switching, and working memory). However, after 12-months of resistance training, improvements to inhibition function in both resistance training groups were found. The contrast in findings following 6-months of resistance training on inhibition function, may be due to differences in resistance training frequency between the home-based program (3 times weekly) and the structured training sessions (once or twice weekly). A later study by Liu-Ambrose et al. (2012) used a different measure of inhibition function, and found 12-months of resistance training resulted in cognitive benefits to the twice-weekly resistance training, but not the once-weekly resistance training group. Ultimately, executive function benefits appear to be specific to inhibition function, but do not extend to the executive functions of task-switching or working memory.

1.5 Coordinative exercise and cognitive function

More recent research has explored types of exercise that are not as metabolically demanding as aerobic exercise and resistance training. Coordinative exercises require fine and gross motor coordination, such as balance and hand-eye coordination. Although many cross-sectional studies have indicated cardiovascular fitness to be associated with cognition, Voelcker-Rehage, Godde, and Staudinger (2010) found that motor fitness (coordinative ability), in addition to cardiovascular fitness, was associated with greater inhibition function and working memory in elderly adults. Moreover, only motor fitness was associated with attention. Training studies investigating the effects of coordinative exercise on cognition are encouraging. Brown et al. (2009) and Williams and Lord (1997) included coordinative exercises within a multicomponent exercise program and found improvements in fluid intelligence, attention and processing speed. Liu-Ambrose et al. (2010) compared resistance training once or twice per week to an active control group, which consisted of coordinative exercises such as tandem walking and single leg stance. These exercises were chosen as they were believed not lead to cognitive benefits, but after 12-months, the balance and toning group had significantly greater whole-brain volume compared to the resistance training group. The benefits of coordinative exercise to memory were demonstrated by Hötting et al. (2012) when comparing the effects of aerobic exercise to stretching and coordinative exercise, in middle aged adults. Following 6-months, both exercise groups significantly improved in short-term and long-term memory, compared to a sedentary control group. Although, only the stretching and coordinative exercising group significantly improved performance in attention. A longitudinal study by Voelcker-Rehage, Godde, and Staudinger (2011) demonstrated similar findings to their earlier cross-sectional study. Elderly participants were randomised into either an aerobic exercise group, coordination exercise group, or a relaxation and stretching group. Following 12-months, significant improvements to performance accuracy in an inhibitory function task were found in the aerobic exercise and coordinative exercise groups. However, improvements to perceptual speed were only found in the coordinative exercise group.

Cognitively demanding exercise and cognitive function

Several intervention studies have investigated cognitive outcomes from exercise performed in a computer-simulated environment (virtual-enhanced exercise). Maillot, Perrot and Hartley (2012) compared 12-weeks of physically demanding video game training (e.g. tennis on a gaming console), to a sedentary control group. It was found the virtual-enhanced exercise group improved cognitive function in several measures of executive function such as task-switching, inhibition function and processing speed. In a similar study, Anderson-Hanley et al. (2012) compared virtual-enhanced exercise (cycling while navigating through a 3D landscape) to aerobic exercise (cycling on a stationary bike). They showed that after 3-months, the virtual-enhanced exercise group had greater executive function in tasks requiring inhibition function and working memory, compared to the aerobic exercise group. It was suggested that the greater improvement to cognitive function in the virtual-enhanced exercise group was due to the additional cognitive demand of responding to challenges in a dynamic environment.

Cognitively demanding exercise also extends to more common types of exercise. Dance requires complex motor skills, memorisation of routines, attention and visuomotor integration (Merom et al., 2016). Similarly, Tai Chi is suggested to require attention and multitasking, in addition to processing speed and episodic memory when learning movement patterns (Yeh et al., 2014). Alves (2013) demonstrated that a 4-month dancing intervention resulted in significant improvements to visual processing (3.5%) and working memory (2.8%), compared to a walking group. On the other hand, Merom et al. (2013) found no significant changes to executive function or memory following 8-months of social dancing, but found marginal improvements to visuospatial learning and memory. A cross-sectional study by Man, Tsang, and Hui-Chan (2010) found that those practising Tai Chi at least 3 times per week for at least 3 years had greater cognitive function in attention, task-switching and verbal learning. Mortimer et al. (2012) demonstrated that 40-weeks of Tai Chi resulted in cognitive function improvements in processing speed, executive function and verbal learning, compared to a walking group. Furthermore, significant increases in whole brain volume for the Tai Chi group were concurrent with increases in cognitive function.

Animal research may offer an insight into the potential mechanisms underlying the cognitive benefits of cognitively demanding exercise. Voluntary exercise, in the form of wheel running, and environment enrichment have been shown to enhance neurogenesis in rodents (Fabel et al., 2009). Exercise appears to stimulate increases in proliferation of precursor cells, specifically in the dentate gyrus, whereas cognitive stimulus in the means of an enriched environment, or specific learning stimuli, provides a survival-promoting effect on new neurons (Fabel et al., 2009). Interestingly, the combination of exercise and cognitive stimulus has been shown to have additive effects, and can be viewed as exercise preparing the brain to respond to cognitive stimulation (Hötting & Röder, 2013).

1.6 Sports and cognitive function

Based on the review of the literature it can be assumed that certain sports positively influence cognition to a greater extent than others. Schmidt and Wrisberg (2008) suggested that sports could be divided into those requiring the performance of predominantly open motor skills, or closed motor skills. Open-skilled sports such as basketball, tennis or fencing, require immediate response to unpredictable stimuli within a dynamic and externally-paced environment. Whereas, closed-skilled sports such as running, swimming or cycling, take place within a stable, predictable environment, and are performed at a self-determined pace (Wang et al., 2013). It has been hypothesised that the unpredictability of open-skilled sports are more cognitively demanding and require the investment of greater cognitive effort (Huang, Lin, Hung, Chang, & Hung, 2014).

Several cross-sectional studies have compared elderly individuals participating in open-skilled sports, with those involved in closed-skilled sports. Spirduso and Clifford (1978) reported that elderly adults participating in open-skilled sports, specifically racket sports, had 3% faster simple reaction time and 6% faster choice reaction times in comparison to elderly adults that ran regularly. Dai, Chang, Huang, and Hung (2013) showed that elderly exercisers involved in at least 3-months of open-skilled sport, had 7% greater task-switching ability when compared to the closed-skilled group. These results were consistent with a later study by Tsai and Wang (2015) who showed that the open-skilled group had greater task-switching ability compared to the closed-skilled group. Tsai et al. (2016) reported that the open-skilled group, but not the closed-skilled group, had a greater inhibitory control compared to the sedentary control group. Although studies examining the effects of open-skilled sports are encouraging, a few studies have found that open-skilled sports had no additional improvement to cognitive function in comparison to closed-skilled sports. For example, Huang et al. (2014) investigated the cognitive function inhibition function, and found no differences between open-skilled and closed-skilled sports. Guo et al. (2016) reported that regular exercisers had greater visuospatial memory than sedentary individuals, but no differences were found between the open-skill and closed-skilled groups. An explanation for the varying outcomes among the studies could be attributed to differences in the specific sports that comprise the open-skilled sports groups. It is unlikely that all open-skilled sports improve cognitive function to the same extent. Rather, certain open-skilled sports have a greater effect on certain cognitive functions, more than others.

It appears the cognitive functions that are commonly performed within a specific open-skilled sport receive the greatest benefit (Voelcker-Rehage et al., 2011). This process, termed "cognitive skill transfer", is supported by several studies investigating cognitive function differences across sport types in young adults (Jacobson & Matthaeus, 2014). For example, fencing requires the inhibition of actions depending on fakes and feints by their opponents (Chan, Wong, Liu, Yu, & Yan, 2011). Chan et al. (2011) examined inhibition control in fencers and non-fencers at varying fitness levels, and found that fencers made significantly less errors (53%) than non-fencers. Individuals with greater fencing experience made significantly fewer errors than fencers with less experience. It could be concluded that the greater experience of inhibiting actions within the sport of fencing transferred to a non-sport specific context, and consequently improved the cognitive function of inhibition control (Jacobson & Matthaeus, 2014). Wang et al. (2013) compared university tennis players and swimmers of similar fitness levels in an inhibitory control task, and found tennis players required less time to inhibit their inappropriate response in comparison to the swimmers. This may be due to tennis players withdrawing pre-planned shots when their opponents shot exceeds the boundaries of the court and is deemed a fault, whereas the withdrawal of pre-planned actions are not typically demanding in swimming. These findings were complimented by Kida, Oda, and Matsumura (2005) who compared inhibitory control performance in university tennis players, baseball players and irregular exercising students. They found that tennis players had significantly greater inhibitory control than irregular exercising students. However, the baseball players demonstrated even greater inhibitory control performance than the tennis players. It may be that withdrawing pre-planned responses as seen when the batter withdraws from a pitch outside of the batters hitting zone, are more common in baseball than tennis. Moreover, after categorising the baseball players into their appropriate skill levels (low, medium, high, professional), they found that the greater the skill of the players, the greater the inhibitory control supporting the hypothesis that greater sporting experience of a cognitive function leads to improvements in that specific domain (Voelcker-Rehage et al., 2010). To further assess the relationship between task specificity and exercise type, tasks reliant on the same cognitive functions commonly used within a sport should be investigated. For example, tennis requires rapid processing of information and inhibition of irrelevant information and thus cognitive task demanding these cognitive functions are required to examine the possible transference of cognitive skills.

Voss, Kramer, Basak, Prakash, and Roberts (2010) further divided open-skilled sports into those that required coordination between a participant's body, parts of the body, or a held implement and an object in the environment such as tennis, table tennis and badminton (interceptive exercise) and those that were team based such as soccer, football, and volleyball (strategic exercise). The meta-analysis found athletes had greater attention and processing speeds in comparison to non-athletes, but interestingly the variable with the largest effect on cognitive function was involvement in interceptive exercise. The effectiveness of open-skilled sports, specifically interceptive sports, on cognitive function, needs further investigation.

1.7 Gaps in the literature

There is a dearth of literature on the effectiveness of tennis on cognitive function, despite tennis being a popular open-skilled (interceptive) sport attracting millions worldwide and enjoyed by individuals of all ages (Fernandez, Mendez-Villanueva, & Pluim, 2006). The physical and cognitive demands of tennis, and thus the potential cognitive benefits of tennis, may differ to other interceptive sports such as badminton or table tennis. Differences in aerobic capacity and strength have been seen among racket sports, presumably due to variations in the game constructs such as court dimensions, required grip strength, and energy systems predominantly used (Lees, 2003). To date the literature comparing tennis to closed-skilled sports has been limited to young adults and the effects of long-term participation on the maintenance of cognitive function in the elderly needs to be explored. Furthermore, the influence of tennis compared to closed-skilled sports on cognitive function in domains such as inhibition function, working memory, and processing speed, is essential to understanding the role of exercise on the maintenance of cognitive function in older people.

1.8 Purpose

The purpose of this project is to investigate the effects of participation in tennis as an open-skilled mode of exercise on cognitive function in the elderly, compared to closed-skilled exercisers and irregular exercisers. To this end, a cross-sectional analysis of tennis players, closed-skilled exercisers (walking, swimming, running), and irregular exercisers was undertaken. It was hypothesised that the longer an individual had been playing tennis, the greater the benefits to cognitive function. Therefore, it is critical that the study examines cognitive function in those that have participated in tennis for a long period of time (>10 years). A cross-sectional study is the ideal design to compare long-term participation across different exercise modes. The present study tested the hypothesis that tennis players would possess superior cognitive function compared to people who had been performing walking, swimming or running, which were considered to be less cognitively demanding.

1.9 Research Questions and Hypotheses

1. Do elderly individuals who exercise regularly (tennis and closed-skilled exercise) have greater cognitive function, as compared to sedentary individuals?
    - The regular exercising groups (tennis and closed skilled-exercise) will have greater cognitive function, as compared to the sedentary groups, especially in higher processes including executive functioning, memory and learning speed.
2. Do tennis-players have greater global cognitive function (MoCA) in comparison to closed-skilled exercise?

- The tennis-playing group will have greater global cognitive function as compared to the closed-skilled exercisers.

