

**PHYSICAL ACTIVITY, PHYSICAL FITNESS, FUNCTIONAL
CAPACITY AND COGNITIVE PERFORMANCE IN OLDER ADULTS:
EFFECTS OF INTERACTIVE VIDEO GAMING**

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DECLARATION

PhD THESIS TITLE

PHYSICAL ACTIVITY, PHYSICAL FITNESS, FUNCTIONAL CAPACITY AND COGNITIVE PERFORMANCE IN OLDER ADULTS: EFFECTS OF INTERACTIVE VIDEO GAMING

I, **Udhir Ramnath**, hereby declare that the research and academic work contained within this thesis is my original work (except where acknowledgements indicate otherwise) while based at the University of Cape Town, under the supervision of A/Prof. Tracy Kolbe-Alexander and co-supervision of Prof. Estelle Victoria Lambert. The contents of this work have not been submitted in any part, as a whole or in any other form for another degree in this or any other university.

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PUBLICATIONS ASSOCIATED WITH THE THESIS

1. Ramnath U, Rauch L, Lambert EV, Kolbe-Alexander TL. The relationship between functional status, physical fitness and cognitive performance in physically active older adults: A pilot study. PLoS One. 2018 Apr 9;13(4):e0194918. doi: 10.1371/journal.pone.0194918. PMID: 29630625; PMCID: PMC5890973.
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LIST OF ABBREVIATIONS

ANOVA – Analysis of Variance
Ave – Average
BBS/T – Berg Balance Scale / Test
BMI – Body Mass Index
bpm – beats per minute
CAMCI – Computerized Assessment of Mild Cognitive Impairment
CDT – Clock Drawing Test
CHAMPS – Community Health Activity Model Program for Senior's
CHIPS – Community Health Intervention Programmes
cm – centimetres
CM – Conventional Multimodal
COAST – California Older Adult Stroop Test
CPOA – Cape Peninsula Organization for the Aged
DSST – Digit Symbol Substitution Test
GAD – Generalized Anxiety Disorder
GARS – Groningen Activity Restriction Scale
HR – Heart Rate
HHR – Heart Rate Reserve
HIV – Human Immunodeficiency Virus
HVOT – Hooper Visual Organization Test
IVG – Interactive Video Gaming
IQR – Interquartile Range

JLO – Judgment of Line Orientation, form V
kcal – kilocalories
kg – kilograms
kg.m² - kilogram per metre squared
m – metres
MCI – Mild Cognitive Impairment
min – minutes
MMSE – Mini Mental State Examination
MoCA – Montreal Cognitive Assessment
MRI – Magnetic Resonance Imaging
ms – milliseconds
MVPA – Moderate-to-Vigorous Physical Activity
NCDs – Non-Communicable Diseases
NEPA – Non-Exercise Physical Activity
OCD – Obsessive-Compulsive Disorder
PA – Physical Activity
PAR-Q – Physical Activity Readiness Questionnaire
PFC – Prefrontal Cortex
PGCMS – Philadelphia Geriatric Center Morale Scale
PTSD – Post Traumatic Stress Disorder
QIDS – Quick Inventory for Depressive Symptoms

RAVLT – Rey Auditory Verbal
Learning Test

RBANS – Repeatable Battery for
Assessment of Neurocognitive Status

Rec - Recovery

REPDS – Revised Elderly Persons
Disabilities Scale

s – seconds

S.D – Standard Deviation

S.E – Seated Exercise

SES – Socio-Economic Status

SMC – Subjective Memory Complaint

SP – Specific Phobia

SPPB – Short Physical Performance
Battery

SWB – Subjective Well-Being

TICS – Telephone Interview for
Cognitive Status

TUG – Timed Up and Go

VFT – Verbal Fluency Test

vs – versus

WAIS-III – Wechsler Adult Intelligence
Scale - III

WHO – World Health Organization

WM – Working Memory

YPAS – Yale Physical Activity Survey

yrs – years

DEFINITION OF TERMS

Alzheimer's Disease Assessment Scale (ADAS) - Cognitive Subscale

ADAS-Cognitive subscale is a widely used tool established in the 1980s to assess the level of cognitive impairment in Alzheimer's disease. Some of the tasks within the ADAS-Cognitive subscale include word recall, follow commands, orientation, language, word finding and recognition (1).

Associative Memory Task

Associative memory is the ability to acquire and remember relationships between unrelated items or objects. An example of an associative memory task is requiring an individual to recall face-scene pairs (2).

Avatar

An image or figure / character that is used to represent a particular individual in a video game.

Berg Balance Scale / Test

The Berg balance scale / test is a 14 item clinical scale made up of static and dynamic activities that are used to assess an individual's balance (3;4).

California Older Adult Stroop Test (COAST)

The COAST is a modification of the traditional Stroop test (measure of executive function) which is specifically designed for the older adult population. The test utilizes fewer items, has a larger typeface and has more distinguishable colours (5).

Chest Press (Horizontal)

During the horizontal chest press, the individual grips the handles of the chest press machine and pushes forward, straightening their arms. This is followed by gradually bending their arms until their elbows are at 90 degrees or slightly

behind their chest, then forward again to complete a repetition. This exercise focuses on the pectorals (major and minor), triceps and shoulder muscles.

Community Healthy Activities Model Program for Senior's (CHAMPS)

This is a public health evidenced based intervention program to promote enhanced lifetime physical activity levels in older adults (6).

Controlled Oral Word Association Test

This test measures verbal fluency and is part of the Multilingual Aphasia Examination. The test uses different letters to assess phonemic fluency. Individuals are given a specific letter and required to name as many words as possible correctly in one minute (7).

Digit Span Test

A short test used to assess cognitive status. Individuals are requested to listen carefully to a series of numbers followed by them repeating the numbers in the correct order. This test can be administered in a forward manner (from the first number to the last number) or backwards (asking the individual to start with the last number and continue until they reach the first number). The forward version of the test measures attention and short term memory while the backward version also assesses working memory (8).

Digit Symbol Substitution Test (DSST)

The DSST is a test administered on a single sheet of paper. Individuals are required to match symbols to numbers using a pencil according to a specific key provided at the top of the page. The time permitted to complete the test is normally between 90 – 120 seconds and the total correct matched symbols constitute the total score (9).

Energy Expenditure

The total amount of energy that an individual consumes on a daily basis to carry out physical tasks such as exercising and digesting of food. Energy expenditure is often measured in calories or kilocalories (10).

Everyday Memory Questionnaire

The Everyday Memory Questionnaire is used to assess cognitive complaints in older adults. Individuals are requested to rate 28 items on the questionnaire according to a 3 point scale (0 = never, rarely; 1 = occasionally, sometimes; 2 = frequently, almost always). The total score can range from 0 – 56 (11).

Everyday Problems Test

This test is used to determine an individual's ability to solve various problems such as health, financial well-being, housework, mobility and transportation, preparation of food and shopping (12).

Exercise

Exercise is a subcategory or form of physical activity that is controlled, planned and repetitive to sustain or enhance health, fitness and physical well-being (13).

Guralnik test battery (Short Physical Performance Battery – SPPB)

The Guralnik test battery (also known as SPPB) is made up of 3 items namely: static balance, ability to rise from a chair and gait / walking speed. Scoring for each item is based on a 4 point scale (0 – 4). Static balance is assessed using 3 stances (side-by-side, semi tandem stance and tandem stance). To test an individual's ability to rise from a chair, the individual must have their arms folded across their chest with their back straight against the backrest of the chair, then to stand up to a straight standing position. This procedure is done as quickly as possible for 5 attempts. Walking speed is measured by asking the individual to walk 8 feet at a normal pace (14).

Hooper Visual Orientation Test (HVOT)

The HVOT is a test that measures an individual's perceptual disparity and conceptual reorganisation (including mental rotation). Individuals are required to reorganise conceptual figures that have been disarranged (15).

Hopkins Verbal Learning Test

The Hopkins Verbal Learning test is a measure of verbal learning and memory. The administrator of the test reads a list of 12 words aloud and the individual being tested is required to recall the words immediately. This procedure is completed for 3 times. The total amount of correct words recalled after 3 trials is recorded and scored (range 0 – 36) (16).

Interactive Video Gaming (IVG)

IVG is the physical engagement of video games while applying cognitive stimulation. It requires an individual to integrate many cognitive processes while navigating complex and changing environment. IVG requires the use of body movements to control the onscreen avatars movement (17;18).

Judgment of Line Orientation, form V

This test measures spatial orientation and requires an individual to estimate angular associations between line segments (30 pairs) by coupling them with numbered lines clustered in a semicircle (15).

Magnetic Resonance Imaging (MRI)

Magnetic Resonance Imaging is used as a diagnostic tool in radiology to demonstrate anatomy, physiology and functionality of the human body in the presence of high magnetic fields without the use of ionizing radiation.

Matrix Reasoning test of the Wechsler Adult Intelligence Scale

Matrix Reasoning is a measure of nonverbal problem solving as well as inductive and spatial reasoning. Individuals are presented with a diagram consisting of a particular pattern and are required to identify the missing piece from the diagram (19).

Maximal Oxygen Uptake / VO₂Max

Maximal oxygen uptake / consumption is the highest amount of oxygen that can be utilized by an individual during exercise using large muscle groups. VO₂Max gives an indication of an individual's cardiorespiratory fitness (20).

Microsoft X-box 360 console

A home-based audio-visual gaming console developed by Microsoft and is the subsequent console to the original version in the X-box series.

Mild Cognitive Impairment (MCI)

This is a transitional phase between normal cognitive function and dementia, where individuals have memory or cognitive impairment greater than one would anticipate for their age, but do not meet the required criteria for a dementia diagnosis (21;22).

Modified Mini-Mental State Examination

The Modified Mini-Mental State Examination is a measure of global cognitive function and is an extended version of the Mini-Mental State Examination. The Modified Mini-Mental Examination includes four additional tests that assess memory, verbal fluency, the ability to identify associations among objects and temporal and spatial orientation (23).

Montreal Cognitive Assessment (MoCA)

The MoCA is a 30-point assessment tool that is used extensively to detect cognitive impairment. The MoCA assesses many different cognitive components such as short-term memory, visuospatial orientation, attention, concentration, language, executive function and abstract reasoning (24).

Multiple-Directional Reach Test

The Multiple-Directional test is used to assess stability and postural control in four different directions (forwards, backwards, left and right). The test is carried out in a similar manner to the Functional Reach test (forward), however, for backwards reach, individuals are required to lean as far back as

possible and for the left and right reach individuals use their respective arms and reach as far as possible along the yardstick (25).

Neurobehavioral Cognitive Status Examination

The Neurobehavioral Cognitive Status Examination is a brief screening tool used to evaluate cognitive function in 5 areas namely: intellectual reasoning, memory, linguistic, calculation and constructions (26).

One Repetition Maximum

Is defined as the maximum amount of weight an individual can lift / push / pull (force generating capacity) in one repetition of an exercise (27).

Physical Activity

Any bodily movement formed by skeletal muscles that will result in energy expenditure (13).

Physical Fitness

Physical fitness is defined as a state of health and well-being, and the capacity to execute everyday tasks and activities with robustness and awareness without causing undue discomfort and fatigue and with adequate energy to continue leisure-time activities (13).

Quick Inventory for Depressive Symptoms (QIDS)

QIDS is a simple 16-item self-report tool to measure depressive symptoms. Scores range from 0 to 48 with a higher score indicating greater depression (28).

Reaction time

Reaction time is defined as the amount of time an individual takes to respond to a stimulus (29).

Repeatable Battery for Assessment of Neurocognitive Status (RBANS)

The RBANS is a neuropsychological assessment and is made up of 12 subtests which constitutes to 5 different scores based on the 5 cognitive domains assessed which are visuospatial orientation, immediate memory, delayed recall, attention and language (30).

Rey Auditory Verbal Learning Test (RVLT)

The RVLT is a neuropsychological instrument used to assess verbal memory. During this test, an individual listens to 15 nouns (List A) aloud and is required to recall as many words as possible. After 5 recall trials (List A), an additional list of words (List B) is administered in the same manner and the individual is required to recall as many words as possible. After the List B trial, the individual is required to recall as many words as possible from the initial list (List A) again. In addition, following a 20 minute delay, the individual is asked to recall words from List A (Delayed Recall) (31).

Rey-Osterrieth complex figure

This is a test of visuospatial abilities, working memory, planning and attention. An individual will be required to replicate a complex line drawing in two steps: In step 1, they will be asked to copy a drawing placed in front of them, using freehand. They will repeat the task in step two, but replicate the drawing from memory (recall) (32).

Rivermead Behavioral Memory Test

This test was designed to identify everyday memory impairment by providing assessment items that resemble activities carried out in everyday life (e.g. remembering to send a message) (33).

Sedentary Behaviour

Any waking actions and / or activities that involve sitting, laying down (while awake), and reclining and are characterized by an energy expenditure of less than or equal 1.5 metabolic equivalents (34).

Senior Fitness Test (Fullerton Functional Test)

The Senior Fitness test is a battery of various test items that measure functional ability and fitness of seniors aged 60 years and older. The various test items utilized measure upper (arm curl test) and lower (chair stand test) body strength, aerobic fitness (6-minute walk test), flexibility (chair sit and reach test and back scratch test) and agility (8-foot up and go test) (35).

Story Recall Test

The story recall test is a cognitive assessment of memory and requires an individual to recall as much details of a story as possible that was read aloud to him or her. Recall of the story is assessed immediately as well as after a specific amount of time, usually after 20 to 30 minutes after hearing the story (delayed recall) (36).

Subjective Memory Complaint

A subjective memory complaint arises when an individual reports having memory problems or difficulties on more than one occurrence. Subjective memory complaints signify a type of complaint made by an individual with adverse cognitive symptoms, but no distinct impairment is noted on objective tests (37).

Sub-Saharan Africa

Geographically includes all countries on the African continent that lies fully or partially south of the Sahara desert (The Sahara is a desert situated on the African continent).

Task Switching

Task switching (also known as set-shifting) is an important executive function. It is the ability to unconsciously shift or switch one's attention between different tasks. It allows an individual to quickly respond to different conditions (38).

The Parallel Walk Test

The Parallel Walk test is a simple measure of balance during walking. An individual is required to walk 6 metres at normal pace and stride rate between 2 parallel lines placed 20, 30.5 and 38cm apart. Total footfall score is based on the number of times the individual's foot makes contact with the line (+1) and when the foot is completely outside the line (+2) or if they use any external object to help maintain balance (39).

Tinetti: Performance-Oriented Mobility Assessment (POMA)

The Tinetti test (also known as the POMA) is used to assess balance and gait in older adults. The Tinetti test comprises of 2 sections:

1) The first section assesses balance using an armless chair and during standing. The individual is required to rise up from an armless chair and stay standing. He or she will then turn 360° and then sit down again. Scoring is based on how the individual rises from the chair and if the individual stays in an upright position while sitting and standing.

2) The second section assesses dynamic balance. The individual is required to stand up from a chair, then walk 15 feet at normal pace, turn around and walk back as quickly as possible and then be seated again.

A total score for both sections out of 28 points is recorded. A lower total score on the Tinetti test is suggestive of higher fall risk (40).

Trail-Making Test (Part A and B)

The Trail-Making test is a measure of visual attention as well as task-switching and is made up of two parts (Part A and B). Both parts of the Trail-Making test have 25 circles scattered on a sheet of paper.

During Part A, the individual is required to draw lines connecting the circled numbers in ascending order (1 – 25). Part B contains a mixture of numbers (1 – 13) and letters (A – L).

During Part B, the individual is required to draw lines connecting the circles in ascending order, but alternating between numbers and letters (1, A, 2, B, 3, C...). The individual is instructed to complete the test as fast possible without lifting the pencil from the paper (41).

Unipedal Stance Test (One Leg Stance / Unipedal Balance test)

The Unipedal Stance test is a simple measure of static balance. An individual is required to stand on one leg with arms crossed over the chest and the other leg raised off the ground. The examiner starts the timer from the moment the individual raises the non-weight bearing leg off the ground. Under normal circumstances, 3 trials per a condition (eyes open and eyes closed) are performed. The timer is stopped when one of the following occurs:

1) Arms are moved from the original position across the chest; 2) Raised foot is used to maintain balance; 3) Movement of weight-bearing foot to maintain or assist balance; 4) 45 seconds has elapsed which is the maximum time for each trial and; 5) Individual opens his or her eyes on the eyes closed trial (42).