3. Do tennis-players have greater cognitive function in higher (e.g., inhibitory function and task switching) but not in simple processes (e.g., simple and choice reaction time), as compared to closed-skilled exercise?
    - The tennis group will show greater cognitive function in higher processes in comparison to the closed-skilled group. Although little to no difference will be seen across the simple processes.
4. Is physical function associated with cognitive function?
    - Physical function (grip strength and 6-minute walk test) will be strongly associated with cognitive function.

1.10 Significance of the Study

This research project will further the understanding of the exercise and cognition relationship. Although exercise has been shown to benefit cognitive function, it is important to determine effective modes of exercise to combat cognitive decline in later life. Research is lacking in cognitive benefits of participation in open-skilled sports such as tennis. Although, several studies have examined the effect of open-skilled sports on cognitive function, few domains have been explored. Moreover, examining whether performance in physical function (grip strength and 6-minute walk test) is associated with performance across each cognitive function task, would further the understanding of the relationship between cognitive function and physical function. This project will increase our knowledge of the cognitive benefits of tennis as an open-skilled sport, in comparison to closed-skilled sports. Furthermore, the relationship between components of physical function and aspects of cognitive function will clarify whether a decline in cognitive function co-occurs with a decline in physical function and in which specific domains. The practical implications of this research is to contribute knowledge of effective modes of exercise in preventing cognitive decline and this may benefit the elderly who are more prone to cognitive decrements. This research however, may be most applicable to a younger population, as this study may demonstrate the cognitive benefits of long-term participation in tennis and may ultimately influence choices on participation in tennis from a young age.

Chapter 2. METHODS

2.1 Study design

To investigate the effect of long-term involvement in different types of exercise on cognitive function, a cross-sectional observational research design was deemed most appropriate, since it is difficult to conduct a longitudinal study. The present study focused on tennis players who had been regularly playing tennis for more than 10 years, compared with people who had been regularly doing walking, running or swimming. The present study chose tennis as an example of an "open-skilled" sport that requires an immediate response to unpredictable stimuli, in a dynamic environment. In contrast, walking, running and swimming were considered to be typical "closed-skilled" exercises, since they are generally performed in a stable, predictable environment, and at a self-determined pace. The present study also included people who did not exercise regularly in the last 2 years, and they were placed in a control group. Cognitive function was assessed by several tests, and their functional physical fitness was also measured by several tests. These variables were compared between the tennis, closed-skilled, and control groups.

The participants were required to attend a single session in which cognitive function and physical function were assessed. The session was conducted in either a singular or small group (2-4 participants) format. The first cognitive function assessment was the Montreal Cognitive Assessment (MoCA) which provided a global measure of cognitive function by briefly assessing many cognitive functions. The MoCA was administered on a one-on-one basis, irrespective of whether the session was conducted in group format. Following the MoCA, the participants undertook a computerised cognitive function task, the modified Eriksen Flanker task. The participants then completed the Cogstate testing battery (details are provided below) whereby multiple domains such as processing speed and working memory were assessed by different cognitive tasks. Following a 5-minute break, the participants commenced physical function testing. Physical function was assessed by a modified version of the senior physical fitness test and included the tests of: chair sit and reach, one-leg balance, 8-ft up and go, grip strength, 30-s chair stand, and 6-minute walk test. Four-minute rest periods were given between each physical function test to allow adequate recovery before undertaking the next as suggested by American College of Sports Medicine guidelines (Lippincott & Wilkins, 2013).

2.2 Participants

Sixty-two participants aged between 62-75 years of age (mean ± SD age: 68.7 ± 8.1 years) were recruited from community and sporting/exercise clubs or groups such as tennis clubs, walking groups and swimming clubs in the Northern Suburbs of Perth, Western Australia. The three groups were comprised of two exercise groups; tennis (n = 20) and closed-skilled (n = 23), and a control group (n = 19). Participants within the tennis group had been playing tennis at least twice a week for a minimum of 10 years. Participants in the closed-skilled group had been involved in walking, running or swimming (closed-skilled exercise) at least twice a week for a minimum of 2 years. Since cognitively demanding sports such as tennis are proposed to provide additional cognitive investment to closed-skilled exercise (Guo et al., 2016), participants partaking in both tennis and closed-skilled exercise were categorised within the tennis group. Participants that had not been regularly partaking in any exercise were placed into the control group. Participants were excluded from the study if they had a neurological disorder or previously had a stroke, as assessed by a medical questionnaire. As caffeine and alcohol are associated with acute changes in cognition (Haskell, Kennedy, Wesnes, & Scholey, 2005), participants were asked to refrain from consuming caffeine 6 hours prior to testing, and alcohol 24 hours prior to testing. The sample size was based on several previous studies that have found significant cognitive differences between exercise types in a similar age range (Dai et al., 2013; Tsai & Wang, 2015). The Edith Cowan University Human Research Ethics

Committee provided ethical approval, and all participants signed an informed consent form after explanation of what the study entails.

After declaring their interest in the study, each participant received a questionnaire booklet containing an information letter of the study and the following questionnaires; Demographics information and health history, Depression Stress and Anxiety Scale (DASS-21), Social Network Index (SNI), and Community Healthy Activities Model Program for Seniors (CHAMPS) as detailed below. All questionnaires were self-reported and the participants were encouraged to contact the chief investigator should they have any queries.

The demographics information and health questionnaire provided information on medical history, occupational history, years of education, and exercise history (Appendix A). The DASS-21 (Henry & Crawford, 2005) measured negative emotional states of depression, anxiety and stress (Appendix B). For 21 questions, each participant indicated how much the statement applied to them (0, 1, 2, or 3). Scores for depression, anxiety, and stress were individually calculated. Each score was then doubled, to best compare to cut-off scores found in the longer 42-item version (maximum of 42). The SNI (Cohen & Skoner, 1997) measured participation in 12 types of social relationships (e.g. spouse, children, work mates, and fellow volunteers) (Appendix C). To assess social network diversity, a point was received if the participant speaks to someone within that social relationship, at least once every 2 weeks (maximum score of 12). Cognitive activity was measured by a questionnaire similar to that used by Wilson et al. (2002). Scores were based on the frequency each participant indicated they performed each of the 11 cognitively demanding activities such as: viewing the television or reading the newspaper (Appendix A). For example, the participants received 1 point if they indicated they attended lectures/talks once a year or less, but scored 5 points if they attended lectures/talks almost daily. The amount of physical activity was assessed by CHAMPS, whereby total energy expenditure and activities of moderate intensity (MET value >/= 3.0) energy expenditure were estimated (Appendix I). Each participant self-reported the number of hours they spent performing different types of physical activity (e.g. playing golf, heavy gardening, or walking to do errands). For each physical activity, the number of hours were multiplied by the corresponding MET value, and after incorporating each participants body weight, total energy expenditure and activity of moderate energy expenditure were calculated (Stewart et al., 2001).

2.3 Physical function tests

The senior fitness test (SFT) is a battery of tests that measures functional fitness, defined as the physiologic capacity to perform everyday activities without excessive amounts of fatigue (Garatachea et al., 2009). The SFT consists of the following physical function tests: back scratch, chair sit and reach, 8-ft up and go, arm curl, 30-s chair stand and 6-minute walk test. However, a modified version of the SFT was used by replacing the arm curl test with the grip strength test as a measure of upper body strength. Grip strength has previously been used as a measurement of upper body strength in the tennis-playing population (Cohen et al., 1994), and has been shown to be associated with cognitive function (Auyeung et al., 2008). Furthermore, the upper body flexibility measurement was removed as two measures of flexibility was not deemed necessary, and a measure of balance, the one-leg balance, was included. An abnormal one-leg balance score (less than 5s) has been shown to predict a higher rate of cognitive decline (Rolland et al., 2009). Physical function tests that are predominantly anaerobic were undertaken prior to measures of aerobic capacity, and were completed in the order presented below. It took approximately 30-40 min to perform the six tests in the order of; chair sit and reach, one-leg balance, 8-ft up and go, grip strength, 30-s chair stand, and 6-minute walk test.

2.3.1 Chair sit and reach

The chair sit and reach is a measure of lower body flexibility and has the advantage of less strain on the lower back and spine as compared to the commonly used sit and reach test (Jones et at., 1998). The participant was instructed to sit near the edge of a chair (44-cm in height) and fully extend their leg with their heel resting on the floor in 90° dorsiflexion, whilst placing the other leg off to the side in a bent position. The participants were instructed to slowly bend forward, keeping their spine as straight as possible, and reach down their extended leg to the furthest possible position and hold this position for 2 s. The distance (cm) short of the toes was recorded as a negative score, whereas reaching past the toes was recorded as a positive score. A measuring ruler recorded the distance. After two maximal efforts on each side, the greatest score was recorded.

2.3.2 One-leg balance

The one-leg balance is a simple balancing test and measures static balance. It is often used to predict falls in the elderly (Rolland et al., 2009). The test was performed by asking the participant to stand unassisted on their preferred leg for as long as possible. The greater score after two attempts was used for further analysis.

2.3.3 8-ft Up and Go (8UG)

The 8UG test is a measure of dynamic balance and mobility. The participants started with their backs pressed against the back rest of an armless chair (44-cm in height). The participants were instructed to stand up and walk around a cone situated 8 feet away, and sit back down on the starting chair, as quickly and safely as possible. The time taken was measured with stopwatch. Two trials were undertaken, and the faster time was used for further analysis.

2.3.4 Grip strength

Grip strength was measured using a Jamar Hydraulic Dynamometer (Model 5030J1, Sammons Preston Inc., Bolingbrook, Ill, USA). The Southampton protocol was utilised whereby the participants were asked to start seated, with their back pressed against the chair back rest, whilst the weight of the hand dynamometer was taken by the investigator. The participants were then instructed to squeeze as tightly as possible, and were instructed to stop once the needle, indicating force in kg, had stopped rising. Verbal encouragement was provided to each participant. Of the five possible handle positions, the second grip position was constant throughout the study, as this position has been deemed to be the most reliable and consistent position (Roberts et al., 2011). The participants performed one maximal effort on each side, with the greater score recorded.

2.3.5 30-s chair stand test

In the 30-s chair stand test, the participants were instructed to start by sitting in the centre of a straight back, armless chair (44-cm in height). While resting their arms across the opposite shoulder, the participant was asked to rise to a fully standing position, and back to the original seated position. A stopwatch recorded time 30-s in duration, and the number of rises was recorded.

2.3.6 6-minute walk test (6MWT)

Swisher and Goldfarb (1998) found the 6MWT was able to estimate peak oxygen uptake in elderly individuals. A 30-m track was measured by a trundle wheel, with cones at either end indicating the turning points. The participants were instructed to walk as far as possible in 6-minutes. A seat was provided at the end of the track, if any participant required a break during the test. The participants were made aware of each minute interval, and were provided with verbal encouragement. A stopwatch recorded the 6-min duration. Upon completion of the 6MWT, the absolute distance walked was recorded.

2.4 Montreal Cognitive Assessment (MoCA)

The MoCA, originally designed as screening tool for the detection of mild dementia and mild cognitive impairment (MCI), is a commonly used to assess global cognitive function (Nasreddine et al., 2005). The MoCA takes approximately 10 minutes and briefly covers the following cognitive domains; memory, visuospatial, executive function, attention and language. All participants were comfortably seated at a desk, directly across from the investigator. The participants were instructed to respond to questions asked by the investigator, either in a verbal manner (memory and language) or by completing a task (visuospatial, executive function, attention). Points received for correct responses were totalled, with an additional point allocated to those with ≤ 12 years of education. A score of 26 out of the maximum 30 points, is the suggested cut-off score for mild cognitive impairment (Nasreddine et al., 2005). The normative data of 228 Americans aged between 65-75 years of age demonstrated an average score of 22.1 ± 4.5 (Rossetti, Lacritz, Cullum, & Weiner, 2011).

2.5 Modified Eriksen flanker task

A modified version of the Eriksen flanker task (Eriksen & Eriksen, 1974) has been included in the NIH toolbox for cognitive function as a measure of inhibition function (Weintraub et al., 2013). The participants read instructions that were confirmed by the investigator, and were provided with an example test before undertaking a practice trial, and then a data collection trial. For each trial, participants were presented with a fixation cross in the centre of the screen. The cross then disappeared, followed by a 500-ms precue, before a central arrow cue flanked by two arrows on each side (five arrows accumulatively) appeared either above or below the cross previously seen. In half of the trials, the flanking arrows pointed in the same direction as the central arrow (e.g., > > > > > ; congruent condition), and in the other half of the trials, the flanking arrows pointed in the opposite direction (e.g., > > < > > ; incongruent condition). The five arrows remained on the screen for 2000 ms. The participants were instructed to respond with either the left or right arrow key on the keyboard that corresponded with the central arrow, as quickly and as accurately as possible. The participants completed forty-eight trials, twenty-four congruent and twenty-four incongruent, taking approximately 3 min. The outcome for the modified Eriksen flanker task was the interference score, calculated by percentage increase in reaction time to incongruent stimuli, over and above the average reaction time to congruent stimuli; incongruent-congruent / congruent x 100. The inference score measures the reaction time cost of irrelevant stimuli, irrespective of simple reaction time.

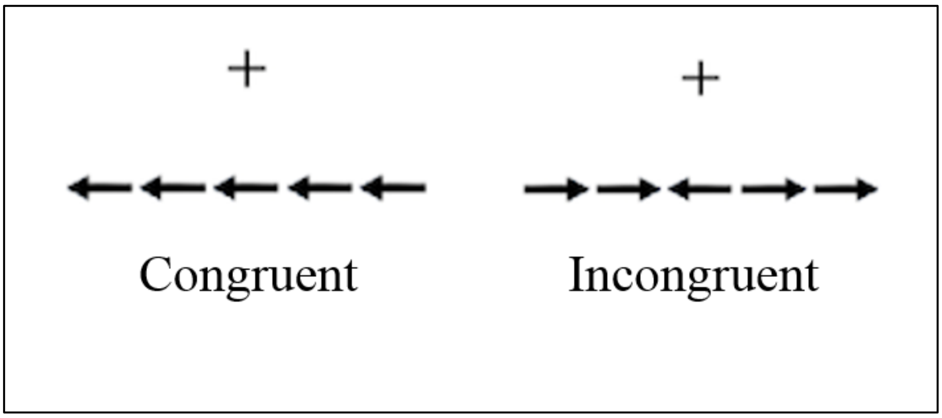

Figure 1. *The modified Eriksen flanker task. The arrows on the left are an example of a congruent trial. The arrows on the right are an example of an incongruent trial.*

2.6 Cogstate tests

Cogstate testing (Cogstate Ltd, Melbourne, VIC, Australia) comprises a number of computerised tasks designed specifically to assess different cognitive functions. The battery of cognitive tasks included measures of processing speed (simple and choice reaction time), working memory, and learning and memory. These specific tasks were chosen to cover several different cognitive functions from more simple cognitive processes (simple and choice reaction time) to higher-order cognitive functions (working memory, and learning and memory). Cogstate measures of processing speed, working memory, learning and memory, have been shown to be correlated with common neuropsychological assessments measuring these domains (r =0.49 to 0.83) (Maruff et al., 2009). For example, the Cogstate identification task (choice reaction time) was correlated with Trail Making test B (r=0.78), and the Cogstate one card learning task was correlated with the Brief Visual Memory test (r=0.83) (Maruff et al., 2009).

Each participant was seated comfortably in front of a computer screen and a keyboard. Covering the “D” and “K” keyboard keys were two tactile pads printed with the letters “Y” and “N”, representing a “YES” or “NO” response, respectively. All the cognitive tests required either a “YES” or “NO” response, except for the Detection task which only required a “YES” response.

Figure 2. Tactile pads representing “YES” and “NO” responses, covering the “D and “K” keyboard keys.

For each cognitive task, the participant was presented with written instructions, and given the opportunity to perform a practise trial, before commencing to the data collection trial. For each task, the participants were asked to respond as quickly, and as accurately as possible.

The cognitive tasks were performed consecutively in the order of more simple to higher processing cognitive tasks; detection, identification, one card learning, All participants undertook the four cognitive tests (4-6 mins per test), which took ~30 min to complete including the instructions and practise trials. Rather than analysing reaction time and accuracy for each cognitive function variable, the primary outcome measure as suggested by Cogstate, was utilised (as detailed below). For tasks that primarily measured speed-of processing (DET, IDN, ONB), reaction time was the outcome measure, as accuracy typically approaches ceiling on these tasks. To account for the negative skew typically evident in reaction time distributions (due to the occasional slow response), a logarithmic base transformation (log10) was performed to normalise the data. Accuracy was deemed the primary outcome measure for OCL. The accuracy data was normalised using an arcsine transformation whereby possible values at the top end of the data range are extended.

2.6.1 Detection task

The detection task used a simple reaction time paradigm to measure processing speed. The participants were required to press “yes” as quickly as possible, as a playing card flipped over into a face up position. Reaction time for responses were transformed using a logarithmic base transformation (log10) and then analysed.

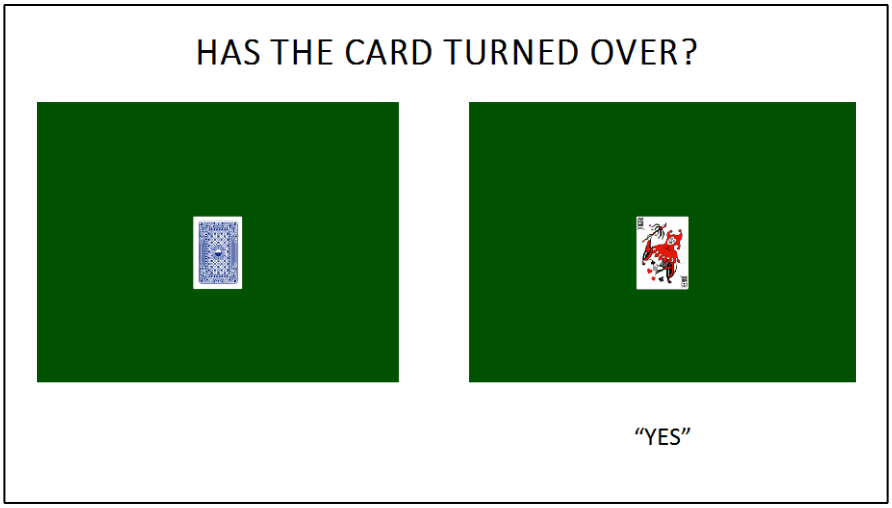

Figure 3. *The detection task. The participants were presented with a face-down card as seen on the left of the figure. Once the card flipped to the face-up position as seen on the right of the figure, the participants were instructed respond "YES" as quickly as possible.*

2.6.2 Identification task

The identification task also measured processing speed however using a choice reaction time paradigm. The participants were shown a playing card of either red or black in colour, if the card was red then the participants were instructed to press "yes" and if not then press "no." Reaction time for responses were transformed using a logarithmic base transformation (log10) and then analysed.

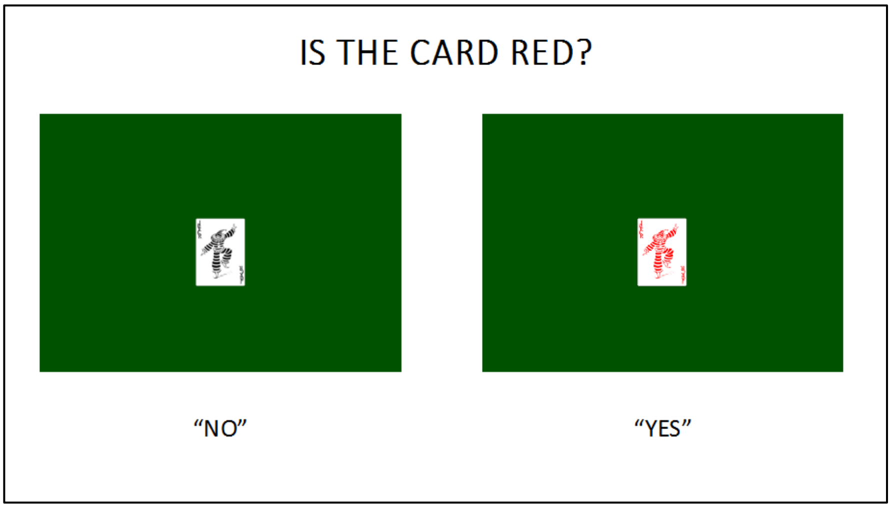

Figure 4. The identification task. If the participants were presented with a black coloured card, then the participants were instructed to respond "NO", as seen on the left of the figure. If the participants were presented with a red coloured card, then participants were instructed to respond "YES", as seen on the right of the figure.

2.6.3 One Card Learning task

The one card learning task is a measure of visual learning and memory. The participants were instructed to respond either yes or no depending on whether or not they believed they had previously seen that identical card during the whole task. Response accuracy (percentage of correct responses) was normalised using an arcsine transformation and then analysed.

Figure 5. The one card learning task. If the participant was presented with a card they believed they had not seen, then the participant must respond "NO", as seen on the left, and centre of the figure. If the participant is presented with a card they believed they had previously seen, then participant must respond "YES", as seen on the right of the figure.

2.6.4 One back task

The one-back task is a measure of working memory that used an n-back paradigm, whereby participants must indicate whether the current stimuli is identical to a previous stimuli, presented "n trials" previously (Owen, McMillan, Laird, & Bullmore, 2005). The participants were instructed to respond either yes or no depending on whether they believed the present card was identical to the last card shown. Reaction time for responses were transformed using a logarithmic base transformation (log10) and then analysed.

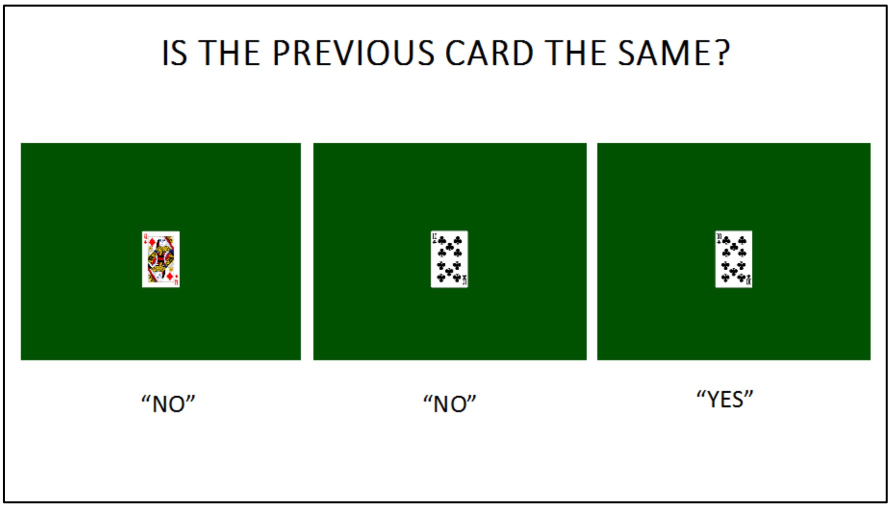

Figure 6. The one back task. If the participants were presented with a card they believed was identical to the last, then the participants were instructed to respond "NO", as seen on the left, and centre of the figure. If the participants were presented with a card they believed they had not previously seen, then participants were instructed to respond "YES", as seen on the right of the figure.

2.7 Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics (Version 23, IBM Inc, Armonk, New York, 2014). One-way analysis of variances (ANOVAs) compared demographic differences and physical function characters among the three groups. One-way ANOVAs were also used to compare the cognitive function variables (MoCA, interference score, DET, IDN, OCL, and ONB) among the three groups. When a significant group effect was found, a Tukey's post-hoc test was followed to compare between two groups. Cognitive function data from the six cognitive variables were individually converted to z-scores and then averaged across all the tasks to create a composite cognitive function score. Correlations between the physical function measures of grip strength and 6-MWT, and each cognitive function variable, including composite cognitive function, were analysed by Spearman rho analysis. The significance level was set at $P<0.05$, and the data are shown in mean ± SD, unless otherwise stated.

Chapter 3. RESULTS

3.1 Participant characteristics

Table 1 presents characteristics of the participants. No significant differences in any of the variables except for moderate intensity energy expenditure were evident among the three groups. A significant difference between groups was found for moderate intensity energy expenditure, and post-hoc test revealed a significant difference between tennis and control groups ($p = 0.008$), but no differences between the tennis and closed-skilled groups ($p = 0.145$), or closed-skilled and control groups ($p = 0.381$) were evident.