Verbal Fluency Test (Category and Letter Fluency)

The Verbal Fluency test is a psychological assessment of verbal function and is often made up of two tasks: Category (Semantic) and Letter (Phonemic) Fluency. In most versions of the verbal fluency test, individuals are given 1 minute to state as many words within a specific category or as many words starting with a specific letter. An individual's score in each task is based on the number of correct words produced within 1 minute (43).

Wechsler Adult Intelligence Scale III (WAIS-III)

The WAIS-III is an IQ test and is the third edition from the original version published in 1935. The WAIS-III is made up of 7 sub-tests that measure verbal, performance and full scale IQ as well as working memory, processing speed, verbal comprehension and perceptual organization. The most current version of this test is the WAIS-IV which was published in 2008 (44).

Wisconsin Card Sort Test

The Wisconsin Card Sort test has been widely used to assess higher cognitive processes such as set shifting, attention, abstract thinking and working memory. During the test, individuals are presented with a variety of

cards and are required to match the cards. This test takes 10 – 20 minutes to complete (45).

THESIS ABSTRACT

The ageing process is inevitable and is associated with a progressive decline in physical fitness, functional ability as well as cognitive performance due to the deterioration of the various biological, neuro-physiological and social systems. This may lead to an increased vulnerability for age-related diseases and a dependent lifestyle. In addition to the ageing process, sedentary behaviour is a contributing factor that can lead to decreased functional independence. The decline in physical, functional and cognitive performance with age, along with the increased possibility of becoming sedentary as one gets older may highlight the importance of participating in physical activity to acquire health and wellness benefits as well as to maintain independence.

The health and wellness benefits of physical activity have been widely studied within the ageing population. Physical activity can be defined as any bodily movement produced by skeletal muscles that will lead to an increase in resting energy expenditure. According to the World Health Organization guidelines on physical activity, adults should accumulate at least 150 minutes of moderate levels of physical activity or at least 75 minutes of vigorous levels of physical activity throughout the week or an equal combination of both levels. Much of the existing research to date has utilized more conventional physical activity interventions, including the use of various training components such as cardiorespiratory, motor coordination, agility, flexibility, balance and strength. These interventions have been shown to improve physical and cognitive parameters in older adults.

In recent times, alternative forms of physical activity interventions such as Tai Chi, Yoga, and Interactive Video Games (IVG) have become increasingly popular among older adults. However, there is limited research on the effectiveness of IVG interventions in older adults, particularly for those with memory complaints. IVG involves combining physical activity and exercise with video game play. It allows the individual to control the “avatar” on screen by using various body movements (e.g. if the individual moves to the right, the onscreen character will also move to the right).

This provides an opportunity for individuals to increase their energy expenditure by actively participating in these video games. In addition to increasing energy expenditure, IVG incorporates cognitive skills such as executive function, visuo-spatial skills, attention, working memory and coordination (hand and eye / foot and eye). Recent review articles have identified that a combination of physical and cognitive training intervention's show greater effects on cognitive performance than single-domain physical and cognitive training and subsequently applied physical and cognitive training. IVG has been shown to intensify the effects of physical exercise by controlling neuroplastic changes via additional cognitive exercise. These neuroplastic changes identified after participation in IVG are referred to as improvements in a specialized neural network and a lower dependency on compensational support. Therefore, IVG combines physical skills and abilities with cognitive skills, creating a cognitively stimulating type of physical activity, which may be different to more conventional physical activity. While these positive neuroplastic changes have been identified in some research studies, the underlying neurophysiological mechanism of IVG on cognitive performance and brain function is still poorly understood.

Although some research studies have been conducted showing the potential benefits of IVG on physical function and cognitive performance in different population groups over various time frames, not many studies have investigated whether IVG can improve cognitive function in older persons with memory complaints. In addition, to our knowledge, no other studies have compared IVG to conventional multimodal supervised standing and seated exercise in individuals with memory complaints.

Therefore, the aim of this thesis was to determine the effects of a 12-week IVG intervention using the X-Box 360 gaming console with Kinect Sports and Adventures games on cognitive performance in older adults, and specifically, in South African older adults, some with memory complaints. The IVG intervention was compared to a conventional multimodal supervised exercise intervention. We hypothesized that the IVG intervention would show greater improvements in measures of cognitive performance and functional ability than the conventional multimodal exercise intervention.

The thesis was undertaken in a stepped manner, firstly to establish the relationship between physical capacity and cognitive performance in highly functioning older adults, in part, to test our tools for measurement. The subsequent studies, examined the feasibility and acceptability of such a gaming intervention in older adults, living in residential homes, compared to more conventional “table games”. The final study was a, cluster-randomized exercise intervention trial, comparing video gaming to more conventional multimodal supervised exercise.

Study 1: An exploratory study was conducted to identify the relationship between fitness, functional ability, physical activity and cognitive performance in older, highly functioning adults. The aim of study 1 was to assess fitness, functional ability and cognitive performance in independent living older adults and to determine which fitness and functional performance tests best explain the variance in cognitive function. We hypothesized that a higher level of physical activity, fitness and functional ability would be associated with higher levels of cognitive performance in high functioning independent living older adults. The information gained from this study was formative for developing an intervention and to test the various measures of functional capacity and cognitive performance which were to be used in the subsequent chapters. Seventy older adults with a mean age of 71.0 ± 4.7 years were recruited for the study. Nearly two-thirds (60%) of the participants completed secondary school and more than two thirds (67%) were taking medication for a chronic medical condition. The Yale Physical Activity Survey was used to quantify self-reported physical activity. Fitness measurements included the 6-Minute Walk test and Bicep Curls in 30 seconds and functional ability was measured using Static and Dynamic Balance, Grip Strength, Sit to Stand, Timed Up and Go and Functional Reach. Cognitive performance was measured using the Modified Stroop task and the 6-Item Cognitive Impairment test, with each test measuring executive function and global cognitive function respectively. Bivariate and multivariate analyses were performed between performance on the Modified Stroop task and fitness, functional and cognitive performance tests.

The results showed a significant relationship between the number of the correct responses on the Modified Stroop task and scores on the 6-Item Cognitive Impairment test ($r=-0.52$, $p<0.001$) and Grip Strength ($r=0.42$, $p<0.01$). In addition, a significant inverse association was found between incorrect responses on the Modified Stroop task and Functional Reach ($r=-0.45$, $p<0.01$). The final multivariate regression model included age, Functional Reach and right arm Grip Strength, and described 28% of the variance in performance of the Modified Stroop task. *In summary, the study illustrated that measures of physical function were related to cognitive performance in high functioning independent living South African older adults. The extent to which a physical exercise intervention can improve these physical function parameters and its effects on cognitive performance warranted further research within South African older adults.*

Study 2: The aim of the second study was to explore the feasibility of IVG in South African, normal functioning, healthy older adults. We hypothesized that those individuals with lower functional and cognitive performance would perceive the IVG as more difficult. Twenty normal functioning, healthy community-dwelling older adults with a mean age of 70.5 ± 5.5 years were invited to participate in the study. Functional ability was assessed using the Dynamic Balance, 'Timed Up and Go', Functional Reach and Grip Strength tests while cognitive ability was assessed using the Modified Stroop task. Participants played in an IVG session using the X-Box Kinect Adventures software package which comprised of 5 games, including: 20000 Leaks, River Rush, Rally Ball, Reflex Ridge and Halo Popper. Heart rate was recorded throughout the session to measure the intensity while playing the game. An interviewer-administered questionnaire was completed after the IVG session, in which participants reported on their levels of enjoyment and the perceived difficulty of each game during the gaming session, using a Likert scale.

The mean resting heart rate for the gaming session was $73.4\text{bpm} \pm 12.6$. Rally Ball produced the highest average heart rate of $88.0\text{bpm} \pm 14.4$ with 20000 Leaks producing the lowest average heart rate of $82.6\text{bpm} \pm 12.3$. The average heart rate response for all games was between 55.2% and 58.7% of age-predicted maximum heart rate, suggesting IVG equates to moderate intensity physical activity according

to the American College of Sports Medicine criteria. Non-dominant handgrip strength (kg) was inversely associated with the perceived level of difficulty, (High perceived level of difficulty = 19.5kg; Moderate perceived level of difficulty = 27.0kg; Low perceived level of difficulty = 29.1kg; $p=0.034$). There were significant relationships between some components of functional ability and cognitive performance with the perceived difficulty of the gaming session. Individuals that perceived the game as more difficult had significantly lower cognitive performance scores than those reporting moderate and low levels of difficulty. Most (95%) participants reported that they were interested in participating in IVG in the future. They perceived the games as fun and enjoyable, as a form of stress reduction and a means to improve physical well-being. In addition, our results indicate that older adults enjoyed the IVG and showed interest in participating regularly. *In summary, the study showed that IVG was an enjoyable activity for older adults and associated with functional and physical well-being. Future research is needed to determine if IVG can result in improved health, functional ability and cognitive performance in older adults.*

Study 3: Therefore, the aim of the third study was to measure the effects of a 12-week IVG intervention, using the X-Box 360 Kinect gaming console on cognitive performance and functional ability in healthy older adults, without any known diagnosis of cognitive impairment. A total of 41 healthy participants with a mean age of 72.7 ± 6.6 years were recruited from 4 different retirement homes and cluster-randomized into either the IVG group ($n=21$) or the Cognitively Stimulating Table Games group ($n=20$). The IVG group participated in moderate intensity X-Box Kinect Adventure games twice a week for one hour while the comparison group participated in Cognitively Stimulating Table games (Board and Card games) for the same duration. Both groups had high attendance rates with all participants completing all 24 of their respective sessions. Baseline physical activity level was assessed using the Yale Physical Activity Survey. Pre-post measures included the 6-Minute Walk test, Dynamic Balance, Timed Up and Go, Grip Strength, Functional Reach, 6-Item Cognitive Impairment test and the Modified Stroop task. Most participants' highest level of education was at primary school level and the most frequent medical condition was hypertension in both groups. More than half of the participants were prescribed medication for various chronic diseases.

Functional Reach was the only significant improvement post intervention in favour of the IVG group ($p=0.049$). The comparison group's average reaction time for all correct responses improved significantly on the Modified Stroop task post intervention compared to the intervention group. After the variables were log transformed, the comparison group showed significant improvement in average reaction time for all correct responses on the Modified Stroop task ($p=0.028$). The IVG group showed a significant improvement in balance, measured by the Functional Reach test. Cognitively Stimulating Table Games showed significant improvements in reaction time measures of the Modified Stroop task illustrating benefits of such games on improving cognitive performance. *In summary, functional ability and cognitive performance improved for most outcomes in both groups, however, many changes were not statistically significant. Therefore, IVG as an intervention program could serve to preserve cognitive and physical function, especially in high functioning, healthy older adults.*

The results of the first three studies (chapters 2, 3 and 4) showed that physical function was related to cognitive performance in high functioning, independently living older adults. IVG was identified as a fun and enjoyable activity, a means to improve physical health and it equated to moderate intensity physical activity. Furthermore, a 12-week IVG intervention using the X-Box 360 Kinect gaming console and Kinect Adventures games significantly improved balance in healthy older adults when compared to Cognitively Stimulating Table Games. Cognitively Stimulating Table Games significantly improved executive function measured by the Modified Stroop task post intervention. We also found that most functional ability and cognitive performance outcomes improved after 12-weeks of IVG however, many did not reach a level of significance in our cognitively healthy older adult participants. In South Africa, the prevalence of diagnosed MCI is 27% while research on the prevalence of subjective memory complaints is scarce. Previous research from systematic reviews and meta-analysis has shown positive effects of physical activity and exercise on cognitive performance in older adults with MCI and memory complaints. This led us to my fourth study, which aimed to examine the efficacy of IVG in older adults with self-reported and objectively determined memory complaints.

A few studies have investigated whether active gaming can improve cognitive performance in older adults with subjective memory complaints, however, to our knowledge; no study has been conducted comparing the benefits of IVG to conventional multimodal supervised exercise in older adults with memory complaints.

Study 4: The aim of the fourth study was to determine the effects of a 12-week IVG intervention, using the X-Box 360 gaming console with Kinect Sports games, on cognitive performance in South African older adults with subjective and objectively determined memory complaints. This intervention was compared to a conventional multimodal supervised exercise program that served as the comparison group. We hypothesized that the individuals in the intervention group would show greater improvements in measures of cognitive function and functional ability than the comparison group. Forty-five participants with a mean age of 72.4 ± 5.4 years were recruited and screened from 6 retirement homes and cluster-randomized into the IVG group ($n=23$) or the Conventional Multimodal Supervised Exercise (CM; $n=22$) group. All participants from both groups completed all 24 of their respective exercise sessions.

An interviewer-administered questionnaire was conducted to determine demographic, health and physical activity levels at baseline for each participant. Pre-post measurements for physical function included the 6-Minute Walk test, Dynamic Balance, Timed Up and Go and Functional Reach. Cognitive performance was measured by the Mini-Mental State Examination (global cognitive function), N-Back task (working memory) and the Modified Stroop task (executive function). The IVG group demonstrated significant improvements in the total number correct responses on the Modified Stroop task ($p=0.028$) and for average reaction time of correct colour-words ($p=0.024$), compared to the CM group. Furthermore, the IVG group showed significant improvements in global cognitive function ($p=0.005$) measured by the Mini-Mental State Examination (MMSE) when compared to the CM group. Functional ability improved significantly in the IVG group, including the 6-Minute walk ($p=0.017$), Dynamic Balance ($p=0.03$), Timed Up and Go ($p<0.001$) and Functional Reach ($p<0.001$). *We concluded that the IVG intervention was more effective than*

Conventional Multimodal Supervised exercise in improving executive and global cognitive performance and functional capacity in older adults with subjective memory complaints.

In summary, measures of physical function which included functional reach, grip strength and dynamic balance were associated with cognitive performance in high functioning older adults. Furthermore, older adults enjoyed participating in IVG as a form of physical activity which was also associated with physical well-being. The feasibility and acceptability of the IVG among older adults prompted the study comparing IVG to table games over a 12-week period in healthy older adults. Both, the IVG intervention and table games were effective in improving functional and cognitive measures in healthy older adults but did not reach a level of statistical significance. Therefore, we conducted a similar study using IVG in older adults with subjective and objectively determined memory complaints to determine its effectiveness on cognitive performance and functional ability. In conclusion, IVG was more effective than conventional multimodal supervised exercise in improving measures of cognitive performance and functional ability in older persons with memory complaints. IVG is recommended to help preserve and maintain quality of life and independent living in healthy older adults residing in low-to-middle income countries such as South Africa while greater cognitive and functional benefits may be achieved in those with some level of memory complaints.

CHAPTER 1: REVIEW OF THE LITERATURE

1.1 Introduction

Ageing is an unassailable biological process in an individual's lifetime. The average age of the world's population is increasing, with the percentage of older people over 65 years the fastest growing segment of the population worldwide (46). The proportion of individuals aged 60 years and older is 9% in developing countries, and is projected to be as high as 20% by 2050 (47). Africa's population is growing older and the number of adults reaching 60 years or more is expected to double over the next 50 years (48). Ageing in Africa is taking place under conditions of social and economic difficulties and the HIV/AIDS pandemic is also ravaging the African continent (49).

In high-income, developed countries, increased life expectancy is due to social and economic conditions associated with overall improvements in health care and technology (50). Conversely, in low and middle-income countries; ageing is occurring at a faster rate and within poorer socio-economic conditions than in high-income countries (51). A large extent of ill-health and disability incurred by sub-Saharan Africa older adults results from non-communicable diseases (52). It is important to note that South Africa has the lowest total fertility rate in Southern Africa as well as in Sub-Saharan Africa (53). This decline in fertility has, and will continue to contribute to the increase in the proportion of older adults in the overall South African population. Approximately 8.4% (4.54 million) of the South African population is 60 years or older, representing the highest proportion of older adults in southern Africa. Lifestyle behaviors such as physical inactivity, unhealthy diets, tobacco and alcohol use are risk factors for chronic disease as well as cognitive disorders such as dementia (52). Alzheimer's as well as other dementias such as Lewy body, Vascular and Fronto-Temporal were among leading causes of disability in older adults globally (54). A large number of risk factors are linked to cognitive impairment and dementia, which include age, female sex, vascular disease, low education and literacy as well as lifestyle factors (dietary habits, smoking, alcohol use and a lack of physical activity) (52). The crude estimate prevalence of dementia was 4.4% in sub-Saharan Africa; the number of people living with dementia in sub-Saharan Africa was 2.1 million in 2015 and is projected to increase to 3.5 million by 2030 and 7.6 million by

2050 (52). The incidence of dementia doubles every 7.7 years in age, from 4.1/1000 person years at age 60 – 64 to 60/1000 person years at age 90+. This leads to an estimated cost of dementia in sub-Saharan Africa at approximately 6.2 billion US dollars (52).

In addition to cognitive impairments and disorders increasing in sub-Saharan Africa, physical function and performance in older adults has also been reported to be decreasing. The HAALSI (Health and Aging in Africa: longitudinal studies of INDEPTH communities) study found that physical performance was lower among South African older adults than those living in Mexico, China and the United States of America (55;56). The prevalence of disability in South Africa was 7.5% (51). Furthermore, 19% and 23% of older persons aged 60 – 64 years and 65 – 69 years reported having a disability respectively. In addition, more than 50% of the older adult population aged 85 years and older reported having a disability. Difficulty in walking was more prevalent in adults aged 55 years and older (51).

As the life expectancy continues to escalate in the older adult population, the prevention of disability and maintenance of independence is becoming increasingly important. This increased proportion of older adults, coupled with the decreased life expectancy for the middle-aged population which is largely due to HIV/AIDS deaths (HIV prevalence rate of 10.5%), underscores the importance of maintaining or improving the health and functional status of older South Africans. Further ageing process changes will be discussed.

Therefore, the primary objective of this literature review is to identify and explore both conventional exercise training and IVG interventions that are associated with cognitive and functional effects of ageing. In addition, I will explore the cognitive changes and disorders that are associated with ageing. Furthermore, I will identify and discuss tools used to measure physical, functional and cognitive domains and describe the relationship between each of these domains in older adults.

1.2 Consequences of Ageing

The ageing process brings about numerous and often progressive cognitive changes to an individual such as a decline in cognitive functioning (57). The decline in cognitive functioning is often associated with changes in social and emotional support and functional independence. Each of these cognitive changes will be discussed in more detail in the next section.

1.2.1 *Cognitive Impairment and Disorders*

Apart from the physical changes that occur with ageing, persons over the age of 65 years' may experience a decline in cognitive function. The degree to which an individual's cognition is affected due to ageing varies among the population. Age-related alterations to the central and peripheral nervous systems cause a slowing of simple and choice reaction time, as well as alterations of one's capacity to integrate sensory information (58). Ageing of the nervous system is illustrated by gradual change in cognitive functioning and motor function (59). Cognitive components which may be affected with ageing include: processing speed, short term memory, reaction time and executive function tasks like planning and problem solving (60). Slow reaction time is linked to the reduced ability for precise motor control resulting in more errors and mistakes on tasks that require coordinated responses within a specific time period (61). As a result, there is likely to be an increase in the number of older adults at risk for mild cognitive impairment and dementia (22). The majority, but not all older adults, develop some level of memory impairment, especially after the age of 70 years (59). Common cognitive disorders that are linked to the ageing process will be discussed in the following sub-sections.

1.2.1.1 Subjective Memory Complaints

Memory complaints are very common in older adults and is an early indication of cognitive impairment or dementia (62). A subjective memory complaint occurs when an individual reports having memory problems or difficulties on more than one occasion, but no clear impairment on objective assessments (37). Subjective memory complaints are associated with poor performance on assessments used to

measure of executive function, as well as having impaired memory on delayed recall tasks (37). An earlier review of clinical and community-based studies conducted by Jonkers and colleagues estimated that the global prevalence of subjective memory complaints in older adults over 65 years range between 25% and 50% (63). Research on the prevalence of subjective memory complaints is scarce in low-to-middle income countries such as South Africa. Independent of memory performance in objective tests, annually 6.6% and 2.3% of older adults with memory complaints will develop mild cognitive impairment and dementia, respectively (64).

A study conducted by Avila-Villanueva et al 2016 used the Everyday Memory Questionnaire that groups items into specific cognitive domains to assess subjective memory complaints (11). Higher scores on domains associated with immediate events, executive function and prospective memory were related to the prodromal stages of dementia (11). Recent studies have shown close relationships between subjective memory complaints and other variables such as depression, perceived health (65), daily activities and quality of life (66). For example, in a study of older adults conducted by Elfgrén et al 2010, the prevalence of psychosocial stress was significantly higher in individuals with subjective memory complaints (71%) compared to individuals with mild cognitive impairment (18%) and individuals with dementia (0%) (67). In addition, feeling anxious was significantly higher in individuals with subjective memory complaints (63%) compared to individuals with mild cognitive impairment (27%). The higher prevalence of psychosocial stress and anxiety in people with subjective memory complaints might be the reason they show a significant reduction in memory performance. Elfgrén et al 2010 suggest that depression, psychosocial stress and anxiety may disturb the memory processes and inhibit an individual's evaluation of their memory function (67).

1.2.1.2 Mild Cognitive Impairment

Mild cognitive impairment (MCI) is defined as an intermediate cognitive state between normal ageing and dementia (21), and the global prevalence rates range between 3% and 42% (68). The prevalence of diagnosed MCI is 27% in South Africa. Individuals with MCI often experience memory loss to a greater extent than

one would expect for their age, yet they do not meet the currently accepted criteria for dementia diagnosis. One of the reasons for the large disparity could be attributed to the lack of a standardized diagnostic criterion for MCI (68). The risk of developing Alzheimer's disease is 10 – 15% higher among those with severe MCI compared to those with less severe forms of MCI (69). The main areas or domains of the brain associated with MCI include memory (recall and retrieval of recent information), language (ability to name items, words and understand sentences), attention (ability to concentrate on a specific task), visuo-spatial (identify and interpret spatial associations) and executive functioning (reasoning, response inhibition, problem solving, behavior control and coordination) (70).

MCI is a well-recognized risk factor for functional dependence, which is associated with the decline in health related quality of life in older adults (71). Individuals with MCI are often at an increased risk of developing Alzheimer's disease and other forms of dementia (22). In addition, they may experience subtle challenges in everyday functioning such as misplacing items, forgetting events and difficulty in finding correct words, all of which could initiate the decline in their quality of life (72). This may lead to individuals feeling helpless and can result in depressive symptoms (73).

Subdivisions of mild cognitive impairment include amnesic (impaired memory) and non-amnesic (another domain is affected) MCI and can affect a single domain or multiple domains. The most common form of MCI is amnesic, mild cognitive impairment (21). Individuals with amnesic MCI present with subjective memory complaints and have an objective memory impairment compared with age and education norms, while performing reasonably well on indexes of general cognitive function and activities of daily living (21). However, the progression of the memory impairment may lead to dementia and possibly Alzheimer's disease (22). As stated above, individuals with amnesic MCI have memory impairment. If this memory impairment is accompanied by deficiencies in one or more domains, the individual's diagnosis would be amnesic MCI in multiple domains. If the individual does not have memory impairment, but has impairment in one of the other cognitive domains, the diagnosis could be non-amnesic MCI in a single domain. Non-amnesic MCI in

multiple domains is diagnosed when an individual has deficiencies in many cognitive domains but does not include memory (74).

1.2.1.3 Dementia

Dementia is an overarching term that relates to memory loss, poor judgment, a decline in complex motor skills and other intellectual functions caused by the permanent damage or death to brain nerve cells (75). Approximately 47 million people worldwide are living with dementia (76), with 58% of the people living in low- and middle-income countries and is expected to increase to 71% by 2050 (77). Furthermore, it is estimated that 250000 older adults suffer from dementia with approximately 35000 of these older adults suffering from Alzheimer's disease. The prevalence of dementia ranges from 2.6% - 8.1% in older adults living in Africa (78-80). There is a paucity of data related to dementia in South African older adults. Available data show the prevalence of dementia among older adults living in the Western Cape is 8.6% (81) and 7.7% for those living in the Free State province (82). Dementia affects one in twenty people over the age of 65 and one in every five people over the age of 80 years (83). Alzheimer's disease (AD), characterized by progressive memory impairment and decreased activities of daily living, is the most common form of dementia in people older than 65 years and represents about 60% of all dementias (75).

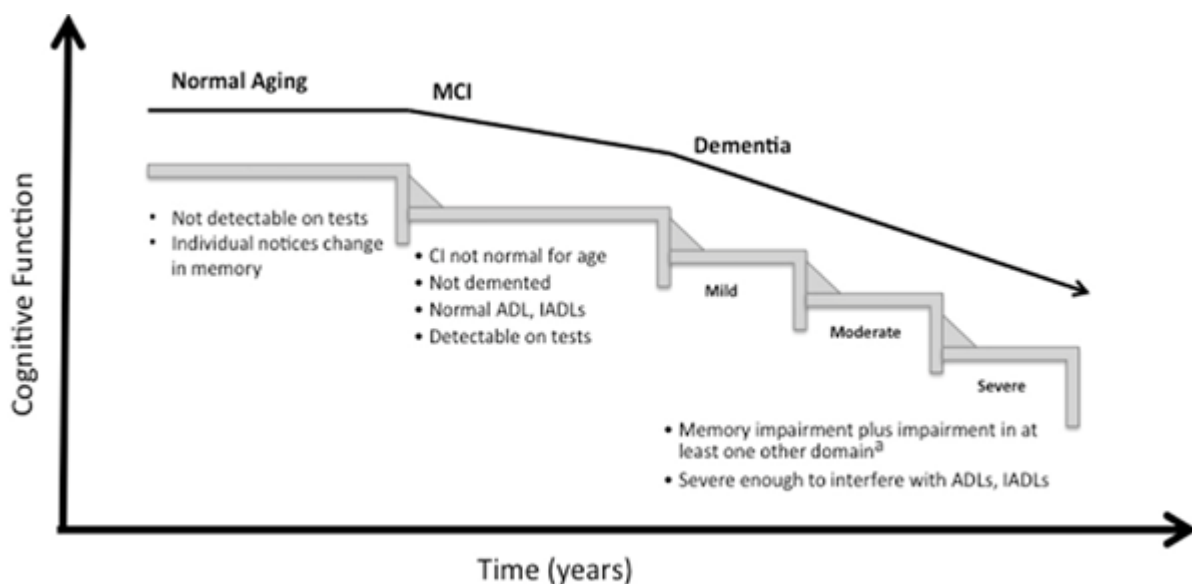


Figure 1.1: Graphical representation of the progression from normal cognitive functioning to developing Dementia (Adapted from Kalantarian and Ruskin. 2016 (84))

Due to a limited number of longitudinal studies, the neuropathology of mild cognitive impairment and demented individuals is not entirely understood (85;86). However, previous studies have demonstrated that neurofibrillary tangles in the hippocampus and entorhinal cortex are the main factors that could lead to MCI in older adults (85-87). Neurofibrillary tangles are insoluble twisted fibers located within brain cells which are made up of hyper-phosphorylated tau protein that is responsible for transporting nutrients and other vital substances from one part of the cell to another. The hippocampus is found in the medial temporal lobe of the brain and is the part of the brain that is involved in forming, organizing and storing memory (86;87) . Therefore, during the early stages of old age, short term memory starts to decline when cells in the hippocampus degenerate due to abnormal neurofibrillary tangles and amyloid plaque which leads to a MCI diagnosis and in later years, possibly dementia (21).

1.3 Functional Ability

From the many physiological changes that take place through the ageing process, declines in functional strength and aerobic capacity are among the most important determinants with regards to quality of life and functional independence (88). Functional ability is defined as the ability to perform regular daily activities in an independent manner without causing any undue pain and fatigue (89). The main link between functional ability and physical fitness is that physical fitness is a general state of good somatic health that provides an individual the functional capacity to perform activities of daily living in a safe and independent manner (59). Important physical fitness factors that are linked to functional ability include: physical strength and power, aerobic capacity, balance and flexibility (90).

1.3.1 Physical Strength and Power

A decline in functional ability associated with ageing is related, at least in part, to decreased muscle size and strength and a decline in speed which can lead to the reduction in one's physical power, ultimately leading to disability (91). An individual's age is undoubtedly a correlate of his/her functional fitness (92). As one gets older, especially from the age of 25 years, there is a progressive decline in muscle strength and size which creates a larger variability in functional ability with age (92). One of the reasons for the decrease in strength between 25 – 80 years of age is the reduction of muscle mass (93). Gill et al has identified that the reduction in lower body strength which is important for walking, climbing up and down stairs and rising from a sitting position, is a strong predictor of disability later in life (94). The inability to maintain muscle power throughout life may also increase the risk of falling, which could lead to fractures. This is because power is made up of both strength and speed of movement and a reduction in either of these two components will decrease one's power output (95). Although these changes may take place with ageing as well as in older adults who are not physically active, previous research studies have shown that physical activity has the ability to attenuate such declines in physical strength and power.

1.3.2 Flexibility

Flexibility is defined as the range of movement that is available at a joint or a group of joints, without causing damage to the joint and surrounding musculotendinous unit (96). Maintenance of flexibility in adults over the age of 60 years is important in maintaining functional independence by improving activities of daily living, such as sitting, standing, walking and change of direction.

Misic and colleagues (97) compared 10 months of flexibility training in older adults to cardiovascular training. Both groups (cardiovascular, n=26 and flexibility, n=29) followed exercise programs for 10 months, 3 days a week for 45 minutes and 2 days a week for 60 minutes, respectively. The flexibility group showed no significant improvements in peak oxygen uptake whereas there was a 6% improvement in the cardiovascular group ($p=0.03$). All measures of lower extremity physical function and strength improved significantly in both groups ($p<0.05$). The overall increase in

strength was between 26% and 51% for cardiovascular and flexibility training groups, respectively. These findings indicate that flexibility exercises can maintain and improve strength in older adults to preserve function and quality of life.

1.3.3 Balance

An individual's ability to balance is coordinated by different physiological systems of the body with the neuro-musculoskeletal system playing a vital part for maintaining balance. If this system is diminished, there is an increased risk of falling in older adults (95). Motor and sensory systems of postural control become altered as a result of ageing which leads to postural instability and balance problems (98). Falls have severe consequences that are accompanied by pain and decreased mobility for daily tasks such as walking up and down stairs. A study conducted by Mayson et al. 2008 (95) was done to determine the effects of limb strength and limb speed on balance in 138 older individuals. Complex tasks were assessed from the Berg Balance test, the Dynamic Gait Index and Performance-Oriented Mobility Assessment as they mimicked tasks of daily life such as sitting, standing and leaning over. The one simple task that was used was the Unipedal Stance Test which required an individual to stand on one leg for as long as possible. A one repetition maximum double leg press was used to assess lower leg strength. Power was measured by assessing the best of 5 repetitions performed the fastest at 40% of the one repetition as the researcher found that lifting a lighter weight at a greater speed was more functional as it mimicked different gait tasks. Limb speed was measured by dividing the maximum power output by the percentage of one repetition maximum resistance.

After using a multivariate logistic regression model to show associations between leg strength, leg speed and balance, it was found that leg strength was strongly associated with single leg balance (OR= 1.1, 95% CI = 1.01 – 1.11, p=0.03) and that leg speed was strongly associated with the more complex tasks on the Berg balance test (OR= 14.2, 95% CI = 1.84 – 109.72, p=0.01), Performance-Oriented Mobility Assessment (OR= 33.9, 95%CI = 3.69 – 312.03, p=0.002) and Dynamic Gait Index (OR= 35.8, 95% CI = 4.77 – 268.71, p<0.01). These results suggest that for every

increase in a unit of strength, there was a 6% greater chance of being categorized as having greater single leg balance whereas leg velocity was associated with better dynamic balance. This indicates that strength and speed are important components that can be trained to maintain one's overall balance.

1.3.4 Aerobic Capacity

Aerobic capacity is defined as the capacity of the cardiopulmonary system to supply blood and oxygen to working muscles and the ability of the muscles to utilize the oxygen and energy to perform work (59). Aerobic training has been shown to counter the age-related reduction in maximal oxygen uptake which is vital for optimal functioning (99). An aerobic threshold for older adults has been defined as having an oxygen capacity between 18 and 20 ml/kg/min (100). A value below this threshold is indicative of a reduced probability of independent living according to Cress et al. 2003 (100). This is supported by Arnett et al who found that a higher aerobic capacity led to an increased aerobic reserve and higher functional performance capacity in older adults (101). An increased aerobic reserve gives older adults the chance to perform activities with reduced cardiovascular risk which helps reduce functional decline and preserves independence (102). This means using a lower percentage of VO_2max to complete functional activities of daily living and being able to perform more activities throughout the day (101). The capacity of older adults to function independently in society depends greatly on maintenance of ample aerobic capacity to perform daily tasks. In many cases, tasks that require extensive effort in those that are de-conditioned are often avoided. The consequences of this can set off a vicious cycle of reduced physical activity, which ultimately leads to a further decline in aerobic capacity, leading to concomitant losses of muscle mass and strength. Thus, the loss of aerobic capacity transforms into diminished levels of physical activity, reduced walking speeds and less fatigue resistance (88).