Table 1. Characteristics of participants in the tennis, closed-skilled and control groups. Mean ± SD values of age, height, and body mass index (BMI), cognitive activity, depression, education, years retired, social network diversity, moderate intensity energy expenditure, and total energy expenditure are shown. In the last column, one-way ANOVA results (F and P values) are shown.

	Tennis (n = 20)	**Closed-skilled (n = 23)**	**Control (n = 19)**	**ANOVA**
Gender (# females)	10 (50%)	10 (43%)	7 (37%)	F = 0.09, p = 0.913
Age (year)	67.5 ± 4.4	69.6 ± 2.8	69.1 ± 2.7	F = 1.78, p = 0.177
Height (cm)	168.9 ± 9.4	166.2 ± 9.4	165.2 ± 8.5	F = 0.49, p = 0.613
Body mass (kg)	75.6 ± 13.7	76.2 ± 13.2	80.4 ± 18.5	F = 6.00, p = 0.554
BMI (kg/m^2)	26.4 ± 3.5	27.6 ± 4.1	29.2 ± 5.0	F = 1.74, p = 0.185
Cognitive activity (11 - 55)	30.0 ± 4.6	28.3 ± 4.4	28.6 ± 4.4	F = 0.57, p = 0.567
Depression (0 - 42)	4.0 ± 3.7	8.5 ± 6.8	5.0 ± 8.4	F = 2.73, p = 0.073
Education (years)	14.2 ± 2.7	13.2 ± 2.5	13.5 ± 3.7	F = 0.28, p = 0.761
Years Retired (years)	8.3 ± 10.1	6.4 ± 5.3	5.4 ± 7.1	F = 0.54, p = 0.585
Social network diversity (0 - 12)	6.0 ± 1.2	5.5 ± 1.1	5.4 ± 1.4	F = 1.62, p = 0.206
Moderate intensity energy expenditure (kcal)	4077.2 ± 3026.6*	2737.5 ± 1927.1	1856.3 ± 1475.2	F = 4.87, p = 0.011
Total energy expenditure (kcal)	5350.5 ± 3678.9	3932.9 ± 2065.6	3488.4 ± 1948.9	F = 2.48, p = 0.095

*Note. * denotes significantly different from controls at p<0.05*

3.2 Physical function

Table 2 presents the results of physical function tests of the three groups. No significant differences were found amongst the three groups for any of the tests.

Table 2. Comparison between tennis, closed-skilled, and control groups for the mean ± SD values of chair sit and reach, one leg balance, 8-ft up and go, grip strength, chair stand, and 6-minute walk test (6MWT). On the right column, F and P values from one-way ANOVA comparing the three groups are shown.

	Tennis	**Closed-skilled**	**Control**	**ANOVA**
Chair Sit and Reach (cm)	0.28 ± 7.43	1.39 ± 8.81	-2.70 ± 9.27	F = 1.17, p = 0.317
One Leg balance (s)	48.4 ± 16.4	41.4 ± 17.1	37.9 ± 19.6	F = 1.65, p = 0.202
8-ft Up and Go (s)	5.49 ± 0.60	5.58 ± 0.55	5.76 ± 0.82	F = 0.754, p = 0.475
Grip Strength (kg)	34.7 ± 10.3	33.4 ± 8.5	33.6 ± 8.9	F = 0.216, p = 0.806
30s Chair Stand (#)	13.5 ± 1.3	13.3 ± 3.14	12.8 ± 1.8	F = 0.492, p = 0.614
6MWT (m)	573.7 ± 103.6	570.14 ± 66.1	564.3 ± 70.5	F = 0.062, p = 0.940

Table 3 shows physical function amongst participants in the present study and normative values. The participants in the current study had greater performance in the physical function tests of one leg balance, grip strength, and 6-minute walk test, in comparison to normative values of the corresponding age ranges. The participants in the current study fell within the normative ranges for chair sit and reach, 8ft up and go, and 30s chair stand.

Table 3. *Comparison between the mean ± SD values of all participants in the present study for chair sit and reach, one leg balance, 8-ft up and go, grip strength, chair stand, and 6-minute walk test (6MWT), and normative data of 60 - 70 years, and 70 - 80 years reported in previous studies (Rikli & Jones, 1999; Springer, Marin, Cyhan, Roberts, & Gill, 2007; Steffen, Hacker, & Mollinger, 2002)*

	Participants	**Normative values (60 – 70 years)**	**Normative values (70 -80 years)**
Chair Sit and Reach (cm)	Male = -2.8 ± 8.5 Female = 1.5 ± 8.3	Male = -2.5 - +3 Female = -0.5 - +4	Male = -3 - +2 Female = -1 - +3.5
One Leg balance (s)	Male = 45.3 ± 17.3 Female = 40.6 ± 18.3	Male = 33.8 Female = 30.4	Male = 25.9 Female = 16.7
8-ft Up and Go (s)	Male = 5.5 ± 0.5 Female = 5.7 ± 0.8	Male = 4.3 – 5.6 Female = 4.8 - 6	Male = 4.6 - 6 Female = 5.2 – 7.1
Grip Strength (kg)	Male = 42 ± 7.2 Female = 27.8 ± 3.9	Male = 40 Female = 24	Male = 33 Female = 20
30s Chair Stand (#)	Male = 13.1 ± 1.9 Female = 13.3 ± 2.5	Male = 14 – 18 Female = 12 - 16	Male = 12-17 Female = 10 -15
6MWT (s)	Male = 601.9 ± 55.1 Female = 546.5 ± 86.4	Male = 572 Female = 538	Male = 527 Female = 471

3.3 Montreal cognitive assessment

No difference (p = 0.426) was evident amongst the tennis, closed-skilled exercise and control groups for the MoCA score (Table 4).

3.4 Modified Eriksen flanker task

No difference (p = 0.496) in the flanker task was evident amongst the tennis, closed-skilled and control groups (Table 4).

Table 4. *Comparisons between the tennis, closed-skilled and control groups for cognitive function measures of Montreal cognitive assessment (MoCA), interference score, detection task (DET), identification task (IDN), one back task (ONB), one card learning task (OCL), and composite cognitive function. In the last column, one-way ANOVA results (F and P values) are shown.*

	Tennis	**Closed-Skill**	**Control**	**ANOVA**
MoCA	26.7 ± 1.9	25.4 ± 3.6	26.7 ± 2.3	F = 0.87, p = 0.426
Interference score	10.9 ± 5.9	12.3 ± 9.7	14.0 ± 7.9	F = 0.71, p = 0.496
DET (ms)	323.3 ± 44.3*	391.1 ± 75.4	335.4 ± 50.0*	F = 7.87, p = 0.001
IDN (ms)	518.3 ± 60.6*	578.6 ± 69.6	550.1 ± 82.7	F = 3.68, p = 0.031
ONB (ms)	794.2 ± 162.6	883.2 ± 206.3	767.9 ± 99.8	F = 2.36, p = 0.104
OCL (%)	71 ± 7.2	65 ± 9.2	68 ± 8.4	F = 2.85, p = 0.066
Composite (Z score)	0.3 ± 0.4*	-0.3 ± 0.6	0.1 ± 0.5	F = 7.78, p = 0.001

*Note. * denotes significantly different from closed-skilled at p<0.05*

3.5 Cogstate tests

As shown in Table 4, a significant group effect was found for DET and IDN. Post-hoc tests showed that the tennis group had significantly faster DET reaction time in comparison to the closed-skilled group (p = 0.001), however the control group also showed faster DET reaction time in comparison to the closed-skilled group (p = 0.013). The tennis group showed significantly faster IDN reaction time in comparison to the closed-skilled group (p = 0.024). No significant differences between groups were found for OCL or OCB.

Figure 7 shows the distribution of individual participants in the tennis, closed-skilled and control groups for DET. Compared with the tennis group, a larger distribution was observed for the closed-skilled group, but little difference was seen between the tennis and control groups.

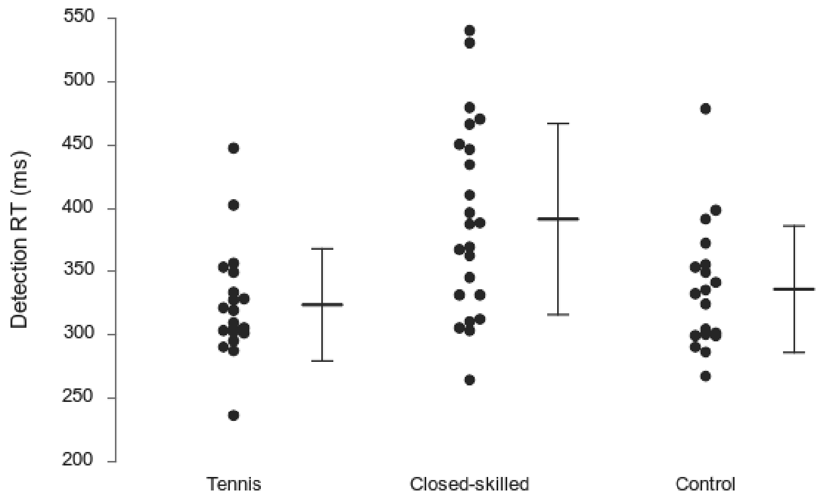

Figure 7. *Distribution of individuals in the tennis, closed-skilled and control groups for detection task (ms). Error bars indicate group mean ± SD.*

Figure 8 shows the distribution of individual participants in the tennis, closed-skilled and control groups for IDN. A trend of slower IDN reaction times for the closed-skilled group is apparent. Similar to DET, a larger distribution was observed for the closed-skilled than the tennis group, but little difference was seen between the tennis and control groups.

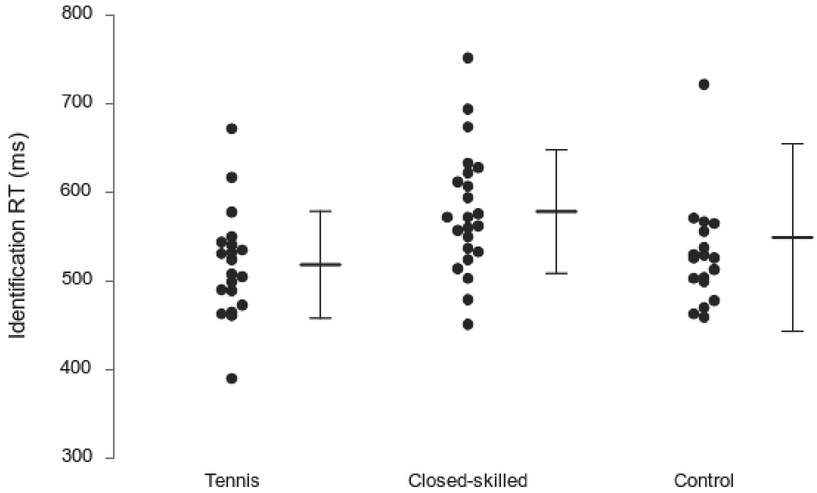

Figure 8. *Distribution of individuals in the tennis, closed-skilled and control groups for identification task (ms). Error bars indicate group mean ± SD.*

Figure 9 shows the distribution of composite cognitive function for the tennis, closed-skilled and control groups. For the tennis group, only 5 out of 20 participants (25%) were below the average in composite cognitive function score, whereas 15 out 22 participants (68%) and 8 out of 19 participants (42%) were below the average in the score for closed-skilled and control groups, respectively.

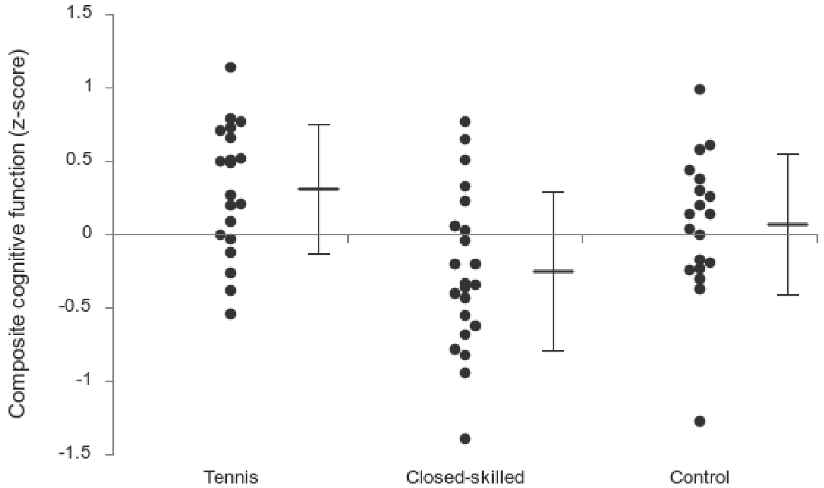

Figure 9. *Distribution of individuals in the tennis, closed-skilled and control groups for composite cognitive function Z-score. Error bars indicate group mean ± SD.*

Table 5 shows the average (± SD**)** values of all participants for MoCA, DET, ONB and OCL in comparison to the normative values. It appears that the values of the participants in the study were better than the normative values for MoCA, DET, ONB and OCL.

Table 5. *Comparison between the mean ± SD values of all participants in the present study by the tennis, closed-skilled and control groups combined (n=62) for Montreal cognitive assessment (MoCA), detection task (DET), identification task (IDN), one back task (ONB), and one card learning task (OCL), and normative data of 60 - 70 years, and 70 - 80 years reported in previous studies (Cromer, Schembri, Harel, & Maruff, 2015; Rossetti et al., 2011).*

	Participants	**Normative values (60 – 70 years)**	**Normative values (70 -80 years)**
MoCA	26.0 ± 3.0	22.7 ± 4.1	21.3 ± 4.8
DET (ms)	352.2 ± 65.8	361.6	383.6
IDN (ms)	550.1 ± 82.7	532.2	563.6
ONB (ms)	819.2 ± 170.6	831.5	877.8
OCL (%)	68 ± 8.4	66.8	66.3

3.6 Associations between physical and cognitive function

Since previous studies reported a significant correlation between the 6MWT and memory (short-term and long-term) (Baldasseroni et al., 2010; Makizako et al., 2013) and between grip strength and global cognitive function (Alfaro-Acha et al., 2006; Auyeung et al., 2008), relationships between 6MWT distance and each cognitive function (Figure 10), and between grip strength and each cognitive function (Figure 11) were examined for all participants.

As shown in Figure 10, a significant but weak correlation was evident between the 6MWT and DET (r_s = -.279, p = 0.034) as well as ONB (r_s = -.274, p = 0.037). However, no significant correlations were found between 6MWT and MoCA (r_s = .202, p = 0.144), interference score (r_s = .116, p = 0387), IDN (r_s = -.190, p = 0.154), and OCL (r_s = 1.43, p = 0.284). As shown in Figure 11, no significant correlations were found between grip strength and cognitive function.

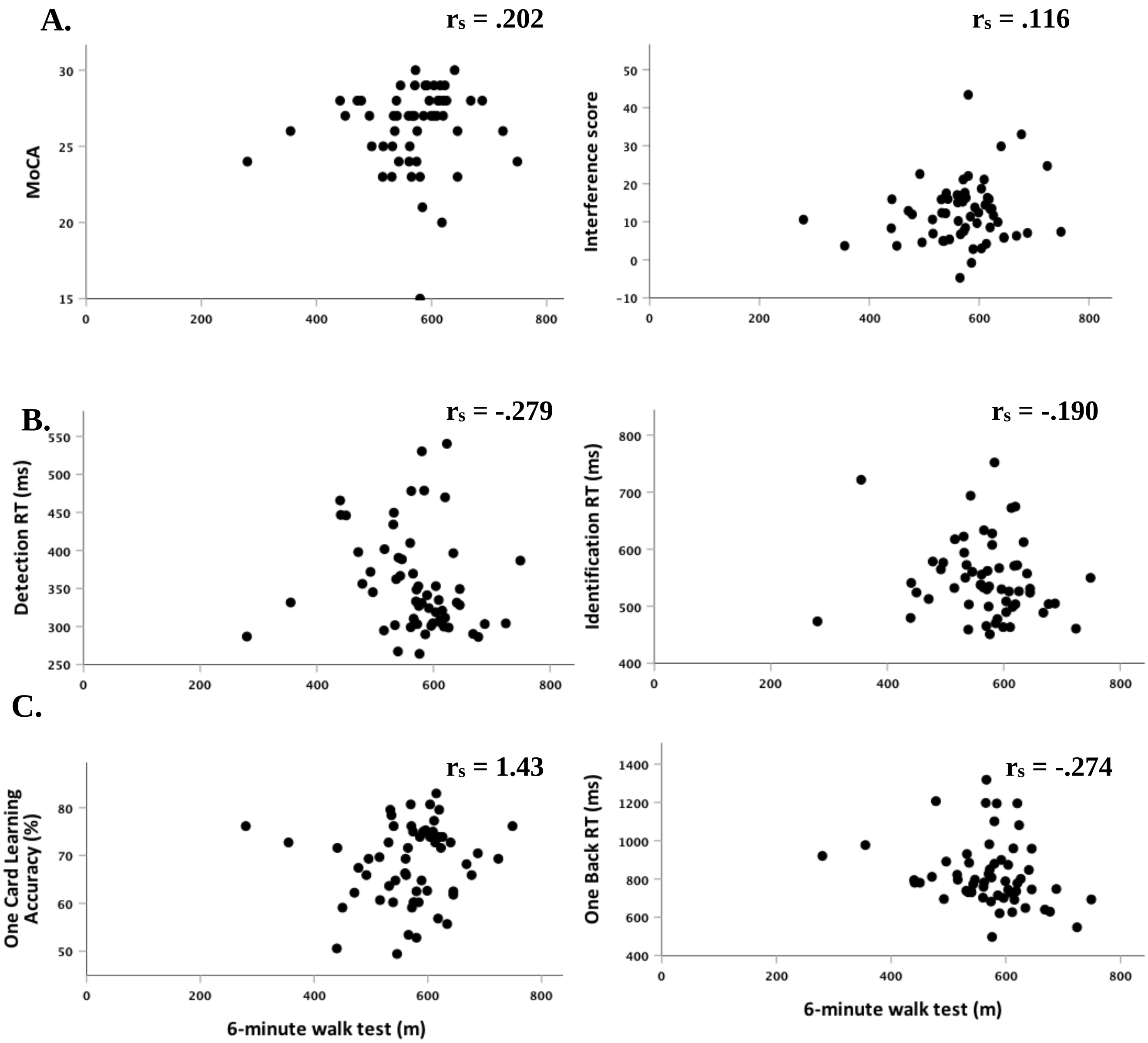

Figure 10. *Relationship between the 6-minute walk distance (m) and MoCA (A), interference score (B), detection (C), identification (D), one card learning (E), and one back (F). Spearman's correlations r_s values are shown in each graph.*

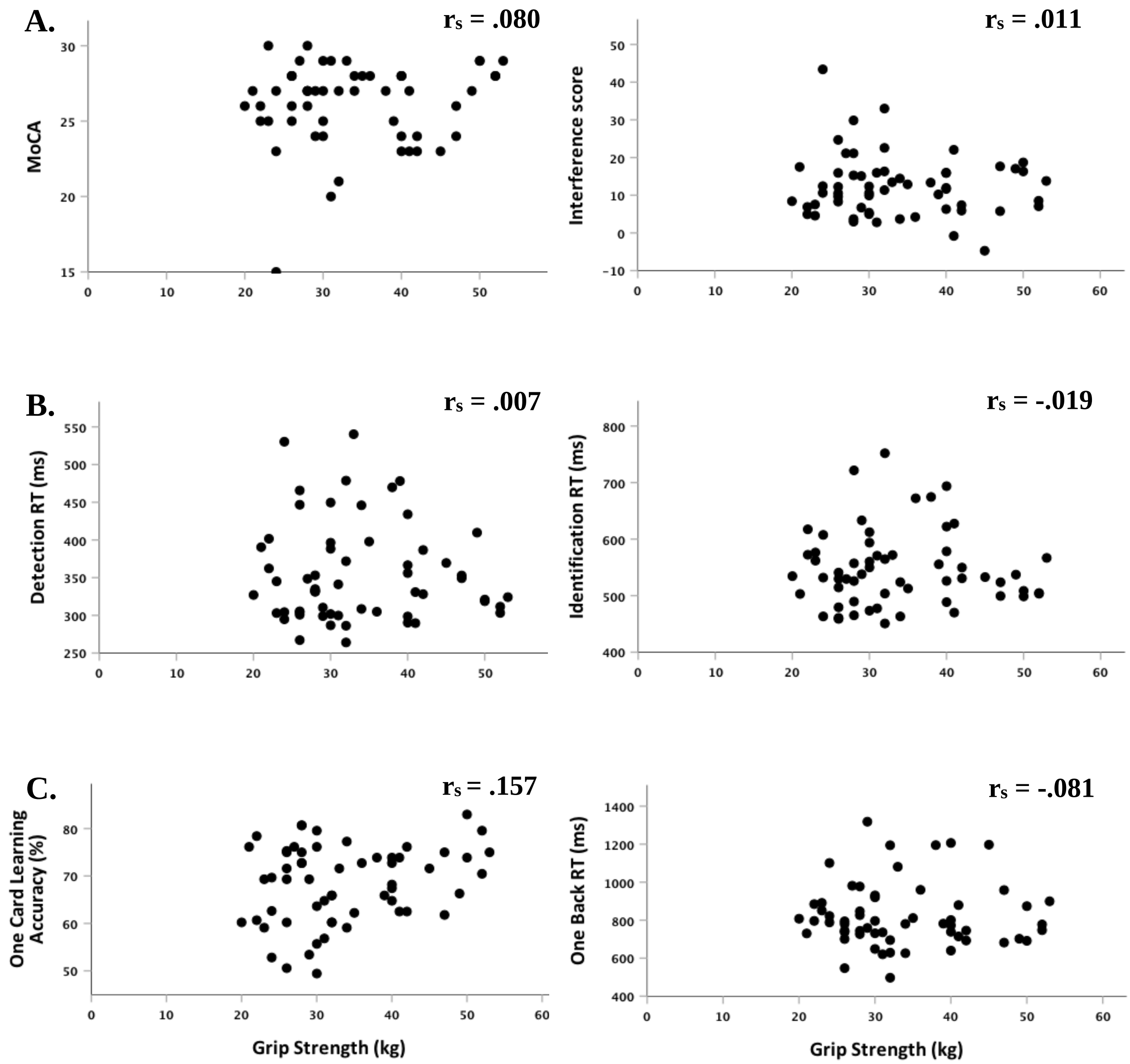

Figure 11. *Relationship between grip strength (kg) and MoCA (A), interference score (B), detection (C), identification (D), one card learning (E), and one back (F). Spearman's correlations r_s values are shown in each graph.*

Chapter 4. DISCUSSION

The present study tested the hypothesis that the tennis group would show superior cognitive function across all cognitive tasks, when compared to the closed-skilled and control groups. The findings of this study did not strongly support this hypothesis, although the tennis group showed faster reaction times in two measures of processing speed (simple reaction time and the choice reaction time) in comparison to the closed-skilled group.

In the present study, the participants were recruited from similar socioeconomic backgrounds. It is of importance that participants' characteristics (Table 1) and physical function (Table 2) did not differ between the three groups, with the exception of moderate intensity energy expenditure, which was greater for the tennis group than the control group. It should be noted that most of the parameters relating to participants' characteristics (e.g., years of retirement, education, cognitive activity, depression, physical activity, energy expenditure) were based on questionnaires relying on self-report. Although many studies used similar questionnaires to those of the present study to obtain information that could affect cognitive function of study participants (Dai et al., 2013; Guo et al., 2016; Tsai & Wang, 2015), one might question their reliability and validity.

It has been documented that many factors such as social activity, cognitive activity, and physical function influence cognitive function (Voelcker-Rehage et al., 2011). Since these were not significantly different between the groups (Table 1), it was assumed that any differences in the assessed cognitive function in the present study were due to the choice of regular exercise; tennis versus walking, running and swimming. It should be noted that some participants in the tennis group also regularly performed walking, running or swimming, thus a difference between the tennis and closed-skilled groups, if any, reflected the effects of playing tennis regularly in the last 10 years or more on cognitive function. In the tennis group, the participant's age ranged from 62 to 75 years old, but the majority of them were in the range of 65 - 70 years old. It is important to note that all of them had been playing tennis at least twice a week on average, for at least an hour a session, for more than 10 years continuously. If playing tennis has any positive effects on cognitive function, the tennis group should have shown better cognitive function in the tests that the present study performed; MoCA, modified Eriksen flanker task, and four tests in the Cogstate tests.