1.4 The Relationship between Physical Fitness, Functional Ability and Cognitive Performance in Older Adults

In terms of physiology, psychology and performance, ageing has previously been defined as a progressive loss of function, with increasing susceptibility to age-related diseases and an associated transition from an independent to a dependent lifestyle (103). It has been widely studied and accepted that regular exercise training stimulates physiological adaptations to improve fitness and functional performance as well as reduce age-related cognitive decline (104). In addition, regular physical activity and exercise throughout an individual's lifespan decreases the risk of developing chronic diseases (105). This will allow individuals to live an independent, functional and healthy life. Although this may be possible, the degree to which physical fitness, functional ability and cognitive performance are related vary from one individual to the next and may largely depend on the current physical and mental (individuals with normal cognitive function versus individuals with cognitive impairment) status of an individual.

Cognitive dysfunction or impairment is a condition that occurs in older adults that adversely affect independent functioning (106). Prolonged cognitive dysfunction can lead to diseases such as Dementia and Alzheimer's disease which can obligate an individual into a long-term care facility (106). Studies have shown that improved physical fitness from regular participation in exercise is associated with the prevention of cognitive dysfunction later in life. A study by Barnes et al. 2003 found that having higher levels of fitness at baseline corresponded with higher cognitive performance levels 6 years later in healthy older adults and that high intensity cardiorespiratory exercise may help prevent cognitive dysfunction late in life (107). This study measured aerobic fitness, self-reported physical activity and cognitive function using the Mini-Mental State Examination, Trail Making Test Part B and the California Verbal Learning Test.

The outcome of the study showed that higher levels of aerobic performance resulted in better performances on many measures of attention and executive function. Similarly, another study showed that in high-functioning community women over the age of 65 years, those who had higher levels of physical activity at baseline showed

smaller declines in cognition compared to their more sedentary counterparts, when assessed using the mini-mental status examination (108). Laurin and colleagues also predicted that higher physical activity levels decreases an individual's chances of cognitive impairment and dementia of any type later in life (109).

More recently, other positive associations between physical fitness and cognitive performance have been demonstrated in healthy older adults (110-112). In 2019, Sherwood and colleagues conducted a study to determine the relationship between physical function measures and cognitive performance in 90 independent community dwelling older adults (112). Physical performance was measured using the 6-minute walk test and maximal grip strength. Individual heart rate was measured at rest, each minute during the walk test and each minute posttest for 5 minutes. Peak heart rate was assessed as the highest heart rate during the 6-minute walk test. Cognitive performance was measured by the Modified Mini-Mental State Examination (global cognitive function), Animal naming (verbal fluency) and the Trail Making Test A & B (complex attention, psychomotor speed and mental flexibility).

After controlling for socio-demographic covariates, they found that peak heart rate during the 6-minute walk test was positively correlated with performance in the Modified Mini-Mental State Examination ($p=0.017$) and part A ($p<0.001$) and B ($p=0.029$) of the Trail Making Test. In addition, physical activity measured by the Physical Activity Scale for the Elderly was also well correlated with part A ($p=0.017$) of the Trail Making Test. The study concluded that a higher peak heart rate during a 6-minute walk test is positively association with cognitive function in community dwelling elders (112). The above-mentioned studies confirm the positive associations between high physical activity levels and physical fitness with cognitive performance in older adults. In addition to cognitive performance, regular participation in exercise and physical activity has also been shown to be associated with better functional ability in older adults.

Functional ability is made up of both physiological and cognitive capacities which contribute to optimizing physical performance in daily function (113). Cognitive decline contributes to impaired functional abilities leading to an increase in formal and informal service use among older adults, and loss of independence (114).

Regular participation in physical activity has been shown to play an important role in functional performance and increasing strength and mobility. Previous studies have shown a strong association between physical fitness and functional performance in older adults. In 2018, Tomás et al. conducted a 3 year follow-up study to characterize functional physical fitness in older adults over the age of 60 years of age (115). In this study, 43 older adults were assessed on functional capacity measures using the Senior Fitness Test (muscle strength, aerobic endurance, dynamic balance and flexibility), handgrip strength and a measure of physical activity.

They found that the 6-minute walk test distance and handgrip strength explained a great variability on functional variables (68% balance and lower and upper body strength) that have changed over the 3 year duration. In addition, they concluded that active individuals exhibited less decrements with ageing in functional variables, than individuals regarded as sedentary or inadequately active ($p < 0.05$) (115). This finding is also supported by Brach and colleagues who conducted a 14-year prospective study in older women on the associations between physical activity and functional status (116). Brach et al. also demonstrated an association between levels of physical activity and functional status suggesting that participation in physical activity plays a pivotal role in maintenance of functional ability later in life (116). Therefore, the consistent outcomes from the above-mentioned studies as well as other studies on physical activity and measures of functional ability provide evidence that regular physical exercise, as well as short term training programs can reduce the risk of frailty and functional limitations later in an individual's life (117).

The relationship between cognitive performance and functional ability plays an important role in the independence and quality of life in older adults. It is known that sensory and cognitive age-related changes are related to functional performance in older adults (118). Wood and colleagues conducted a study to determine the relation between sensory and cognitive factors on functional abilities in 530 elderly individuals between the ages of 62 and 94 years (118). A wide range of measures for sensory (far and near acuity and hearing), cognitive (executive function, intellectual functioning, attention switching, working memory) and functional

performance (Timed Instrumental Activities of Daily Living) were assessed. Functional performance was strongly associated with cognitive processing speed while sensory factors accounted a significant amount of variance in functional performance ($p < 0.05$). These findings are in line with other work by Voelcker-Rahage and colleagues who showed that a decline in function and mobility were associated with reduced mental speed and flexibility (119).

1.5 Objective Physical, Functional and Cognitive Measurements in Older Adults

1.5.1 Physical Fitness Measurements

1.5.1.1 Cardiorespiratory Fitness

The ageing process is accompanied by a reduction in exercise capacity due to the decrease in cardiorespiratory fitness (120;121). Direct measurement for maximal oxygen uptake using graded exercise testing provides a precise measure of physiological responses induced by exercise (122). Although it may be an accurate measure of cardiorespiratory fitness, more often than not, the application of cardiorespiratory graded exercise testing can be expensive, requires complex equipment and must be administered by highly skilled professionals (122). In addition, maximal testing might not be suitable for individuals with chronic illnesses and the elderly, and also requires strong motivation to exercise until exhaustion. Due to the complexity of graded exercise testing to measure maximal oxygen uptake, it may not be the most feasible method to assess cardiorespiratory fitness in older adults, especially in large samples.

The 6-minute walk test is a simple, rapid and inexpensive physical performance measure that has been widely used in research and physical rehabilitation for impaired and healthy older adults (122-125). This walk test was originally developed in 1982 and was used to assess the total distance an individual walked as quickly as possible in 6 minutes. It has been recognized as a reliable and valid measure for overall physical functional performance in older adults (126). A study by Sperandio et al. 2015 evaluated the 6-minute walk test in middle aged and older adults, to predict

oxygen uptake against a direct method of maximal oxygen uptake in 86 participants between the age of 40 and 74 years (122). They found that the maximal oxygen uptake in the 6-minute walk test corresponded to $78\pm13\%$ and peak heart rate corresponded to $80\pm23\%$ of that in the maximal oxygen uptake exercise test (122).

Similarly, another study was conducted to determine the reliability and validity of the 6-minute walk test and the Tecumseh step test (low intensity test using a step with a height of 20.3cm and a rate of 24 steps per minute for 3 minutes) against a bicycle ergometer maximal test in 54 women aged 50 – 70 years of age with Type 2 Diabetes (124). They found that the 6-minute walk test distance ($r=0.54$) and recovery heart rates after the step test ($r= - 0.49$) correlated highly with maximal oxygen uptake measured on the cycle ergometer. These studies suggest that the 6-minute walk test and step test may be alternative indirect measures to determine cardiorespiratory fitness in older adults, as they are more feasible than direct methods (124).

Many factors are associated with performance on the 6-minute walk test including age, gender and weight (127). In addition, other studies have shown associations between certain physical measurements and 6-minute walk test performance. Benavent-Caballer and colleagues identified strong associations between mobility, balance and lower-limb function and the 6-minute walk test (127). They found that better balance, mobility and lower limb-function measured by the Berg Balance Test (BBS), Timed Up and Go (TUG) and the Short Physical Performance Battery (SPPB) resulted in a greater total distance covered by healthy older adults. This suggests that lower body functional ability has a strong positive association with walking distance in community-dwelling older adults (127). Due to the 6-minute walk test requiring minimal space and equipment, it is feasible to apply to clinical research populations of older adults.

1.5.1.2 Lower and Upper Body Strength

Strength plays an important role in the maintenance of functional independence, especially in older adults. A reduction in muscle strength with ageing often leads to

physical disability and frailty (128). Consequently the evaluation of muscle strength is important as an individual gets older to determine weaknesses that may lead to future physical disability (128). Muscular strength is often described and assessed according to muscles of the upper and lower body (129). Upper body strength involves all muscles of the upper body which include the biceps, triceps, pectorals, deltoids, trapezius and forearm muscles. Many upper body strength tests have been conducted in older adults such as the arm curl test, wall press in 30 seconds and horizontal chest press. These tests can be conducted using free weights, isokinetic equipment or an individual's own body weight. Grip strength has also previously been used as an upper body strength test or as a measure of functional capacity (130).

One of the most feasible and reproducible upper body strength tests in older adult research is the arm curl test in 30 seconds using free weights (131). Many previous studies have used the arm curl test to measure upper body strength due to its ease of administration and low cost of equipment (131-133). The arm curl test requires individuals to sit with good posture on a chair with no arm rests. The weight is held down at the side with the arm completely straight. Individuals are required to curl the weight up until the elbow reaches the end of elbow flexion, after which the weight is returned to the start position in a controlled manner. This test is normally done for 30 seconds and the number of arm curls completed is scored (89). A study was conducted by Liu et al. 2017 to examine how arm curl strength and grip strength contributed to hand functioning in community dwelling older adults (134). Arm curl strength was an independent contributor to time-based and self-reported hand function assessments. This indicates that upper body muscular strength of the arm and forearm are essential in conducting hand function activities (134). This is important as older adults use their upper limbs and strength for activities of daily living such as carrying groceries, hanging up washing, washing and drying dishes, as well as playing and carrying grandchildren.

Lower body strength also plays an important role in activities of daily living and living an independent lifestyle (135). Lower body strength involves all the muscles of the lower limbs such as the quadriceps, hamstrings, adductors, gluteal muscles and the

calves. Reduced lower body strength is a major risk factor associated with impaired balance and mobility in older adults (136;137). Many lower body muscle strength tests have been used in older adult research such as a 1- repetition max leg press on a gym machine or isokinetic dynamometer (138), leg extensions (138) or Sit to stands / Chair stands in 30 seconds (139). Currently, the gold standard for lower body muscle strength is using a computerized isokinetic dynamometer which enables an individual to measure muscle strength of various different muscle groups at different speeds and torque (140). Although this may be the gold standard to measure muscle strength, it is not always feasible due to the high cost, time consumption and skilled personal required (140;141).

Many previous research studies have opted for lower body strength tests that are less expensive and complex such as the Sit to stand test / Chair stands in 30 seconds test (139;142). The chair-stand test a simple test that requires minimal equipment such as a standard chair with no arm rests and a stopwatch. Individuals are requested to be seated on the chair in a comfortable posture with their back against the backrest of the chair and both arms across their chest. Once the test begins, the individual is required to rise to a straight standing position and then return to the seated position. The test is scored as the number of chair stands / sits to stands an individual can complete in 30 seconds (139;142). A study by Jones and colleagues was conducted to measure the test-retest reliability, criterion-related validity and construct validity of the chair stand test in 30 seconds as a measure of lower body strength in older adults over the age of 60 years (139). Individuals were required to perform two 30-second chair stands as well as two maximum leg press tests, each conducted between 2- 5 days apart. They found moderately high test-retest associations ($r = 0.89$) for all participants along with a non-significant change in scores from day one and two testing. This may indicate that the chair stand test provides a reliable measurement of data. In addition, a moderate correlation was identified between chair stands and weight-adjusted leg press scores for all participants ($r = 0.77$) which supports the criterion-related validity of the chair stand test as a measure of lower body strength (139).

1.5.2 Functional Ability Measurements

Many tests have been developed over the years and used widely to assess the different components of functional ability. The components of functional ability include balance, mobility, flexibility and isometric strength (143). Assessing functional ability parameters can be conducted by either 1) Observation of an individual performing an activity and scoring accordingly or; 2) Performance tests using standardized equipment (143). The selection of the type of tests used to assess functional ability depends on a number of factors such as feasibility, affordability and sensitivity of the test. Both have advantages and disadvantages. Observational assessments limit reliability of data when compared to equipment-based measures. On the other hand, equipment can be costly as well as difficult to transport therefore requiring individuals to be tested in laboratories (143). Tests should also be chosen to measure specific characteristics rather than a variety of parameters that provide an overall summary score. In this section of the review we discuss the tests used in this thesis to assess the various components of functional ability.

1.5.2.1 Balance

Balance can be defined as the ability to maintain the body's position over a base of support, whether the base is stationary or moving (144). Balance is often categorized as either static balance or dynamic balance (144). Several assessment methods often combined balance with mobility and gait. Static balance refers to controlling postural sway during standing still whereas dynamic balance refers to being able to react to instability or using muscles in anticipation to changes in balance (143;145). Due to both types of balance being different in nature, the tests used to measure individual's balance vary for both static and dynamic balance.

Previous research studies confirm that a decreased static balance is associated with falls in older adults (144;146;147). Static balance may therefore be a predictor for individuals with an increased fall risk (144;146;147). Individual's static balance may be measured using different stances such a side-by-side stance, semi tandem stance, tandem stance and single leg balance (14). Side-by-side standing involves

standing with feet side-by-side touching. Semi tandem stance requires the individual to stand with one foot forward and the heel of that foot in line with the toes of the opposite foot. Tandem stance requires the individual to stand with the heel of one foot directly in front and touching the toes of the opposite foot. Single leg balance stance requires the individual to stand still balancing on one leg with hands on their hips and the other leg approximately 10cm off the ground (14).

Many studies have used these stances with a combination of other measures in test batteries such as the Guralnik test battery (14), Berg Balance Scale (148) and the Tinetti Balance Assessment (149) to assess balance. The limiting factor with these test batteries is that the scoring for each task is subjective and scoring may vary from person to person. In addition, these test batteries and scales often offer overall balance scores and therefore do not differentiate between static and dynamic balance. However, these tests are inexpensive and require minimal space and equipment, and can be administered in a short space of time. A study by Franchigoni et al. 1998 was conducted to determine the intra-observer and test-retest reliability of four balance tests (Static tandem stance, One-legged Stance, Sit-to-Stand test and functional reach) in healthy community-dwelling senior females (150). Amongst all balance tests conducted, the intra-class correlation coefficient ranged between 0.95 – 0.99 for scoring consistency between individual scorers and 0.73 – 0.93 within individual scorers. Furthermore, the inter-correlation between test scores were moderate with r coefficient values ranging between 0.40 – 0.66 indicating that the tests represent reliable scores and measures of balance in older adults (150). Similarly, another study by Sahin and colleagues also found the Berg Balance Scale as reliable and valid measure of balance in older adults (151).

Dynamic balance is defined as the ability to anticipate change in different directions and to coordinate muscle activity in response to these changes (143). Dynamic balance is known to decline at a faster rate with age due to it stressing the balance control systems such as the vestibular, visual and somatosensory more compared to static balance (152). Dynamic balance can be measured using tests that often also measure other parameters such as walking speed, gait stability, agility and mobility.

These tests include the functional reach test (153), dynamic balance using tandem gait (154), the parallel walk test (155) and the timed up and go test (156).

The dynamic balance test requires individuals to walk along a strip of tape for 10 metres using the tandem gait. The tandem gait involves walking heel to toe. When the right foot is in front, the left foot heel will move forward touching the right toe and when the left foot is front, the right foot heel will move forward touching the left toe (154). During the functional reach test, individuals are required to stand next to a wall and reach as far forward as possible along a wall mounted yard stick or a measuring tape (150cm vertically above the ground) without moving their feet, taking a step or lifting their heels. Individuals are not allowed to use the wall for support (153). The distance reached in centimetre's is recorded. Both, the functional reach and dynamic balance tests have been used widely in older adult research previously, however, the dynamic balance test has been measured using the tandem gait for various distances such as 10 steps (157) or 20 steps (158).