As shown in Table 2, the tennis group showed significantly faster reaction time in DET and IDN when compared to the closed-skilled group, but no significant differences between the tennis and control groups were evident. This was also depicted in Figures 7 and 8, showing a similar distribution of individuals for the DET and IDN between the tennis and control groups. Spirduso and Clifford (1978) reported that elderly racket sports players with at least 20 years of experience, had a 3.1% faster simple reaction time and 6.1% faster choice reaction time, when compared to a running group. They concluded that racket sports might be important in the maintenance of relatively simple processes. The faster reaction times in the current study could be explained by the specific demand in tennis to respond to unpredictable stimuli within a dynamic and externally-paced environment. The cognitive skill of rapid processing of information seems to have transferred to a non-sporting context. Although, it does not appear that the effects of tennis on the reaction times are large, since no difference between the tennis and control groups was evident.

The tennis group did not show greater executive function in inhibition function, compared to the closed-skilled and control groups (Table 4). Huang et al. (2014) reported no differences in inhibition function between open-skilled and closed-skilled sport groups of elderly people (mean = 69.4), and explained exercise, irrespective of the type, was beneficial to inhibition function. Studies that have used other executive function tasks showed some differences between sport types (Dai et al., 2013; Kida et al., 2005; Wang et al., 2013). For example, Dai et al. (2013) found elderly individuals partaking in at least 3 months of open-skilled exercise had greater task-switching ability in comparison to closed-skilled exercise. Tsai et al. (2016) reported that only open-skilled exercisers had faster reaction times in an inhibitory control task when compared to sedentary elderly adults. It is possible that tennis participation does not provide cognitive benefits to inhibition function but improves other executive functions such as task-switching and inhibitory control. However, it is worth noting that the present study used the same test for inhibition function as that by Huang et al. (2014), a modified Eriksen flanker task. The Stroop task is another cognitive measure thought to assess inhibition function, however performance in the Eriksen flanker task and Stroop task have previously been found to differ (Tillman & Wiens, 2011). It may be that other inhibition function tasks such as the Stroop task are more successful in distinguishing inhibition function differences between sport types than the Eriksen Flanker task. Given the minimal differences between the three groups for the other cognitive variables it seems unlikely that the lack of difference was due to the particular inhibition function task chosen.

No differences between the three groups were found for working memory or learning and memory (Table 2). Tsai et al. (2017) compared the effects of open-skilled (table tennis) and closed-skilled (cycling) exercise on an n-back task paradigm to measure working memory elderly adults. They found that 6-months of table tennis training improved performance in the 1-back condition, but cycling training resulted in improvement of the more difficult 2-back condition. They concluded that the greater improvement was likely due to the greater increase in aerobic fitness assessed by the Rockport fitness walking test in the cycling group than the table tennis group. This is notable as the present study found the 6MWT was associated with working memory (Figure 10). A cross-sectional study by Guo et al. (2016) compared passive (seldom requires manipulation) and active (requires manipulation) visuospatial working memory, and found that only open-skilled exercisers had greater passive working memory than the sedentary group. It is important to note that no significant difference in 6MWT was found between groups in the present study (Table 2). If the 6MWT is a good indicative of aerobic fitness (Swisher & Goldfarb, 1998), no significant difference in the working memory between the groups was due to the similar aerobic fitness rather than the main exercise performed (i.e., tennis vs walking, running or swimming).

Interestingly, the present study did not find significant differences in the cognitive function between the regular exercise (i.e., tennis and closed-skilled) groups, when compared with the control group. These results appear to contradict with the findings of several cross-sectional studies (Colcombe et al., 2004; Dustman et al., 1990; Shay & Roth, 1992) comparing regular exercisers and sedentary controls, where cognitive function was greater for the regular exercisers than sedentary individuals. However, it should be noted that the participants in the control group were not necessarily sedentary as demonstrated by similar physical activity level and the total energy expenditure amongst the three groups (Table 1). Moreover, no significant differences in physical function tests were evident between the groups (Table 2). This suggests that the participants in the control group were similarly fit to the participants in other groups. It is possible that the participants in the control group perform physical activities, although they were not necessarily structured and regular. It is important to assess actual physical activities of the study participants using an activity monitor in the future studies.

As shown in Table 3, the cognitive function of the participants in the present study appeared to be better than the normative values of the same age population. The normative values of MoCA for healthy elderly adults of 60-70 years and 70-80 years old are 22.7 and 21.3 out of 30, respectively, whereas the average score of all participants in the present study was 26.0. When comparing to the normative values for Cogstate test performance, the average scores of the participants in the present study also appeared to be better for simple reaction time and working memory. It seems likely that the participants in the present study had better cognitive function than "general" population of the same age group. Importantly, all physical function test results of the participants in the present study also appeared to be within the normative ranges of the same age groups or greater (one leg balance, grip strength, and 6MWT

(Table 3). It is possible that the higher levels of physical function of the participants in the present study contributed to the increased cognitive function, when compared with the general population. In fact, many studies reported positive relationship between the physical function and cognitive function in older adults (Alfaro-Acha et al., 2006; Rosano et al., 2004; Watson et al., 2010). Thus, it can be assumed that the influence of exercise choice (e.g. tennis vs closed-skilled) on cognitive function is reduced for older adults who are physically active and relatively fit.

Many studies have suggested a relationship between cognitive function and physical function in older adults (Clouston et al., 2013). This study found that the cognitive functions of processing speed and working memory were significantly associated with the 6MWT (Figure 10), although grip strength was not associated with cognitive function (Figure 11). Similarly, Makizako et al. (2013) found the 6MWT was correlated with short-term and long-term memory in four different measures ($r = 0.303 – 0.394$) in elderly individuals with MCI. Alfaro-Acha et al., (2006) investigated the associations between global cognitive function and grip strength, and found over a 7-year period that those with the lowest grip strength had the greatest cognitive decline. In agreement, Auyeung et al. (2008) found elderly individuals with cognitive impairment showed poorer performance in the physical function tests of grip strength ($p < 0.001$) and the chair stand test ($p < 0.001$). Although associations suggest a relationship between physical function and cognitive function, the nature of the relationship remains unknown. Whether a common cause mechanism results in concomitant decline in cognitive and physical function, or a decline in cognitive function precedes the decline in physical function or vice versa, is yet to be determined.

There are several limitations to the current study. As the study was cross-sectional by design, it is possible that rather than tennis causing the cognitive function differences, those with greater cognitive function chose tennis, although this is highly unlikely. The study used self-reported measures of physical activity, the use of an actigraph unit may provide more reliable physical activity measures. Additionally, this study lacked an accurate measure of cardiovascular fitness such as a VO_2 max test. There are many avenues for future research. More randomised controlled intervention trials are needed to investigate a causal relationship between the various types of exercise and cognitive function. Moreover, rather than categorising exercises into varying types of exercise (e.g. open-skilled or closed-skilled), different exercises should be individually compared to other types of exercise for their specific cognitive benefits. Secondly, more comprehensive cognitive testing batteries should be used to gain an understanding of the effectiveness of different exercises over an array of cognitive functions, and several cognitive tests should be used for each cognitive function. Finally, the effects of the competition level (e.g. social vs competitive) in a person's chosen exercise on cognitive function seems to be of importance in younger adults. The investigation of varying competition levels in the elderly would be of interest.

In conclusion, the results in this study replicate earlier findings of increased processing speeds in elderly racket sport players. However, differ to other studies that have found open-skilled exercise to benefit the cognitive functions of working memory, learning and memory, and executive function (inhibition function). Furthermore, the results suggest that high levels of social, cognitive, and physical activity may lead to greater cognitive function compared to those of lower levels. These results have important implications for public health and suggest that being active is of great importance. Moreover, the participation in tennis may be an appropriate exercise for the maintenance of processing speed, a necessary cognitive function for the performance of daily activities.

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APPENDICES

Appendix A Demographic Information and Healthy History

Edith Cowan University
School of Medical and Health Sciences

Demographic Information and Health History Questionnaire

First name ____________ Last name ____________

Date of birth ____________ Age ______ Sex ______

Postal Address ______________________________________

Home Phone ____________ Mobile Phone ____________ Email Address ____________

Emergency Contact Name ____________ Phone Number ____________ Relationship ____________

1. **Are you or have you ever been a smoker?** Yes No

   If yes:

   Are you a past or current smoker? ____________

   Age you started smoking: ____________

   Age you quit smoking (for past smokers only): ____________

   Average number of cigarettes smoked per day: ____________

2. **How many drinks of alcohol do you have per week (standard units)?** ____________

3. **Have you been told that your blood pressure was abnormal?** Yes No

   If yes, do you take any medication (please provide details)? ____________

4. **Do you have diabetes?** Yes No

   If yes, type 1 or type 2 and how is it controlled? ____________

5. **Do you have cardiovascular disease?** Yes No

   If yes, please provide details of condition and how it is controlled ____________

http://www.ecu.edu.au/schools/medical-and-health-sciences/overview

6. **Do you have any neurological disorders?**

   Yes No

   If yes, please provide details of condition and how it is controlled ______________________

   ____

   ____

7. **Do you have any neuromuscular disorders?**

   Yes No

   If yes, please provide details of condition and how it is controlled ______________________

   ____

   ____

8. **Do you have any muscle or joint injuries that would make exercise problematic?**

   Yes No

   If yes, please provide details ____

   ____

9. **Has a doctor or nurse ever told you that you had any of the following conditions?**

High blood pressure.........	Yes	No	High cholesterol..........	Yes	No
Heart attack.......................	Yes	No	Stroke..........................	Yes	No
Emphysema.......................	Yes	No	Chronic bronchitis.......	Yes	No
Arthritis.............................	Yes	No	Thyroid Disease...........	Yes	No
Peripheral Vascular Disease..........	Yes	No	Angina..........................	Yes	No

10. **Do you have any other medical conditions not previously mentioned that may affect your ability to participate in this study?** Yes No

    If yes, please provide details ____

    ____

    ____

    ____

11. Are you currently taking any prescription medications? Yes No

If yes, please list the medications below.

Medication	Duration (in years and months)	Reason for taking (i.e. which medical condition) and other comments

12. How many years of formal education have you had? (i.e. school, university, tafe, college)?

____

13. Have you completed a traineeship or higher degree (i.e. apprenticeship, university or tafe certificate)? Yes No

If yes, please provide details and time taken ______________________________

____

14. Have you retired? Yes No

If yes, at what age? ____________

15. Please provide your occupation history:

Title	Full-time/ Part-time	Year started (yyyy)	Year finished (yyyy)

16. Typically how often do you perform the following cognitive activities?
Please tick the appropriate box.

Cognitive Activity	Every Day Or About Every Day	Several Times A Week	Several Times A Month	Several Times A Year	Once A Year Or Less
Viewing Television					
Listening To The Radio					
Reading Magazines & Newspapers					
Playing Videogames					
Reading Books					
Playing Structured Games (cards, board games)					
Going to museums, plays, concerts					
Producing art (e.g. painting, drawing, sculpture)					
Playing a musical instrument					
Producing non-artistic writing, diary, essay, blogs)					
Attending Lectures/Talks					

17. **Please list the previous types of exercise you participated in at least once per week (e.g. sports, lifting weights, running, Yoga, and swimming):**

Type	Start (yyyy)	Finish (yyyy)	Duration/Session (min)	Frequency/week

I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

Participant's Name______________________________

Signature______________________________

Date................................

Appendix B DASS-21

BLACK DOG INSTITUTE

DASS 21

NAME ______________________ DATE _________

Please read each statement and circle a number 0, 1, 2 or 3 which indicates how much the statement applied to you <u>over the past week</u>. There are no right or wrong answers. Do not spend too much time on any statement.