Recently, Robertson and Gregory found a moderate to high correlation between the 10 step tandem gait and clinical dynamic balance tests such as the Biodex Balance System dynamic limits of stability ($r=0.81$) indicating that the 10 step tandem gait can be regarded as an objective measure of dynamic balance in a healthy population (157). Similarly, the functional reach test has also been shown to be a valid and reliable measure of limits of stability and dynamic balance in older adults (159;160). Newton 2001 conducted a study to develop a convenient and valid instrument to measure an individual's limits of stability in multiple directions (forward, backward, left and right) (159). The multiple directional reach test showed significant correlations (Bonferroni adjustment, $p=0.0004$) in all directions (forward reach: $r=0.48$; backward reach: $r=0.36$; right reach: $r=0.39$; and left reach: $r=0.39$) with the Berg balance test and an inverse relationship with the timed up and go test (forward reach: $r= -0.44$; backward reach: $r= -0.33$; right reach: $r= -0.26$; and left reach: $r= -0.31$). In addition, the forward reach had the highest correlation scores with the Berg balance test and timed up and go test. Newtown concluded that the multiple directional reach test is a valid, reliable and inexpensive instrument to measure limits of stability in older adults (159).

1.5.2.2 Mobility

The maintenance of mobility is essential for active ageing which allows older adults to live an independent lifestyle and maintain a good quality of life (161). Mobility is defined as the ability to move oneself by either walking and / or running, the use of assistive devices and / or by transportation from one place to another (161). As one ages, the loss or decrease in mobility can be identified as individuals not being able to walk independently due to physical disabilities or when an individual cannot drive a vehicle safely (161). Previous studies have shown that impaired mobility is highly associated with falling, which is ultimately linked to physical disability in older adults (162-164).

Various tests have previously been used in older adult research to measure mobility such as the Timed Up and Go (TUG), backwards walking, 5 times sit-to-stand, stair ascent and descent and the 6 metre walk (163;164). The timed up and go test has been one of the most feasible and widely used tool to clinically assess functional mobility in older adult research (165). Previous studies have shown that the timed up and go test is a valid and reliable measure of both, mobility and dynamic balance in older adults (166-168). Sebastião and colleagues examined the validity of the timed up and go test as a measure of mobility in older adults with multiple sclerosis. Overall, they found that the TUG was strongly associated with other measures of ambulatory mobility such as the timed 25 foot walk (T25FW) ($r = 0.90$) and the 6-minute walk test ($r = -0.89$) (168). Similarly, Blackwood. 2017 also found the TUG to be a reliable and valid measures dynamic balance and mobility in older adults (166). In addition, the ease of setting up and administering the test as well as the use of portable inexpensive equipment makes the TUG a feasible measure of mobility.

1.5.2.3 Isometric Strength

It is well known that the ageing process leads to significant changes in the quality and quantity of muscle mass and strength. The decrease in muscle mass leads to physical weakness which affects overall health and quality of life (169). Although muscle mass is associated with a reduction in strength, other factors may also play a

role in decreased strength such as neuromuscular activation and the intrinsic ability of muscle to produce force (169). Muscle strength can be measured using different types of measurement techniques such as an isotonic muscle contraction (dynamic contraction) or an isometric muscle contraction (static contraction). An isometric muscle contraction is a contraction whereby a force is generated by the muscle but there is no change in the joint angle and muscle length (170). Currently, the gold standard for measuring isometric strength in upper and lower body muscle groups is isokinetic dynamometers such as the Biodex system II (140;171). The Biodex system II dynamometer is a large computerized machine that has a variety of settings that provides accurate measurements of isotonic and isometric muscle strength, peak force, power and endurance (140). Although an isokinetic dynamometer may be the gold standard to measure isometric strength, there are many limitations and disadvantages to using this type of equipment in large population based research studies. Firstly, the cost to purchase an isokinetic machine is very expensive compared to other equipment that measure isometric force such as a hand-held dynamometer (141). In addition, isokinetic dynamometers may require ongoing maintenance and calibration which will add to yearly cost of the running machine. Secondly, isokinetic dynamometers such as the Biodex II system are large and stationary devices, making it nearly impossible to be used portably. This will therefore require participants to be transported to laboratories for testing thereby incurring higher research costs. Lastly, due to such dynamometers having highly technical computerized systems, skilled professionals are required to administer strength testing in a safe and controlled manner.

Therefore, research studies have opted for alternative equipment to measure isometric strength such as hand-held dynamometers. A hand-held dynamometer is a specifically designed instrument for objectively measuring isometric muscle strength (172). It is widely used in older adult research to measure static force that is produced by hand and forearm muscles and is measured in kilograms (kg) of isometric force. Although the dynamometer is commonly used to measure hand grip strength, certain hand held dynamometers can measure isometric muscle strength at other muscles such as the quadriceps (171). Previous studies have been conducted to compare the hand-held dynamometer with the gold standard isokinetic

dynamometer. Studies have identified the hand-held dynamometer as a valid and reliable measure of isometric strength at various upper and lower body muscle groups in older adults (140;171;173-175).

1.5.3 Cognitive Performance Measurements

The change in cognitive performance over time is inevitable. Moreover, the changes that occur with ageing are not uniform for each person and are determined by many factors such as age, gender, education, lifestyle choices such as drinking and smoking, social activities and occupation (176). In addition, cognitive performance changes over time may affect different cognitive components from individual to individual which explains why it is important to measure the various cognitive components with instruments that are reliable and valid for each specific component. Cognitive performance can be broken down into various components such as executive function, short term and long term memory, orientation, concentration, working memory, global cognitive function, visuo-spatial organization and abstract thinking (60). In the sub sections below, we discuss the different components of cognitive performance and the relevant tests to measure each component.

1.5.3.1 Executive Function

Executive function is described as not one, but a set of processes that allow for abstract thinking, formulating goals, problem solving, initiating, planning and scheduling of complex behaviors as well as cognitive inhibition of dominant responses and inhibitory control (177). These executive functions are known to be higher order cognitive abilities and are performed in the frontal lobe of the brain by the prefrontal cortex (177). Executive function is considered critical for performance in novel situations or when an individual is required to inhibit a previous learned response (178).

With ageing, there is a decrease in brain size which accelerates from anterior regions to posterior regions therefore affecting the prefrontal cortex (177). This deteriorates the executive function processes due to the combination of structural

and functional changes that occur. Previous studies on regional brain volume and cognitive ageing found that the quality of an individual's executive function processes with age largely depends on the intact volume of the prefrontal cortex, anterior cingulate and cerebellum (179-181). Age related changes in structure and function of synapses, neuronal loss and a dysfunction of neuronal networks are also associated with a reduction in cognitive performance with age (177). Due to these age-related structural and functional changes within the frontal lobe of the brain, the cognitive components that arise from these brain areas need to be measured, to identify those at risk for cognitive decline.

Many different tests have been used in older adult research to assess executive function such as the Trail Making Test (TMT) Form B, Verbal Fluency Test (VFT), Digits Forward and Backward Subtest, Wisconsin Card Sorting Test and the Stroop Test (182). Although all these tests measure executive function, some of these tests measure specific domains within executive function. For example the Trail Making Test (TMT) and Wisconsin Card Sorting Test predominantly measure mental flexibility, whereas the Stroop Test measures inhibitory control and the Verbal Fluency Test (VFT), as the name implies, measures verbal fluency (182).

The Stroop Task (Stroop JR 1935) is one of the most frequently used measures of executive function (183). A number of variations of this test (cards and computerized) have been used in research and clinical settings. The Stroop task is a widely used cognitive test of increasing difficulty used to measure three executive functions: Shifting between tasks, updating and monitoring working memory representation, and inhibition of dominant or pre-potent responses (184;185). The Modified Stroop task is a computer-based version of the original Stroop Task in which prompts appear in the centre of a computer screen (186). The prompts consist of 4 text words (red, blue, green and yellow) which appear every 3.2 seconds on a black background and are displayed for 600ms after which a black screen is displayed for 2600ms constituting the response period. The 4 words are presented in 5 different colour inks: red, blue, green, yellow and grey. The words are either presented in grey ink or in a colour ink that is incongruent with the meaning of the word. Individuals are required to respond as quickly and as accurately as possible by

pressing one of the four response buttons to indicate either the ink colour of the word (if the text is written in either red, blue, green or yellow ink), or the word itself (if the word is written in grey ink). The objective of the Modified Stroop task is to determine the balance between speed and accuracy, which is also known as the speed accuracy trade off (186).

Previous studies have shown that when subjects concentrate more on responding as fast as possible, their number of mistakes increases, thereby sacrificing accuracy for speed (187). The Modified Stroop task has been previously validated as an objective measure of executive function in older adults. In addition, due to the Modified Stroop task being computer-based, it allows the test to be portable, administered and scores recorded at most places as it can be uploaded on a personal computer or laptop. Furthermore, the Modified Stroop task used is of a short duration and does not consume much time allowing for many individuals to be assessed within a certain time period. Due to the ease of access, administration and feasibility, executive function was measured in each of the study chapters using the Modified Stroop task (184). In chapter 2, it was conducted to determine the relationship between functional, physical and cognitive parameters and to best understand which functional and physical parameters best predicts performance on a novel Stroop task, while in Chapter 3 we utilized the Modified Stroop task to determine the association between cognitive performance and difficulty in playing IVG. Furthermore, due IVG requiring high order executive function abilities to successfully play the active games, it was imperative that we measured executive function by administering the Modified Stroop task in Chapters 4 (Cognitively healthy) and 5 (Subjective memory impairment) (185;188-190).

1.5.3.2 Global Cognitive Function

Global cognitive function is an extended term used to describe overall cognitive function from the various domains (191). It is known to include the different cognitive aspects and processes such as orientation, concentration, registration, short-term recall, attention and language (191). Global cognitive function can be measured using a variety of neurocognitive tests to assess the different domains and determine

an overall composite score for global function or it can be measured using single item tests and examinations (192). In some instances, studies prefer to determine cognitive function of specific domains and assess according to those specific domains while other studies opt to use a single item to assess overall cognitive performance (192).

The 6-Item Cognitive Impairment test is a brief test that was developed in the United Kingdom to assess cognitive function in older adults (193). The 6-Item Cognitive Impairment test measures individual's concentration, orientation and short-term memory. During the test, the first 3 questions assess an individual's orientation by asking them to recall the correct month and year. The latter questions assess concentration and memory by asking the individual to count backwards from 20 to 1, recall the months in reverse order and repeat a memory phase that was previously read to them. The 6-Item Cognitive Impairment test has been validated as a global cognitive measure and has been shown to have high inverse association ($r = -0.91$, $p < 0.01$) with the Mini-Mental State Examination (193). In addition, the test has been adjusted for use in South African adults (194).

The Mini-Mental State Examination (MMSE) is one of the most widely used tests to assess cognitive function in older adults and has also been previously used as a screening tool of dementia (195-197). In addition, the MMSE has also been used extensively to track the severity and progression of cognitive impairment and changes in older adults over time in clinical settings (198). The Mini-mental state examination is a quick and easy interview-administered cognitive outcome measure of global cognitive function concerning orientation, memory, registration, attention and calculation, recall and language (199). The questions administered focus on different cognitive aspects such as the time and place of the test, recalling a list of words, arithmetic calculations, motor skills, language and comprehension. The maximum that can be scored for the MMSE is 30 points with a score between 24 and 30 indicating normal cognitive function. Scores between 9 and 23 represent moderate to mild cognitive impairment while a score < 9 points is an indication of severe cognitive impairment (199). The MMSE has previously been validated and a known reliable measure of global cognitive functions in older adults (198;200;201).

In addition to both tests being valid and reliable measures of global cognitive function in older adults, the 6-Item Cognitive Impairment test and MMSE can be administered within 5 – 10 minutes, thereby allowing for a short and precise testing period. Furthermore, no specialized training or equipment is required to administer the test which makes it affordable to use in most circumstances. Moreover, the test can be conducted at an office desk or at a bedside thus requiring minimal space. Therefore, both tests are feasible outcome measures to determine global cognitive function in older adults in a research setting.

1.5.3.3 Working Memory

Working memory is described as a domain of cognition that allows for temporary storage and manipulation of information that will be required for complex cognitive tasks such as reasoning, learning, language and comprehension and planning (202;203). Working memory is conceptualized as relating several components that function and work together. Working memory is known to decline with increasing age and the decline is more pronounced in males than females (203). This decline in working memory occurs due to changes in brain function, particularly within the Prefrontal Cortex (PFC). Recent neuroimaging research studies have shown that the dorsolateral prefrontal cortex plays a role in manipulation and updating of information in working memory (204). In addition, the left side of the prefrontal cortex is involved in verbal activities while the right in visuo-spatial activities (204). Due to these brain area changes with increasing age and the consequences in working memory, measuring and monitoring working memory regularly is important using appropriate cognitive tests.

Assessment of working memory in older adult research has been conducted using various working memory tests; however, each test assesses a specific aspect of working memory. For example, the Reading Span task measures verbal working memory and processing, while the *N*-Back task measures active recall, short term memory and fluid intelligence. The *N*-Back has been widely used and validated as a tool to assess working memory in older adults (205;206). During the *N*-Back task (“*n*” represents the level number; example: 1-back, 2-back), individuals are presented

with a sequence of letters one at a time in the middle of a computer screen and are requested to compare and match the current letter on the screen with the letter presented “*n-Back*” in the sequence. When performing the 2-back task, the current letter is the target when it matches the letter presented two positions ago. For example, in the sequence “U-D-H-I-R-?” the individual should respond by pressing the middle of the screen if the 6th letter in the sequence is a “I” because it would match the letter which occurred two places prior.

As the “*n-Back*” level increases, the task difficulty increases as individuals have to recall and match correct letters further down the sequence (e.g. 6-back or 7-back). Majority of studies using the *N-Back* task to assess working memory in older adults research have used between 0-Back and 4-Back task as it allows for this age group to cope with the difficulty of the test (207). The *N-Back* task is simple, quick and easy to be administered and requires 15 minutes to be completed therefore being an efficient test to assess working memory. In addition, the *N-Back* task can be administered in most places as the application can be set up on most desktops, laptops and I-pads making the test portable.

In summary, cognitive performance is made up of the functioning of different cognitive domains. Various tests are therefore administered to assess each domain as a whole or in part. In this thesis I primarily focused on assessing executive function, global cognitive function and working memory in older adults.

1.6 Effects of Combined Physical and Cognitive Interventions and Physical Activity-Based Interventions on Cognitive Performance in Older Adults

For many years, research studies have illustrated the effects of physical activity and exercise on individual’s cognitive performance or functioning in those with or without cognitive impairment. These intervention studies have varied in duration, intensity, frequency as well as in different populations. A number of systematic reviews and meta-analyses have also shown the benefits and effectiveness of physical activity on cognitive performance however, other studies have also illustrated contrasting results. Tables 1.1 and 1.2 provide a summary of original studies and review studies

respectively that have utilized physical activity or exercise interventions as well as a combination of physical and cognitive interventions and its effectiveness on cognitive performance in older adults. In addition, studies in the systematic review by Cai and Abrahamson 2015 and Tseng et al. 2011 have been respectively included (208;209). In this section, I will discuss the effects of such interventions on cognitive performance in those with healthy cognitive function as well as individuals with some level of cognitive impairment such as subjective memory complaints, mild cognitive impairment and Dementia.

Table 1.1: The effectiveness of supervised physical activity-based interventions on cognitive performance in older adults

Author (Year)	Participant Characteristics				Exercise Intervention		Comparison group	Cognitive Outcomes	Summary Results & Findings
	Exercise n=	Control n=	Mean Age	Population	Intervention Content	Duration & Sessions			
Toots et al. (2017)	93	93	85 yrs.	Dementia	High Intensity Functional training intended to improve strength, mobility and balance with exercises being performed using body weight. Individual strength exercises were conducted and adjusted according to their 1 repetition	45 minutes per a session 5 days per a 2 week period for 4 month	The control group was involved in activities structured around topics that interested older adults such as holidays, different seasons and wild life for the same duration as the intervention group.	Global Cognitive Function: - Mini-Mental State Examination - Alzheimer's Disease Assessment Scale – Cognitive Subscale Verbal Fluency (Executive Function): - Animal Naming	The high intensity functional training group showed no significant superior effects on any of the cognitive outcomes (global cognitive function and executive function) when compared to the attention control group after 4 months.

					maximum.				
Park et al. (2019)	25	24	72 yrs.	Mild Cognitive Impairment	Physical and cognitive activities encouraging aerobic exercise, modification of behavior and cognitive and physical dual tasks activities	24 weekly sessions with each session lasting 110 minutes	No intervention	Global Cognitive Function: - Korean Mini-Mental State Examination - Modified Alzheimer's Disease Assessment Scale – Cognitive Subscale Verbal Fluency - Category & letter fluency test Attention: - Digit Span test (Forward & Backward) Executive Function - Korean color-word Stroop test	The dual task exercise group significantly improved in the Modified ADAS-Cognitive subscale ($p<0.01$), Digit Symbol Span test ($p=0.02$) and executive function measured by the Stroop test ($p<0.01$) compared to the control group.
McEwen et al. (2018)	SEQ = 26	SIM = 29	66 yrs.	Subjective Memory Impairment	Sequential exercise group (SEQ) participated in aerobic cycling at 60% heart rate reserve (10 minute warm up, 40 minutes	2 hour sessions twice a week for 4 weeks	Simultaneous exercise group (SIM) participated in flexibility and toning exercises for the first 60 minutes followed by memory	Cognitive outcome measures were performed on a desktop computer and included the following: Verbal Memory: - Word List Learning Visual Memory Recognition: - Figure Learning	The SIM exercise group significantly improved on composite memory ($p=0.01$) and complex attention ($p=0.003$) when compared to the SEQ exercise group post intervention.

					cycling and 10 minutes cool down) followed by 60 minutes of a memory training program while sitting still.		training for 60 minutes during stationery cycling (10 minute warm up, 40 minutes cycling at 65 % heart rate reserve and 10 minute cool down). The duration and frequency of the SIM exercise and memory training was the same as the SEQ group.	Psychomotor Speed: - Finger Tapping - Symbol Digit Coding Executive Function (Simple and Complex Reaction Time and Shifting Attention): - Stroop test - Continuous Performance test (sustained attention) Non-verbal Reasoning test (Identifying associations among visual-abstract concepts)	Conversely, the SEQ exercise group significantly improved in executive function ($p=0.0001$) compared to the SIM exercise group post intervention.
Silva et al. (2018)	M4 group = 63	M2 group = 64	68 yrs.	Subjective Cognitive Complaints	The M4 (Multiple-Modality Mind-Motor) group completed 45 minutes of multiple-modality exercise (5 minute warm up, 20 minutes of aerobic exercise	60 minutes per a session 3 days per a week for 24 weeks	The M2 (Multiple-Modality) group completed the same multiple-modality exercise as the M4 intervention group followed by 15 minutes of flexibility, balance and	The Cambridge Brain Sciences computerized cognitive test battery was used which involved 12 non-verbal tasks assessing 4 cognitive domains: - Memory - Reasoning - Concentration - Planning	There were no significant differences between the M4 and M2 group for any of the cognitive domains post intervention.

					at 65-85% heart rate maximum, 5 minute cool down and 5 minutes of stretching) followed by 15 minutes of mind-motor training using square-stepping exercises (complex stepping patterns on a gridded mat)		breathing exercises. The duration and frequency was the same as that of the M4 intervention group.		
# Baker et al. (2010)	19	9	70 yrs.	Mild Cognitive Impairment (MCI)	High intensity aerobic exercise using a stationary bike, treadmill or elliptical trainer at a heart rate reserve between 75-85%	45-60 minutes per a session, 4 days a week for 6 months	Stretching and balance exercises at or below a heart rate reserve of 50% for the same duration as the intervention group	Executive Function: - Trail-Making test - Stroop Colour-Word test - Verbal Fluency - Self-Ordered Pointing test - Task Switching Memory: - Story Recall - List Learning	Women in the aerobic exercise group showed improvements on multiple executive function measures with the men showing favorable effects in the Trail-Making test B at 6 months

# Chang et al. (2011)	11	N/A	85 yrs.	Cognitive Impairment	Sun-style 12-form Tai Chi for older adults	20-40 minutes, twice a week for 15 weeks	N/A	- Mini-Mental State Examination - Digit Symbol-Coding on the Wechsler Adult Intelligence Scale III (WAIS III) - Digit Span on the WAIS III - Stroop Colour-Word test - Hopkins Verbal Learning test	No significant differences in cognitive performance were identified when pre-post scores were compared.
# Doi et al. (2013)	16	N/A	75 yrs.	Mild Cognitive Impairment (MCI)	Two Walking Styles: 1) Dual Task Walking (DTW - walking while performing a task) 2) Normal walking (NW – walking at preferred speed)	3 trials for each walking style (1 trial =60 seconds) in one session	N/A	Global Cognitive Function: - Mini-Mental State Examination Executive Function: - Stroop Colour-Word test - Modified Stroop test	Brain activation during Dual Task Walking was significantly associated with Executive function measured by the Stroop test ($p<0.05$)
# Lam et al.	171	218	78 yrs.	Cognitive	24 forms	30 minutes	Stretching and	Alzheimer's Disease	No significant

(2012)				Impairment	simplified Tai Chi	per a session, 3 or more sessions per a week for 12 months	toning exercises for the same duration as the intervention group	Assessment Scale – Cognitive Subscale • Category Verbal Fluency test • Digit Span • Trail-making Test • Delayed Recall • Mini-Mental State Examination	differences for cognitive function were seen between groups at 12 months. Analysis for those who completed the programs showed significant improvements in delayed recall in favour of Tai Chi intervention ($p<0.05$)
#* Lautenschlager et al. (2008)	85	85	69 yrs.	Subjective Memory Impairment	Home-based individualized physical activity program consisting of walking and strength training + PA diary	50 minute sessions 3 times a week for 24 weeks	Usual care and educational material regarding stress, diet, alcohol consumption, smoking but not physical activity	• Alzheimer's Disease Assessment Scale – Cognitive Subscale • Digit Symbol Coding test • Verbal Fluency test	The intervention group significantly improved in the Alzheimer's Disease Assessment Scale – Cognitive Subscale compared to the usual care group post intervention
# Law et al. (2014)	43	40	74 yrs.	Subjective Memory Impairment or suspected Cognitive Impairment	FeTSim Program – Functional program consisting of light stretching, core FeTSim and cool down	50 minutes sessions with the aim of completing 13 sessions over 10	Active cognitive training program over 10 weeks with the aim of completing 6, 60 minute sessions	• Neurobehavioral Cognitive Status Examination • Chinese version Verbal Learning test • Trail-Making test –A • Trail-Making test – B	The FeTSim group illustrated significant improvements in general cognitive function, executive function and memory post intervention

						weeks		Category Verbal Learning test	compared to the active cognitive program group
# Li et al. (2014)	22	24	76 yrs.	Cognitive Impairment	Tai Ji Quan: Moving for better balance. Set of movements for older adults focusing on motor performance, visualization, orientation and mental execution	60 minutes sessions twice a week for 14 weeks	Usual daily physical activity for 14 weeks	Mini-Mental State Examination.	The Tai Ji Quan group showed significant improvements in global cognitive function compared to the usual care group post intervention.
# Nagamatsu et al. (2012)	Ex. Group 1 = 26 Ex. Group 2 = 24	27	75 yrs.	Subjective Memory Complaints / Probable Mild Cognitive Impairment	Ex Group 1: Resistance Training (RT) using air pressure system and free weights Ex Group 2: Aerobic Training (AT) outdoor walking program with heart rate reserve between	60 minutes per a session twice a week for 26 weeks	Balance and Toning (BAT) exercises including stretching and relaxation techniques for same duration as RT and AT	Primary Outcome: - Stroop test Secondary Outcome: - Trail-Making test, Verbal Digits test, Everyday Problems Test, Associative Memory task	The RT group significantly improved Stroop performance (p=0.04) and associative memory task (p=0.03) compared to the BAT group. No other significant cognitive function changes were identified.

					40 – 80%				
# Nascimento et al. (2014)	24	21	68 yrs.	Mild Cognitive Impairment	Multicomponent exercise program involving resistance, aerobic and balance training at 60-80% heart rate max.	60 minutes per a session three times a week for 16 weeks	Usual daily activity	Montreal Cognitive Assessment (MoCA)	Cognitive function (p=0.03) significantly improved in the MCI multicomponent group
# Suzuki et al. (2013)	25	25	75 yrs.	Amnesic Mild Cognitive Impairment (aMCI)	Multicomponent exercise program involving resistance training, cardiovascular exercise, postural balance and dual-task training	90 minutes per a session twice a week for 6 months	Educational classes about health promotion twice during 6 months	General Cognitive Function: - Mini-Mental State Examination - Alzheimer's Disease Assessment Scale – Cognitive Subscale Memory Function: - Wechsler Memory Scale – Logical Memory Subtest - Immediate and Delayed recall	The multicomponent exercise group significantly improved in the Mini-Mental State Examination (p=0.04) and logical memory scores (p=0.04) compared to the control group post intervention
# Tsai et al.	28	27	79 yrs.	Moderate, Mild or Subtle	12-form Sun Tai Chi for older	20-40 minutes per	Attentional control program	Mini-Mental State	No significant differences in Mini-

(2013)				Cognitive Impairment	adults	a session 3 times a week for 20 weeks	involving health education and social and cultural activities for the same duration as the intervention group.	Examination	Mental State Examination between groups post intervention (p=0.096)
#* van Uffelen et al. (2008)	77	75	75 yrs.	Subjective Memory Complaint and Objective Memory Impairment	Moderate intensity aerobic walking program consisting of a warm up, walking exercises and cool down	60 minutes per a session twice a week for 12 months	Placebo activity program involving non-aerobic exercises such as balance, flexibility and relaxation exercises.	Attention: • Stroop Colour-Word test Processing Speed: • Digit Symbol Substitution test Executive Function: • Verbal Fluency test Memory: • Auditory Verbal Learning test	No significant difference between groups in cognitive function post intervention
# Varela et al. (2012)	Group A = 17 Group B = 16	15	78 yrs.	Mild Cognitive Impairment	Group A: Aerobic training (cycling) at 40% heart rate reserve	30 minutes per a session 3 times a week for 3 months	Recreational activity program including playing cards and reading the	• Mini-Mental State Examination	No significant differences were identified between groups for the Mini-Mental State

					Group B: Aerobic training (cycling) at 60% heart rate reserve		newspaper for 3 months		Examination post intervention
* Carral and Perez. (2007)	27	29	68	Normal Cognitive Function	Aquatic and Resistance Training (ART)	45 minutes per a session 5 days a week for 5 months	Aquatic and Calisthenic Training (ACT) for the same duration as the intervention group	Mini-Mental State Examination	Both groups significantly improved in cognitive function (ART: $p=0.03$) (ACT: $p=0.002$)
* Cassilhas et al. (2007)	EMODERATE = 19 EHIGH = 20	23	68 yrs.	Normal Cognitive Function	EMODERATE: Moderate intensity resistance training at 50% of 1 repetition maximum EHIGH: High intensity resistance training at 80% of 1 repetition maximum	60 minutes per a session 3 days a week for 24 weeks	Warm up and stretching with overload once a week	- Wechsler Adult Intelligence Scale III - Wechsler Memory Scale – Revised - Toulouse-Pieron's concentration attention test - Rey – Osterrieth complex figure	Both resistance training groups (EMODERATE and EHIGH) had significantly ($p<0.05$) better scores than the control group on: - Digit Span forward - Corsi's block- tapping - Rey- Osterrieth (immediate

									recall) Toulouse-Pieron's concentration attention test
* Christofoletti et al. (2008)	Group 1 = 12 Group 2 = 12	17	74 yrs.	Mixed Dementia	Group 1: Multidisciplinary program consisting of occupational therapy, physiotherapy and physical education Group 2: Physiotherapy program consisting of Kinesitherapeutic exercises	Group 1: 2 hours per a session 5 days a week for 6 months Group 2: 60 minutes per a session 3 days a week for 6 months	No intervention	- Mini-Mental State Examination - Brief Cognitive Screening Battery consisting of 8 tests	No significant differences between group 1 and control as well as group 2 and control except in the clocking drawing test ($F=4.4$, $p<0.05$) and Verbal Fluency test ($F=26.5$, $p<0.05$)
* Colcombe et al. (2006)	30	29	67 yrs.	Normal Cognitive Function	Cardiovascular training (aerobic group) between 40 – 70% heart rate reserve	60 minutes per a session 3 days per a week for 6 months	Non-aerobic stretching and toning exercises for the same duration as the intervention group	Magnetic Resonance Imaging	Cardiovascular training (aerobic group) significantly increased brain volume in gray and white matter within the prefrontal cortex as

									well as the temporal cortices ($p<0.05$)
* Kwak et al. (2008)	15	15	81 yrs.	Senile Dementia	Training program consisting of upper and lower body exercises	30 – 60 minutes, 2 – 3 days a week for 12 months	No intervention	Mini-Mental State Examination	The intervention group significantly improved on the Mini-Mental State Examination ($p<0.01$) compared to the control group after 12 months
* Marmeleira et al. (2009)	16	16	68 yrs.	Normal Cognitive Function	Physical activities	60 minutes per a session 3 days per a week for 12 weeks	Usual daily activities	- Trail-Making test B - Stroop Colour-Word test	Cognitive function significantly improved in the exercise intervention group compared to the control group post intervention
* Scherder et al. (2005)	Walking group = 15 Hand & face exercises group = 13	15	86 yrs.	Mild Cognitive Impairment	Walking group: Self-paced walking with aid Hand & face exercise group: Hand exercises such as stretching and bending fingers and facial	30 minutes per a session 3 days per a week for 6 weeks	Social visits	Executive Function: - Category Naming - Trail-Making test A & B Memory: - Rivermead Behavioral Memory test (faces and pictures) - Verbal Learning and	The walking group ($F(1.27) = 5.02$; $p=0.02$, effect size = 0.16) and hand & face group ($F(1.25) = 3.27$; $p=0.04$, effect size = 0.12) performed significantly superior in Category Naming than the control group after 6 weeks.

					exercises such as different facial expressions			Memory test (direct and delayed recall) - Digit Span - Visual Memory Span	The hand & face group also performed significantly better than the control group for the Trail-Making test A & B ($F(1.12) = 5.03$; $p=0.02$, effect size = 0.19)
* Smiley-Oyen et al. (2008)	28	29	70 yrs.	Normal Cognitive Function	Cardio group: Exercises on aerobic equipment of their choice such as treadmills, steppers, stationary bicycles and cross trainers	50 minutes per a session 3 days per a week for 10 months	Flex-Tone group: Participated in strength, flexibility and balance exercises using free weights, flex bands and stability equipment for the same duration as the intervention group.	- Stroop test (Colour, Word, and Colour-Word conflict) - Reaction time tests (Simple, Choice, Incompatible and Go / No-Go reaction time) - Wisconsin Card Sort test	The cardio group illustrated significant improvements in Stroop test colour-word conflict ($p=0.001$) as well as colour-word conflict error ($p=0.002$)
* Stevens and Killeen (2006)	Exercise Group = 24 Social Visits Group = 21	30	21 yrs.	Dementia	Exercise Group: Movements involving large muscle groups and joints accompanied	30 minutes per a session 3 days per a week for 12 weeks	No intervention	The Clock-Drawing test	The social visits group significantly increased their Clock-Drawing score post intervention which is indicative of cognitive

					with music Social Visits Group: Social visit by researcher that included discussions on health topics excluding exercise				decline ($p<0.00$). No other significant differences were identified for cognitive function.
Legend: #* = Studies that were cited in both systematic reviews (Cai and Abrahamson. 2015 and Tseng et al. 2011); # Studies cited in systematic review by Cai and Abrahamson. 2015; * Studies cited in systematic review by Tseng et al. 2011; yrs. = years; N/A = Not Applicable; Ex = Exercise									

Table 1.2: Review studies on the effectiveness of combined physical and cognitive interventions and physical activity-based interventions on cognitive performance in older adults