The rating scale is as follows:

0 Did not apply to me at all - NEVER

1 Applied to me to some degree, or some of the time - SOMETIMES

2 Applied to me to a considerable degree, or a good part of time - OFTEN

3 Applied to me very much, or most of the time - ALMOST ALWAYS

FOR OFFICE USE

		N	S	O	AA	D	A	S
1	I found it hard to wind down	0	1	2	3			
2	I was aware of dryness of my mouth	0	1	2	3			
3	I couldn't seem to experience any positive feeling at all	0	1	2	3			
4	I experienced breathing difficulty (eg, excessively rapid breathing, breathlessness in the absence of physical exertion)	0	1	2	3			
5	I found it difficult to work up the initiative to do things	0	1	2	3			
6	I tended to over-react to situations	0	1	2	3			
7	I experienced trembling (eg, in the hands)	0	1	2	3			
8	I felt that I was using a lot of nervous energy	0	1	2	3			
9	I was worried about situations in which I might panic and make a fool of myself	0	1	2	3			
10	I felt that I had nothing to look forward to	0	1	2	3			
11	I found myself getting agitated	0	1	2	3			
12	I found it difficult to relax	0	1	2	3			
13	I felt down-hearted and blue	0	1	2	3			
14	I was intolerant of anything that kept me from getting on with what I was doing	0	1	2	3			
15	I felt I was close to panic	0	1	2	3			
16	I was unable to become enthusiastic about anything	0	1	2	3			
17	I felt I wasn't worth much as a person	0	1	2	3			
18	I felt that I was rather touchy	0	1	2	3			
19	I was aware of the action of my heart in the absence of physicalexertion (eg, sense of heart rate increase, heart missing a beat)	0	1	2	3			
20	I felt scared without any good reason	0	1	2	3			
21	I felt that life was meaningless	0	1	2	3			
					TOTALS			

Appendix C Social Network Index

Social Network Index

Instructions: This questionnaire is concerned with how many people you see or talk to on a regular basis including family, friends, workmates, neighbors, etc. Please read and answer each question carefully. Answer follow-up questions where appropriate.

1. Which of the following best describes your marital status?
____ (1) currently married & living together, or living with someone in marital-like relationship
____ (2) never married & never lived with someone in a marital-like relationship
____ (3) separated
____ (4) divorced or formerly lived with someone in a marital-like relationship
____ (5) widowed

2. How many children do you have? (If you don't have any children, check '0' and skip to question 3.)
____0 ____1 ____2 ____3 ____4 ____5 ____6 ____7 or more

2a. How many of your children do you see or talk to on the phone at least once every 2 weeks?
____0 ____1 ____2 ____3 ____4 ____5 ____6 ____7 or more

3. Are either of your parents living? (If neither is living, check '0' and skip to question 4.)
____ (0) neither ____ (1) mother only ____ (2) father only ____ (3) both

3a. Do you see or talk on the phone to either of your parents at least once every 2 weeks?
____ (0) neither ____ (1) mother only ____ (2) father only ____ (3) both

4. Are either of your in-laws (or partner's parents) living? (If you have none, check the appropriate space and skip to question 5.)
____ (0) neither ____ (1) mother only ____ (2) father only ____ (3) both ____ (4) not applicable

4a. Do you see or talk on the phone to either of your partner's parents at least once every 2 weeks?
_____ (0) neither _____ (1) mother only _____ (2) father only ____ (3) both

5. How many other relatives (other than your spouse, parents & children) do you feel close to? (If '0', check that space and skip to question 6.)
____0 ____1 ____2 ____3 ____4 ____5 ____6 ____7 or more

5a. How many of these relatives do you see or talk to on the phone at least once every 2 weeks?
____0 ____1 ____2 ____3 ____4 ____5 ____6 ____7 or more

6. How many close friends do you have? (meaning people that you feel at ease with, can talk to about private matters, and can call on for help)
____0 ____1 ____2 ____3 ____4 ____5 ____6 ____7 or more

6a. How many of these friends do you see or talk to at least once every 2 weeks?
____0 ____1 ____2 ____3 ____4 ____5 ____6 ____7 or more

7. Do you belong to a church, temple, or other religious group? (If not, check 'no' and skip to question 8.)
_____ no _____ yes

7a. How many members of your church or religious group do you talk to at least once every 2 weeks? (This includes at group meetings and services.)
____0 ____1 ____2 ____3 ____4 ____5 ____6 ____7 or more

8. Do you attend any classes (school, university, technical training, or adult education) on a regular basis? (If not, check 'no' and skip to question 9.)
_____ no _____ yes

8a. How many fellow students or teachers do you talk to at least once every 2 weeks? (This includes at class meetings.)
____0 ____1 ____2 ____3 ____4 ____5 ____6 ____7 or more

9. Are you currently employed either full or part-time? (If not, check 'no' and skip to question 10.)
____ (0) no _____ (1) yes, self-employed _____ (2) yes, employed by others

9a. How many people do you supervise?
____0 ____1 ____2 ____3 ____4 ____5 ____6 ____7 or more

9b. How many people at work (other than those you supervise) do you talk to at least once every 2 weeks?
____0 ____1 ____2 ____3 ____4 ____5 ____6 ____7 or more

10. How many of your neighbors do you visit or talk to at least once every 2 weeks?
_____0 ____1 ____2 ____3 ____4 ____5 ____6 ____7 or more

11. Are you currently involved in regular volunteer work? (If not, check 'no' and skip to question 12.)
_____ no _____ yes

11a. How many people involved in this volunteer work do you talk to about volunteering-related issues at least once every 2 weeks?

____0 ____1 ____2 ____3 ____4 ____5 ____6 ____7 or more

12. Do you belong to any groups in which you talk to one or more members of the group about group-related issues at least once every 2 weeks? Examples include social clubs, recreational groups, trade unions, commercial groups, professional organizations, groups concerned with children like the PTA or Boy Scouts, groups concerned with community service, etc. (If you don't belong to any such groups, check 'no' and skip the section below.)

______ no ______ yes

Consider those groups in which you talk to a fellow group member at least once every 2 weeks. Please provide the following information for each such group: the name or type of group and the total number of members in that group that you talk to at least once every 2 weeks.

Total number of group members

Group that you talk to at least once every 2 weeks

1.

2.

3.

4.

5.

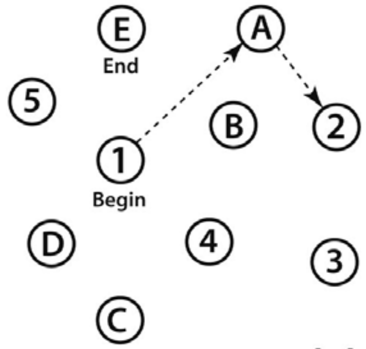
6.

Appendix D Montreal Cognitive Assessment

MONTREAL COGNITIVE ASSESSMENT (MOCA)
Version 7.1 Original Version

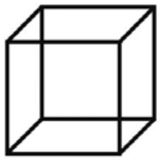
NAME :
Education : Date of birth :
Sex : DATE :

VISUOSPATIAL / EXECUTIVE



[ ]

Copy cube



[ ]

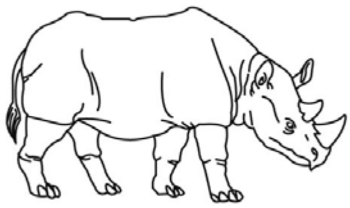
Draw CLOCK (Ten past eleven)
(3 points)

[ ] Contour [ ] Numbers [ ] Hands

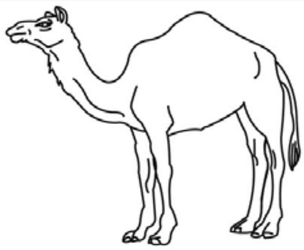
POINTS: __/5

NAMING

[ ]



[ ]



[ ]

__/3

MEMORY

Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.

	FACE	VELVET	CHURCH	DAISY	RED
1st trial					
2nd trial					

No points

ATTENTION

Read list of digits (1 digit/ sec.).
Subject has to repeat them in the forward order [ ] 2 1 8 5 4
Subject has to repeat them in the backward order [ ] 7 4 2
__/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors
[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B
__/1

Serial 7 subtraction starting at 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65
4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt**
__/3

LANGUAGE

Repeat : I only know that John is the one to help today. [ ]
The cat always hid under the couch when dogs were in the room. [ ]
__/2

Fluency / Name maximum number of words in one minute that begin with the letter F [ ] ____ (N ≥ 11 words)
__/1

ABSTRACTION

Similarity between e.g. banana - orange = fruit [ ] train – bicycle [ ] watch - ruler
__/2

DELAYED RECALL

		FACE	VELVET	CHURCH	DAISY	RED	
DELAYED RECALL	Has to recall words WITH NO CUE	[ ]	[ ]	[ ]	[ ]	[ ]	Points for UNCUED recall only
Optional	Category cue						
	Multiple choice cue						

__/5

ORIENTATION

[ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City
__/6

www.mocatest.org
Normal ≥26 / 30
TOTAL __/30
Add 1 point if ≤ 12 yr edu

Administered by: ______________________________

Appendix E Recruitment Flyer

Edith Cowan University
School of Medical and Health Sciences

FREE COGNITIVE TESTING!

Participants Required for Masters Research

Previous research has shown exercise can benefit cognition. We need your help to find the most effective type of exercise in preventing a decline in cognitive function (mental abilities)

Who: Males & females (65-75 yrs) exercising at least once per week in either tennis, walking, running, swimming or cycling OR no regular exercise

Time commitment: One session - 3 hrs

Where:

- Edith Cowan University, Joondalup

When: Book a time now!

What is required:

- Participation in 7 cognitive tests (e.g. memory & attention test)
- Participation in 6 physical function tests (e.g. rising from a chair & hand grip strength)

If you or someone you may know are interested in participating in this research or have any questions, please contact:

Scott Culpin
[redacted]
Email: sculpin@our.ecu.edu.au

http://www.ecu.edu.au/schools/medical-and-health-sciences/overview

Appendix F Information Letter

Edith Cowan University
School of Medical and Health Sciences

Information Letter to Participants

Effects of long-term participation in tennis on cognitive function in elderly individuals

Study background

Many studies reported the effects of physical activity on cognition with conflicting results. This may be due to differences in exercise intervention durations, session lengths and intensities, and type of exercises. It is not yet known if certain types of exercise are of more benefit to cognition than others. Research has commonly used aerobic exercises (e.g., running, swimming, walking and cycling) to examine the effects of exercise on cognition. Small improvements to cognition have been found as a result of aerobic exercise, however it is not known whether exercises that have been suggested to require greater effort such as tennis, have similar or even greater benefits to cognition. It would be of interest to compare cognitive function in individuals who have participated in different types of exercise. Currently, of the scarce literature comparing the effect different types of exercise have on cognition, only a few domains of cognitive function (inhibitory function, task switching, visuospatial) have been investigated. It is necessary to compare the effects of different types of exercises (tennis, running, swimming, walking, cycling) across many aspects of cognition (e.g., memory and attention).

Aim of the study

The purpose of this project is to investigate the effects of long-term participation in different types of exercises (tennis, swimming, running, walking and cycling) on cognitive function, in comparison to participants who are not involved in any specific exercise, to understand the effects of exercise on changes in cognitive function with aging.

Participation in the study

One hundred and fifty healthy men and women aged between 65-75 years of age will be recruited for this study. For you to participate in the study, you must be aged between 65-75 years of age and have; at least 6 years of education, been involved in tennis, swimming, running, walking or cycling at least once per week for a minimum of 10 years. Furthermore, you can participate in the study if you do no regular exercise at all.

Sessions

You will be asked to come to the Laboratory (J019.145) for one session. The session will consist of cognitive screening, cognitive function testing, familiarisation of physical function testing, and physical function testing. You will be asked to wear trainers and clothes appropriate for physical activity. You will also need to refrain from consuming caffeine 6 hours prior to testing, and alcohol 24 hours prior to testing.

You will be asked complete a self-reported activity questionnaire (Community Health Activities Model Program for Seniors) followed by a medical questionnaire, and a demographics questionnaire. You will then partake in the first measure of cognition (global cognition). You will be sat at a desk opposite an examiner. You will be required to respond to questions asked by the examiner, either in a verbal manner or by completing a task. You will then move to be seated in front of desktop computer in the same room (JO19.145), in preparation for cognitive testing. Before each cognitive test commences, you will read the instructions for the specific cognitive test and perform several practise attempts. You will then move onto the next cognitive test, repeating the same protocol for 7 cognitive tests in the battery (Stroop test, detection task, identification task, one-back task, learning task, set-shifting task). Between each cognitive test you may have a short break. After completion of the battery of cognitive test, you will be given a 15-minute break. After the break, you will complete a questionnaire indicating distress during cognitive testing (DASS-21) before commencing to physical function familiarisation and testing. You will first be guided through a 10-minute dynamic warm-up. Next, you will be familiarised with the physical function tests you will be performing later in the session. Each physical function test will be explained to you in a verbal manner, followed by a demonstration, you then will be encouraged to attempt the physical function tests yourself. After a short 5-minute break you will be required to perform 6 physical function tests (6-minute walk test, chair stand test, grip strength, 8-feet up and go, back scratch, and chair sit and reach test. Between each physical function test, you will be given a 4-minutes rest period. To finish the session, you will undertake a light cool-down.