Review Article	Population	Mean Age or Age Range	Number of RCT's	Exercise Intervention	Control Comparison	Cognitive Outcomes	Summary Results and Findings
Zhu et al. (2016)	Healthy older adults	50 yrs. and older (Mean age range 65 – 81.9 yrs.)	20 eligible studies included	20 studies included interventions: • 6 studies used combined simultaneous dual-task interventions • 14 studies conducted cognitive interventions and physical activity interventions separately.	15 studies included control groups: • 9 included a passive control group • 6 included an active control group which included activities such as lectures, book clubs, health education and leisure activities	• Overall cognition • Memory • Executive function • Attention • Processing speed • Global cognition • Visuospatial abilities • Everyday cognition	• Overall cognition effect size for combined intervention versus control group was 0.29 (95% CI 0.12 to 0.46, $p=0.001$). • Combined intervention resulted in superior effects on overall cognition effect size (SMD 0.22, 95% CI 0.06 to 0.38, $p<0.01$) when compared to physical exercise. • No significant differences were observed between the combined intervention and cognitive intervention for all cognitive domains as well as overall

							cognition.
Northey et al. (2018)	Mixed baseline cognitive status.	50 yrs. and older	36 eligible studies included	36 studies included one of the following interventions: • Aerobic exercise • Resistance exercise • Multicomponent exercise • Tai chi • Yoga	Control groups utilized one of the following : • No contact • Waiting list • Attention control • Sham exercise • Alternative active program	• Working memory • Memory • Global cognition • Attention • Executive function	• Data analysis from the 36 studies found that exercise improved cognitive function significantly (SMD 0.29, 95% CI 0.17 to 0.41; $p<0.01$) • All modes of exercise resulted in significant and positive estimates ($p<0.01$) aside from yoga ($p=0.27$). • Moderate ($p=0.02$) and vigorous ($p<0.01$) exercise had similar effect sizes while low intensity was not significant ($p=0.11$) • Exercise training improved all cognitive domains significantly, except for global cognition.
Sanders et al. (2019)	Older adults with and without cognitive impairment	The mean age in 23 studies of healthy older adults	36 eligible studies included (23 studies in cognitively	36 studies included one or more of the following intervention components: • Aerobic exercise • Anaerobic exercise • Multicomponent	Control groups utilized one of the following: • Non-active / No exercise • Stretching or progressive	• Global cognition • Executive function • Memory	• Exercise had small positive effects on executive function ($d=0.27$, 95% CI 0.15 – 0.40, $p<0.01$) and memory ($d=0.24$, 95% CI 0.06 – 0.41, $p<0.01$)

		was 70.3 yrs. The mean age in 13 studies of older adults with cognitive impairment was 78.3 yrs.	healthy older adults and 13 studies in older adults with cognitive impairment)	exercise • Psychomotor exercise	muscle relaxation • Balance and toning exercise • Leisure activities • Social interaction • Health or lifestyle education • Wait list • Book club • Social visits • Standard or usual care		in healthy older adults. • In older adults with cognitive impairment, exercise had a moderate effect on global cognition ($d=0.37$, 95% CI 0.15 – 0.60, $p<0.01$) with exercise interventions of short duration and high frequency to predict greater effect sizes ($d=0.43 - 0.50$)
Falck et al. (2019)	Mixed cognitive status	60 yrs. + (Mean age of 73 yrs.)	49 eligible studies included (30 studies in cognitively healthy older adults, 9 studies in older adults with MCI and 10 studies in older adults	49 studies included one of the following interventions: • Aerobic training • Resistance training • Multicomponent training	* NR	• Global cognitive function • Memory • Processing speed • Executive function	• Exercise training had significant positive effects on physical function ($g=0.39$; 95% CI 0.23 to 0.54, $p<0.001$) and cognitive function ($g=0.24$; 95% CI 0.15 to 0.33 $p<0.001$). • Cognitively and physically healthy older adults had the largest effect sizes on cognitive outcomes ($g=0.31$ and $g=0.32$, respectively).

			with mixed cognitive status)				
Law et al. (2020)	MCI and Dementia	Mean age range 68 – 86 yrs.	46 eligible trials included (50 papers). 14 trials in older adults with MCI, 7 trials in older adults with mild dementia, 19 trials in older adults with moderate dementia, 2 trials in older adults with severe dementia and 4 trials that were NR.	46 trials included one of the following interventions: • Aerobic training • Integrated training • Resistance training • Walking program • Other (e.g. Tai chi, handball training)	Control groups utilized one of the following: • No intervention • Placebo intervention • Other intervention	• Global cognition • Memory • Executive function • Reasoning • Attention • Language	• Exercise improved global cognition (SMD 0.44, 95% CI 0.27 to 0.61) with aerobic exercise of moderate to high intensity having the most notable effect (SMD 0.60, 95% CI 0.21 to 0.98. • No significant effects of exercise on memory components. • Exercise significantly improved executive function (Working memory), however, the effect was small (SMD 0.28, 95% CI 0.04 to 0.52. No worthwhile effects were identified for cognitive flexibility and reasoning. • Exercise had no clear effect on attentional performance. • Exercise improved language ability moderately (SMD 0.17,

							95% CI -0.03 to 0.36)
Legend: yrs. = years; NR = Not Reported ; SMD = Standard Mean Difference							

1.6.1 Physical Activity and Exercise effects on Healthy Cognitive Function

The effect of physical activity-based interventions in normal functioning older adults has been widely studied. Various physical activity interventions of different durations and frequency have shown favorable results on domains of cognition such as executive function, global function, working and short term memory and attention.

Smiley-Oyen et al. 2008 found significant improvement in executive function measured by the Stroop test (210). In this study, older adults participated in either aerobics or strength and flexibility training 3 times a week for 10 months. Although both groups surpassed the levels of cognitive function at 10 months when compared to the level at one month and 4-5 months, the aerobics group showed significantly better improvements in colour-word conflict ($p=0.001$) and colour-word conflict error ($p=0.002$), measured by the Stroop test post intervention (210). Similarly, Marmeleira et al. 2009 also found positive significant effects of 12 weeks of exercise 3 times a week for 60 minutes per a session on cognitive function (211). However, the exercise group participated in activities that had high cognitive demands such as dual-tasking, planning and decision making, dependence on working memory, speed processing and response inhibition. The high cognitive demands of the intervention may possibly account for the significant executive function improvements shown (211).

These findings suggest that improvements in executive function are possible using activities of aerobic nature that require high cognitive demands for at least 3 times per a week. In addition, improvements in global cognitive function, working and short term memory and attention have also been shown to improve in response to aerobic based aquatic exercise and high intensity strength training. In a study by Carral and Perez 2006, individuals were randomized into a combined aquatic exercise and high intensity strength training or combined aquatic exercise and calisthenics training. Individuals participated in their respective programs 5 times a week for 5 weeks. Post intervention, both groups showed significant improvement in global cognitive function measured by the MMSE (Combined aquatic group and strength training $p=0.034$ and combined aquatic and calisthenics group $p=0.021$) (212). In another study by Cassilhas et al. 2007, moderate intensity resistance training and high

intensity resistance training 3 times a week for 24 weeks were shown to have equal benefits on cognitive function, when compared to the non-exercise control group (213). Both resistance training groups performed significantly better than the control group in forward digit span, Corsi block-tapping, Toulous-Pieron test and Rey-Osterrieth (213). Studies by Carral and Perez 2006 and Cassilhas et al. 2007 highlight the importance of participating in resistance training alone or in combination with an aerobic activity at least 3 times to improve global cognition as well as working and short term memory and attention in normal cognitive functioning older adults.

Furthermore, Colcombe et al. 2006 conducted a study comparing 6 months of cardiovascular exercise three times a week for one hour to non-aerobic exercise controls (214). Magnetic resonance imaging of the brain and maximal oxygen uptake were measured before and after 6 months of the program (214). They showed significant improvement in maximal oxygen uptake and brain volume in the dorsal anterior cingulate cortex, middle frontal gyrus, left superior temporal lobe and anterior matter tracts after 6 months of cardiovascular exercise three times a week for one hour when compared to non-aerobic exercise controls (214). Colcombe and colleagues further highlight the significance of participating in aerobic activity to improve cognitive performance in normal functioning older adults.

Apart from the above-mentioned original research studies, recent systematic reviews and meta-analyses have been conducted to investigate the effects of exercise and physical activity on cognitive function in healthy older adults.

Zhu and colleagues conducted a meta-analysis to determine the efficacy of combined interventions on cognition (215). The participants of the included studies were older than 50 years (mean age 65 – 81.9 years) and without any known cognitive impairment. The intervention studies included comprised of a combination of cognitive and physical exercise, had at least one outcome measure on cognition and had an active or passive control group or a comparison intervention group. Cognitive outcome measures were further grouped into 8 domains: overall cognition, memory, executive function, attention, language, processing speed, visuospatial abilities and everyday cognition. Of the 20 studies included, 6 used simultaneous

mode of training (4 studies utilized dual-task and 2 studies exergaming) while 14 studies conducted cognitive intervention and physical exercise separately. The length of the combined intervention ranged from 6 – 96 weeks (median = 12) with the total number of sessions ranging from 12 – 672 sessions (median = 31). Weekly sessions ranged from 1 – 4 times per a week in 13 studies, and > 5 times per a week in 7 studies. The overall effect size of the combined intervention on overall cognition was 0.29 (95% CI 0.12 – 0.46, $p=0.001$). When compared to the control group, the combined intervention illustrated significant changes for memory (0.10, 95% CI 0.003 – 0.20, $p<0.05$), executive function (0.13, 95% CI 0.04 – 0.23, $p<0.01$) and attention (0.38, 95% CI 0.06 – 0.70, $p<0.05$). Moderate effect sizes were identified for global cognition (0.51, 95% CI 0.01 – 1.01, $p=0.04$) and visuospatial ability (0.59, 95% CI 0.21 – 0.96, $p<0.01$). There were no significant differences between the combined intervention and cognitive intervention for overall cognition as well as for each cognitive domain alone. When compared to physical exercise, combined intervention showed a significant difference in overall cognition (0.22, 95% CI 0.06 – 0.38, $p<0.01$). Domain specific analyses revealed significant differences on global cognition (0.87, 95% CI 0.31 – 1.44, $p<0.01$) and visuospatial ability (0.53, 95% CI 0.10 – 0.94, $p<0.05$) however, analysis was conducted on 1 and 2 studies respectively. The review concluded that combined cognitive and physical intervention was effective at improving cognitive function in healthy older adults. Furthermore, combined cognitive and physical interventions showed greater and more significant improvements on cognitive function compared to physical activity only. No significant differences were detected between combined interventions and cognitive interventions for cognitive function (215).

Similar to the meta-analysis conducted by Zhu et al. 2016, a larger systematic review with a meta-analysis was conducted by Northey and colleagues to identify if physical exercise can improve cognitive function in older adults aged 50 years and older (216). Contrary to the review by Zhu et al. 2016 who included participants without any known cognitive impairment, the review by Northey and colleagues included individuals with varying baseline cognitive status. A total of 36 randomized control trials that utilized one of the following interventions: aerobic training, resistance training, multicomponent training, tai chi and yoga were included in the review. All

trials had a control group for comparison and had at least one outcome measure of cognitive function at baseline and follow up. A total of 333 effect sizes from the included trials showed that exercise improved cognitive function (0.29; 95%CI 0.17 – 0.41; $p<0.01$). Furthermore, it was found that all modes of exercise except yoga ($p<0.27$) induced significant and positive effect size estimates ($p<0.01$). Studies with exercise intervention durations between 45 – 60 minutes ($p<0.01$) were associated with statistically significant effect size estimates when compared to shorter and longer duration exercise which was not significant. Moderate to vigorous intensity ($p<0.01$) had similar significant effect size estimates when compared to low intensity exercise ($p=0.11$). When the results were analyzed further, Northey and colleagues found that studies using resistance training as an intervention had significant effects on executive function (0.49; 95%CI 0.20 to 0.78; $p<0.01$), memory (0.54; 95%CI 0.23 to 0.85; $p<0.01$) and working memory (0.49; 95%CI 0.16 to 0.82; $p<0.01$). Control groups using no contact or health education ($p<0.01$) were significantly associated with the effect size estimate when compared to those that utilized an active control or social group. This is important as the data analysis suggest that health education on its own may not be sufficient to promote a change in an individual's lifestyle. In summary, Northey and colleagues concluded that physical exercise interventions such as resistance, aerobic, multicomponent training and tai chi are successful in improving and promoting cognitive function in older adults over 50 years, regardless of baseline cognitive status (216).

Similar to the reviews by Zhu et al. 2016 and Northey et al. 2018, Sanders and colleagues also conducted a systematic review and meta-analysis to examine the dose-response relationship between exercise and cognitive function in older persons with and without cognitive impairment (217). In regards to healthy cognitive functioning older adults, 23 studies with a total of 1225 participants were included in the analysis. The mean age of the healthy cognitive functioning older adults was 70.3 years old. Minor positive effects of exercise on memory ($d=0.24$, 95% CI 0.06 – 0.41, $p<0.01$) and executive function ($d=0.27$, 95% CI 0.15 – 0.40, $p<0.01$) were identified. In addition, in healthy cognitive function older adults, dose-response parameters such as duration, frequency and intensity of exercise did not predict the magnitude of the effect size (217).

In addition to the positive effects of physical activity and exercise on cognitive performance in cognitively healthy older adults, a recent review has also identified the impact of exercise training on physical and cognitive performance in older adults with varying levels of cognitive function (218). In the review by Falck et al. 2019, a total of 6281 participants took part in 49 studies (218). Of the 49 studies, 30 studies (63%) included healthy older adults, 9 studies (19%) with MCI and 10 studies (21%) with a mixed cognitive status. Inclusive of all studies, 19 examined aerobic training interventions while 9 studies examined resistance training and 24 studies multimodal interventions. Post analysis data (Hedge's g statistic) suggested that exercise training significantly improved physical function ($g=0.39$, 95% CI 0.23 – 0.54, $p<0.001$) and cognitive function ($g=0.24$, 95% CI 0.15 – 0.33, $p<0.001$). Cognitively healthy and physically healthy older adults had the largest effect sizes for cognitive outcomes ($g=0.31$ and $g=0.32$ respectively), while the smallest effect sizes were observed in older adults with mixed cognitive status ($g=0.06$) and mixed mobility status ($g=0.10$). Furthermore, Falck et al. suggest that multimodal programs are favorable for cognitive and physical function in older adults aged 60 years and older. In term of physical function, the impact of exercise training was identified to be moderate-to-large for functional capacity ($g=0.49$) and body strength ($g=0.42$). The review was summarized by suggesting that exercise training has beneficial effects on physical and cognitive function, and the induced effects on both, physical and cognitive domains are associated (218). In summary, based on the information from several systematic reviews and meta-analyses in older adults aged 50 years and older, with varying exercise interventions and cognitive performance outcome measures, it can be concluded that physical activity and exercise has positive effects on cognitive performance in older adults. These effects are more pronounced in multimodal interventions that include aerobic and resistance training, with superior effects identified for executive function, memory and attention.

1.6.2 Physical Activity and Exercise effects on Subjective Memory and Cognitive Complaints

Earlier studies on the effects of physical activity-based interventions on cognitive performance in older adults with subjective memory impairment have shown mixed results. In 2008, Lautenschlager and colleagues randomized 170 participants with subjective memory complaints into either a 6 month home-based physical activity program (50 minutes, 3 times a week with walking being the most frequent type of activity chosen during the program) or an educational care control (219). Post intervention, the exercise group significantly improved 0.26 points (95% CI, -0.89 to 0.54) on the Alzheimers Disease Assessment Scale – cognitive subscale, compared to the control group, whose average score decreased by 1.04 points (95% CI, 0.32 - 1.82). Word list delayed recall and Clinical Dementia Rating Scale also improved moderately in the exercise group. In contrast, another study by Van Uffelen et al 2008 did not find any positive effects on immediate or delayed recall and executive function in individuals with a subjective memory complaint and an objective memory impairment following 12 months of a group-based moderate intensity walking program, when compared to a low intensity placebo activity program (220). However, the lack of difference may have been due to low adherence to the program (63%), with 20% of participants having not attended a single session but were included as intention-to-treat in the final analysis of the intervention effects.

In 2012 and 2014 respectively, alternative physical activity-based interventions using Tai Chi found positive results on cognitive performance. Lam et al. 2012 found positive improvements in memory but negative results in executive function after 12 months of a Tai Chi program, 30 minutes per a session for at least 3 session a week (221). Furthermore, Li et al. 2014 reported improvements in global cognitive function ($p < 0.001$) measured by the Mini-Mental State Examination in individuals that participated in Tai Ji Quan: Moving for better balance over 14 weeks compared to the usual care control group (222). However, individuals in the study by Li and colleagues participated in Tai Chi sessions twice a week for 60 minutes. One of the reasons for improvement in memory and overall cognition could be due to individuals being required to remember the series of Tai Chi movements over the course of the intervention. These findings show the importance of non-traditional physical activity

in improving certain domains of cognition in older adults with subjective memory complaints.