Measurements and Variables

1) *Characteristics and demographics*: Your age, sex, height, body mass, years of education, medical history, self-reported activity.
2) *Cognitive function*: Your global cognition performance (Montreal Cognitive Assessment) and your cognitive functioning performance (Stroop test and Cogstate computerised testing).

Montreal Cognitive Assessment

- You will be instructed to respond to questions asked by the examiner, either in a verbal manner (memory and language) or by completing a task (visuospatial, executive function, attention).

Stroop test

- You will be shown a colour-word, however presented in an inconsistent colour ink (e.g. the word "red" is printed in black ink). You must respond to the colour of the ink as quickly as possible by pressing an electronic button of that colour.

Cogstate computerised testing

- Detection task: You will be required to press "yes" as quickly as possible, as a playing card flips over into a face up position.
- Identification task: You will be shown a playing card of either red or black in colour, if the card is Red then you should press "yes" and if not then "no" should be pressed.
- One-back task: The one-back task is a measure of working memory. You must respond either yes or no depending on whether you believe the present card matches the last card shown.
- Learning task: The test begins by presenting a playing card face up. You must decide whether or not you have previously seen the card presented during the task, if so you should respond by pressing "yes".
- Set-shifting task: You must guess whether the first card presented contains a predetermined target stimulus dimension (a colour or a number). If you choose correctly, the card will flip, if the

guess is incorrect the card shall remain face up and the participant must try to determine the identity of the stimuli. This process teaches that a specific dimension of the card (either a number of colour) is “correct”. After completion of a set of cards, task-switching occurs and the stimulus dimensions change and the must then identify the new stimuli.

- Groton Maze task: A 10x10 grid of tiles is presented on the participants screen with a hidden pathway below the tiles. Using the mouse, you must move one tile at a time from the starting tile to the finishing tile, as quickly and as accurately as possible.

3) *Physical function*: Your performance in the following tests will be recorded:

- Back scratch: You will place one hand behind the back of your head and reach as far down as possible. You will place your other hand behind your back and reach upwards, whilst your palm is facing outwards. You will attempt to overlap your two hands as far as possible.
- Chair sit and reach: You will be instructed to sit near the edge of a chair and fully extend your preferred leg with your heel resting on the floor in 90 degrees dorsiflexion, whilst placing the other leg off to the side in a bent position. You will slowly bend forward, keeping your spine as straight as possible, and reach down your extended leg to the furthest possible position and hold this position for 2 seconds.
- 8-feet Up and Go: You will start with their back pressed against the back rest of an armless chair. When instructed to begin, you will stand up and walk around a cone situated 8 feet away, and sit back down on the starting chair.
- Grip Strength: You will use your dominant hand to maximally squeeze a hand dynamometer.
- 30-s chair stand: You shall start by sitting in the centre of a chair. While resting your arms across the opposite shoulder, you will attempt to rise to a fully standing position, and back to the original seated position as many times as possible for 30 seconds.
- 6-minute walk test: You will be required to walk your maximum distance in 6-minutes around a 30m track.

Benefits of study participation

You will be provided with your performance in the cognitive tests and can be informed how that compares will age appropriate normative scores. You may then wish to seek further cognitive testing if you are concerned about your scores. You will also be informed how your physical function compares with normative scores. The scores may encourage you undertake more physical activity to improve your physical function.

Potential risks of the study

You may experience a short spell of mental fatigue given you will be required to perform 6 cognitive test to the best of your ability. You may experience some muscle soreness following the physical function testing, however these symptoms will disappear in a few days. There is a small risk of musculoskeletal injury when undertaking physical function testing. This risk is minimised through the use of an appropriate warm-up, familiarisation session and supervision by the researcher. If you experience any pain during the protocols, please inform us immediately.

Participant rights

Participation in this study is completely voluntary. You retain the right to withdraw from the study or refuse to participate in any of the cognitive or physical function test at any time, and without the need to give a reason for your decision. There will be no consequences for your withdrawal or refusal to participate. Reporting of the study findings will be done with the complete confidentiality and your identity will not be disclosed to anyone outside of the study at any time. You have the right to receive information regarding your own data/results at any time during the study from the investigators.

Data collection and storage

The obtained data will be stored securely so that the personal information cannot be accessed by those external to the study. Back-up copy of the data will be stored on a hard-drive which is protected by a password know only be the researcher.

The use of the study results

The results of this study will be published in a peer-reviewed scientific journal, and will also be presented in conferences in the future. Your cognitive function and physical function results will remain anonymous when reporting the data.

Questions and further information

This project has been approved by the ECU Human Research Ethics Committee. If you wish to volunteer as a participant, please read carefully and sign the informed consent form attached below. By signing this form, you are acknowledging that you are aware of the procedures, risks involved; signing this form does not remove your right to withdraw from the study at any time without prejudice. Should you have any questions or require additional information concerning the research, you may contact the following persons. We would be more than happy to assist you.

Scott Culpin

Mobile: [redacted]

Email: sculpin@our.ecu.edu.au

Ken Nosaka

Telephone: +61 8 6304 5655

Email: k.nosaka@ecu.edu.au

If you have any concerns regarding the study or would like to speak to an independent person, you may contact the research ethics officer at the following:

Telephone: 6304 2170 Email: research.ethics@ecu.edu.au

Thank you very much for your interest in this study and time taken to read the information.

Appendix G Informed Consent

Edith Cowan University
School of Medical and Health Sciences

Effects of long-term tennis participation on cognitive function in elderly individuals

Informed consent form
Mr Scott Culpin

Participant consent to the study

- I confirm that I have read the above information form, which has described the purpose, methodology (including possible risks) and participant rights.
- I have had an opportunity to discuss the procedures with the lead researcher and have had any questions answered to my own satisfaction.
- I agree to the experimental protocol as explained to me and give consent to participate in the testing program.
- I will not participate if I: have flu, fever, am intoxicated or otherwise unwell.
- I will not participate if I have consumed the following: caffeine or energy drinks for 8 hrs prior to testing.
- I can withdraw from the project or refuse to participate in single measurements at any time without reason for my decision.
- My results may be used in scientific reports (e.g. in peer-review publication) and presentations, in which my personal data or identity will remain anonymous.
- **I will ask for a copy of this signed form if I wish to retain one for my records**.

Date Participant name and signature

http://www.ecu.edu.au/schools/medical-and-health-sciences/overview

Appendix H Ethics Approval

Dear Scott

Project Number: 17401 CULPIN
Project Name: Effects of long-term participation in tennis on cognitive function in elderly individuals

Student Number: [redacted]

The ECU Human Research Ethics Committee (HREC) has reviewed your application and has granted ethics approval for your research project. In granting approval, the HREC has determined that the research project meets the requirements of the National Statement on Ethical Conduct in Human Research.

The approval period is from 17 July 2017 to 22 January 2018.

The Research Assessments Team has been informed and they will issue formal confirmation of candidature (providing research proposal has been approved). Please note that the submission and approval of your research proposal is a separate process to obtaining ethics approval and that no recruitment of participants and/or data collection can commence until formal notification of both ethics approval and approval of your research proposal has been received.

All research projects are approved subject to general conditions of approval. Please see the attached document for details of these conditions, which include monitoring requirements, changes to the project and extension of ethics approval.

Please feel free to contact me if you require any further information.

Kind regards

Rowe

Rowe Oakes
Ethics Support Officer
Office of Research & Innovation, Edith Cowan University
Phone: +61 08 6304 2943
Email: research.ethics@ecu.edu.au
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Appendix I CHAMPS Activities Questionnaires for Older Adults

This questionnaire is about activities that you may have done in the past 4 weeks. The questions on the following pages are similar to the example shown below.

INSTRUCTIONS

If you DID the activity in the past 4 weeks:

Step #1 **Check the YES box.**

Step #2 **Think about how many TIMES a week you usually did it, and write your response in the space provided.**

Step #3 **Circle how many TOTAL HOURS in a typical week you did the activity.**

Here is an example of how Mrs. Jones would answer question #1: Mrs. Jones usually visits her friends Maria and Olga twice a week. She usually spends one hour on Monday with Maria and two hours on Wednesday with Olga. Therefore, the total hours a week that she visits with friends is 3 hours a week.

In a typical week during the past 4 weeks, did you…							
1. Visit with friends or family (other than those you live with)? ☒ **YES** How many TIMES a week? 2 ➔ ☐ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	(3-4½ hours)	5-6½ hours	7-8½ hours	9 or more hours

If you DID NOT do the activity:

- **Check the NO box and move to the next question**

2

In a typical week during the past 4 weeks, did you …							
1. Visit with friends or family (other than those you live with)? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
2. Go to the senior center? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
3. Do volunteer work? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
4. Attend church or take part in church activities? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
5. Attend other club or group meetings? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
6. Use a computer? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

In a typical week during the past 4 weeks, did you …								
7. Dance (such as square, folk, line, ballroom) (do not count aerobic dance here)? **YES** How many TIMES a week?_____ → **NO**	How many TOTAL hours a week did you usually do it? →	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
8. Do woodworking, needlework, drawing, or other arts or crafts? **YES** How many TIMES a week?_____ → **NO**	How many TOTAL hours a week did you usually do it? →	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
9. Play golf, carrying or pulling your equipment (count walking time only)? **YES** How many TIMES a week?_____ → **NO**	How many TOTAL hours a week did you usually do it? →	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
10. Play golf, riding a cart (count walking time only)? **YES** How many TIMES a week?_____ → **NO**	How many TOTAL hours a week did you usually do it? →	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
11. Attend a concert, movie, lecture, or sport event? **YES** How many TIMES a week?_____ → **NO**	How many TOTAL hours a week did you usually do it? →	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
12. Play cards, bingo, or board games with other people? **YES** How many TIMES a week?_____ → **NO**	How many TOTAL hours a week did you usually do it? →	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

In a typical week during the past 4 weeks, did you …							
13. Shoot pool or billiards? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
14. Play singles tennis (do <u>not</u> count doubles)? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
15. Play doubles tennis (do <u>not</u> count singles)? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
16. Skate (ice, roller, in-line)? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
17. Play a musical instrument? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
18. Read? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
19. Do heavy work around the house (such as washing windows, cleaning gutters)? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

In a typical week during the past 4 weeks, did you …							
20. Do light work around the house (such as sweeping or vacuuming)? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
21. Do heavy gardening (such as spading, raking)? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
22. Do light gardening (such as watering plants)? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
23. Work on your car, truck, lawn mower, or other machinery? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
****Please note: For the following questions about running and walking, include use of a treadmill.**							
24. Jog or run? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
25. Walk uphill or hike uphill (count only uphill part)? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

In a typical week during the past 4 weeks, did you …							
32. Swim moderately or fast? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
33. Swim gently? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
34. Do stretching or flexibility exercises (do <u>not</u> count yoga or Tai-chi)? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
35. Do yoga or Tai-chi? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
36. Do aerobics or aerobic dancing? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
37. Do moderate to heavy strength training (such as hand-held weights of <u>more than 5 lbs</u>., weight machines, or push-ups)? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL <u>hours a week</u> did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

In a typical week during the past 4 weeks, did you …							
38. Do light strength training (such as hand-held weights of 5 lbs. or less or elastic bands)? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
39. Do general conditioning exercises, such as light calisthenics or chair exercises (do not count strength training)? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
40. Play basketball, soccer, or racquetball (do not count time on sidelines)? **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours
41. Do other types of physical activity not previously mentioned (please specify)? ______________________ **YES** How many TIMES a week?_____ ➔ **NO**	How many TOTAL hours a week did you usually do it? ➔	Less than 1 hour	1-2½ hours	3-4½ hours	5-6½ hours	7-8½ hours	9 or more hours

Thank You