Conventional forms of supervised physical activity interventions have also shown positive effects on domains of cognition such as executive function, short term memory and visual attention in older adults with subjective memory complaints. Nagamatsu and colleagues compared a resistance training group, an aerobic training group and an active control group over 6 months (223). Each group met twice a week for 60 minutes to complete their respective programs. Post intervention, when compared to the control group, executive function measured by the Stroop test and associative memory performance task scores improved in the resistance training group but not in the aerobic group. Similar results were found in a different study where a 10-week functional task exercise intervention in individuals with subjective memory complaints or suspected cognitive impairment resulted in significant improvements in cognition (224). There were no significant improvements in individuals who participated in computer-based cognitive training (224). The functional task exercise program group showed an improvement in cognitive function measured by the Neurobehavioral Cognitive Status Examination ($p=0.001$), Chinese version Verbal Learning test (immediate recall $p=0.028$; delayed recall $p=0.022$), Trail-Making test ($p=0.045$) and the Category Verbal learning test ($p=0.029$).

More recently, in 2018, two other studies were conducted to determine the effects of simultaneous and sequential physical and cognitive training in older adults with subjective cognitive complaints (225;226). McEwen et al. 2018 conducted a study to determine the effects of a short-term combined exercise and memory training program done simultaneously (SIM) compared to sequential (SEQ) exercise and memory training in older adults. The SIM and SEQ groups met twice a week for two hours for 4 weeks and participated in their respective programs. Post intervention, the SIM group significantly improved in complex attention ($p=0.003$) and memory ($p=0.01$) compared to the SEQ group. Conversely, a significant difference in favour of the SEQ group was identified for executive function ($p=0.0001$) post intervention.

These results suggest that simultaneous physical and cognitive exercise may have positive effects on specific cognitive domains compared to undertaking physical and cognitive exercise in a sequential order. In contrast to McEwen et al. 2018, another study was conducted to determine changes in cognition following multiple-modality exercise and mind-motor training in older adults with subjective cognitive complaints (226). In the study by Silva et al. 2018, individuals were randomized into either a multiple-modality exercise group with additional mind-motor training (M4) or multiple-modality exercise group with additional flexibility, balance and breathing exercises (M2) over 24 weeks. Both groups participated in multiple-modality exercises for 45 minutes followed by the respective additional activities for 15 minutes equating to 60-minute sessions, 3 days per a week. No significant differences were identified between groups for any cognitive outcomes post intervention (226).

1.6.3 Physical Activity and Exercise effects on Mild Cognitive Impairment

Earlier studies have also shown some benefits of physical activity and exercise on cognitive performance in older adults with MCI. In 2005, Scherder and colleagues conducted a study to compare two types of exercise interventions in individuals with mild cognitive impairment (227). Cognitively impaired individuals (n=43) were randomized into a walking group, hand / face exercise group or a social visit control group. All participants received individual treatment 30 minutes a day, 3 times a week for 6 weeks. Post intervention, both exercise groups had significant improvements in verbal fluency and executive function measured by the Category Naming and Trail-Making A + B respectively when compared to the control group (227). This study suggests that participating in exercise may improve verbal fluency and executive function compared to non-participation.

Baker and colleagues showed favorable effects of 6 months of aerobic exercise, 4 times per week on measures of executive function (Trails B, Task Switching and Stroop Colour-Word Interference) compared to stretching and balance control group (228). No improvement was found in either group for measures of memory (Story Recall and List Learning). Doi et al. 2013 also found a positive association between dual task walking and executive function. Findings from this study suggest that dual

task walking is associated with prefrontal activation and that brain activation during dual task walking is positively associated with executive function. These studies by Baker et al. 2010 and Doi et al. 2013 suggest that high intensity aerobic exercise or fast paced walking are associated with improvements in executive function.

In addition to executive function, exercise has also been identified in improving global cognitive function in older adults with mild cognitive impairment. A study conducted by Suzuki and colleagues showed an improvement in the Mini Mental State Examination but not the Alzheimer's Disease Assessment - cognitive subscale after 6 months of a multi component exercise program (229). Individuals in the exercise group participated in 90 minutes of aerobic, strength training, balance and proprioception twice a week and the control group attended 3 sessions a week of educational classes regarding health for the duration of the study. In addition, another non-randomized control trial also reported positive effects of 4 months of multi component physical training (muscular strength, aerobic fitness and motor coordination) on general cognitive function measured by the Montreal Cognitive Assessment (230). In contrast, studies by Varela et al. 2012 and Tsai et al. 2013 did not find significant improvements in global cognitive function after conducting physical activity-based interventions using aerobic training 3 times a week for 3 months and 12-form Sun Tai Chi 3 times a week for 20 weeks respectively (231;232).

More recently, Park and colleagues 2019 sought to determine the effects of a combined exercise and cognitive intervention on risk factors for dementia and cognitive decline in individuals with mild cognitive impairment (233). Individuals in the intervention group participated in a dual-task physical and cognitive activities program which lasted 110 minutes weekly for 24 weeks while the control group did not participate in any program. After completion of the trial, significant improvements in global cognitive function, attention and executive function were identified in favour of the dual-task intervention group. This may suggest that exercise combined with a cognitive activity may improve specific components of cognitive function in older adults with mild cognitive impairment (233).

In addition to the above-mentioned studies, a recent review by Law et al. 2020 was conducted to determine the effect of physical exercise on cognitive decline and behavioral problems in people with MCI and dementia (234). A total of 50 articles (46 trials) involving 5099 participants was included in the review. Studies were included in the review if they were randomized controlled trials, the primary diagnosis of participants were either MCI or dementia, included an exercise intervention and measures of cognitive function and had a comparison group. The mean age of the participants that were included in the various studies ranged between 68 and 86 years. Participant's level of cognitive impairment varied from MCI to severe dementia (MCI= 14 trials; mild dementia= 7 trials; moderate dementia= 19 trials; severe dementia= 2 trials and 4 trials not reported). Exercise interventions were categorized according to aerobic (17 trials), integrated (15 trials), resistance (3 trials), walking (4 trials) or other (7 trials) exercise type. Cognitive function was classified into 6 domains namely: global cognition, memory, executive functioning, reasoning, attention and language. The standardized mean difference was used to summarize the effect of exercise. Post data analysis showed that exercise had positive effects on cognitive function. Exercise (26 trials involving 2079 participants) improved global cognition (0.44, 95% CI, 0.27 – 0.61). Further to this finding, aerobic training of moderate to high intensity could further augment the improvements in global cognition (0.60, 95% CI 0.21 – 0.98). In respect to executive function, 8 trials that included 646 participants revealed that exercise significantly improved working memory (0.28, 95% CI 0.04 – 0.52) Reasoning was assessed in two studies with MCI participants with one study (6 months resistance training intervention) showing a small effect size while the other study involving a 3-month walking program showed no effect. In addition, no effects of exercise on attention were identified in 15 trials. In summary, the review concluded that exercise may decrease global cognitive decline in people with MCI and dementia, with more pronounced improvements in working memory. The effects of such exercise are further enhanced when moderate to high intensity studies were analyzed (234). These findings are similar to those by Sander and colleagues who conducted a systematic review and meta-analysis to determine the dose-response association between exercise and cognitive function in older persons with and without cognitive impairment (217). In regards to older adults with cognitive impairment, 13 studies involving 782 participants with cognitive impairment

with various etiologies were analyzed. The mean age of the participants was 78.3 years. Post data analysis revealed positive effects of exercise on global cognition ($d=0.37$, 95% CI 0.15 – 0.60, $p<0.01$). In addition, higher effect sizes in global cognition ($d=0.43 – 0.50$) were found when exercise programs were of shorter duration (<30 minutes) but higher frequency (> 4 sessions per week) (217).

1.6.4 Physical Activity and Exercise effects on Dementia

The effects of supervised physical activity and exercise based interventions on cognitive performance in older adults with dementia have shown mixed results. Kwak et al. 2008 conducted a study to determine the effects of an exercise intervention on cognitive performance in 30 females with senile dementia (235). Individuals were assigned to an exercise group or control group. The exercise group participated in an exercise intervention 2 to 3 times a week for 12 months with each session lasting between 30 to 60 minutes. The exercises included stretching, walking and upper and lower extremity exercises. After 12 months, the exercise group improved significantly ($p<0.01$) on the MMSE compared to the control group (235). However, contrasting results to the above mentioned study have also been observed. Christoforetti et al. 2008 conducted a study whereby 54 individuals with mixed dementia were allocated into one of three groups namely: 1) an interdisciplinary program group comprising of physiotherapy, occupational therapy and physical education; 2) a physiotherapy program; and 3) a control group with no intervention. Groups 1 and 2 completed the intervention 5 and 3 times a week respectively for 6 months (236). Cognitive function was measured using the MMSE and The Brief Cognitive Screening Battery at baseline and post intervention. Results revealed that global cognition did not improve through treatment but an attenuation was observed in the decline of global cognition on two specific domains (236).

Similarly, Stevens and Killeen 2006 also found results indicating exercise as ineffective after a 12 week intervention (237). Individuals were randomized into one of three groups. Group 1 received no intervention; group 2 received social visits of equal duration and frequency as the exercise program in group 3; and group 3 received 30 minutes of group exercises 3 times a week for 12 weeks. The outcomes

from this study showed that the Revised Elderly Persons Disabilities Scale (REPDS) slowed down disability in some activities of daily living. Furthermore, the improvements in the clock drawing test suggests that exercise may slow down the dementia related decline in cognitive symptoms (237).

More recently, Toots et al. 2017 also showed contrasting effects of exercise and physical activity on cognitive performance in older adults with dementia (238). Toots and colleagues conducted a study to determine the effects of exercise on cognitive performance in older adults with dementia (238). Individuals (n=186) were randomized into either a high intensity functional exercise intervention group or a seated attention control activity group. Both groups met twice every 2 weeks for 4 months. Post intervention, there were no significant differences in global cognitive function and executive function between groups which would suggest that high intensity functional exercise could not significantly improve cognitive performance in older adults with dementia (238). These results are in line with Christofolletti et al. 2008 and Stevens and Killeen 2006 who also found exercise ineffective in improving global cognition in older adults with dementia.

1.7 Social Sedentary Card and Board Games

There is an increased interest for improving or at least maintaining “brain health and fitness” in the later years of one’s life (239). While there is a substantial body of research on the effects of exercise and physical activities on cognitive performance (208;209;240), there is relatively little research identifying the effects of social sedentary games such as checkers, dominoes, bridge, scrabble and various other card and board games on cognitive performance. In this section, I have identified and explored the literature concerning the effects of playing social card and board games, on cognitive performance, physical function and individual well-being in older adults.

Hughes et al. 2010 explored the association between reading and participation in hobbies with the risk of incident dementia in 942 individuals, who were followed biennially for 6 years (241). Individuals self-reported if they participated in leisure

time activities which included reading books, magazines and newspapers or hobbies such as board games, crafts, puzzles, musical instruments, bridge and other card games. The frequency of participation in hobbies and reading was based on the number of hours of engagement per a week and grouped into either low (0-3 hours / week: less than 30 minutes / day), medium (4-6 hours / week: 30 – 60 minutes / day) or high (> 6 hours / week: 1 or more hours / day). Covariates in the analysis included age, education, gender, depressive symptoms, physical activity, instrumental activities of daily living and overall health. Results from this study showed that during follow up, individuals who participated in higher levels of physical activity and had superior global cognitive ability, were less likely to be diagnosed with dementia. In addition, participation in a greater number of activities and hobbies for a longer duration was associated with a decreased incidence of dementia, after adjusting for covariates. Hughes et al concluded that participation in hobbies for 1 or more hours daily could possibly protect individuals from dementia later in life (241).

Similar findings were identified in 2013 by Dartigues and colleagues who investigated the relationship between playing board games and the risk of dementia in a cohort of French older adults (n=3675) over a 20 year period of follow up (242). In this study, the board games played included were bingo, chess, draughts and cards. A neuropsychological test battery was conducted at baseline and follow up (3, 10 and 20 year follow ups) to measure language, executive function, simple logical reasoning and visual and verbal memory. A French version of the MMSE was used as an index of global cognitive performance. The findings revealed that 32,2% of participants played board games on a regular basis and they were younger, more educated and had better cognition at baseline than those who didn't play board games. In addition, the cumulative risk of dementia was significantly higher in non-players than board game players ($p<0.001$). Those that played board games had a 16% risk of dementia at the 10-year follow up compared to 27% risk in non-players. Similarly, those that played board games (47%) had a lower risk of dementia at the 20-year follow up compared to non-players (58%). Furthermore, those who participated in board games had less cognitive decline on the MMSE than non-players, even after adjusting for covariates such as age, education, marital status and other confounders. This study suggested that playing board games is a

stimulating sedentary activity, as it allows planning, decision-making and competition (242). In addition, participation in board games also encourages social interaction between family and friends. Other studies have also found that participation in games may improve cognitive performance in semantic memory, working memory and executive function (243;244).

Furthermore, Wang et al. 2013 conducted a study to determine if participation in different leisure time activities benefited specific cognitive domains and protected against cognitive decline in a cohort of healthy functioning Chinese older adults over an average of 2.4 years of follow up (245). Cognitive assessments were conducted face-to-face at the participant's home for global cognitive function, episodic memory, language and executive function. In addition, participants were asked the frequencies' of engagement in specific mental (sewing, reading, playing cards and chess), social (visiting family and friends) and physical activities. The study concluded that high levels of mental activity were associated with significantly less decline in global cognitive function ($p<0.01$), executive function ($p<0.05$) and language ($p<0.05$) compared to low levels of mental activity. Furthermore, high physical activity levels were associated with significantly less decline in episodic memory ($p<0.05$) and language ($p<0.01$) while high social activity was significantly associated with less decline in global cognitive function ($p<0.01$) compared to low levels of physical and social activity respectively. These findings indicate that overall participation in leisure activities may slow down cognitive decline while participation in specific activities may be more beneficial for certain cognitive domains than others (245). Similar findings were confirmed by Krell-Roesch et al. 2017 who found an association between participation in mentally stimulating activities later on in life and the risk of incident mild cognitive impairment in a cohort of 1929 older adults cognitively normal at baseline (246). During a follow up of 4 years, the results showed that participation in mentally stimulating activities such as playing games (HR: 0.78; 95%CI 0.65-0.95) was associated with a reduced risk of mild cognitive impairment. This finding further highlights the importance of participating in mentally stimulating activities to reduce the risk of cognitive impairment in later years of adulthood.

In another study, one of the main objectives was to determine the association between cognitive performance and sedentary pastimes in 125 cognitively healthy older adults (247). The Community Health Activity Model Program for Seniors (CHAMPS) questionnaire was used to capture information on three domains namely: Non-Exercise Physical Activity (NEPA), Moderate-to-Vigorous Physical Activity (MVPA) and Sedentary Pastimes. Sedentary pastimes were identified as activities such as: playing cards, dinner with friends and computer usage. It was found that the sedentary pastimes composite score was negatively associated with executive function (measured using the CogState computerized battery). Specifically, lower scores on executive function were associated with more sedentary behavior (247). However, in a different study, watching television was associated with lower scores on executive function while computer usage scores showed better performance on executive function and verbal memory (248). This suggests that not all sedentary behaviors have negative implications for cognitive performance.

While most of studies have been either cohorts or cross-sectional in nature, with the potential for reverse causality or selection bias the study by Overman and Robbins 2014, explored the feasibility of a game-based cognitive intervention in older adults of low socio-economic status to improve cognitive performance (46). Individuals participated in a 10-week pilot intervention for one hour per a week. The intervention included 3 non-computerized social games that were specifically chosen for working memory and executive function. The games included 1) SET – a card game in which the individual attempts to recall a unique combination of cards that qualifies as a set during each round of the game; 2) Mastermind – a board game in which a player secretly selects a combination of coloured pegs and the opponent attempts logically unlock the correct combination and; 3) Non-computerized dual *n*-back card game which requires the individual to remember if the current card was the same suit and number of the *n*-back cards shown previously. Pre and post cognitive performance outcome measures included tests that assessed working memory, executive function and processing speed such as the Trail Making test, Digit Span test of the Wechsler Adult Intelligence Scale and the Matrix Reasoning test of the Wechsler Adult Intelligence Scale. This study showed that individuals had fun, enjoyed the gaming and looked forward to participation on a weekly basis. Although participants enjoyed

all games, the dual *n*-back game was their favourite game. Moreover, participants reported a sense of satisfaction with the games, as they purchased the gaming material and played with family and friends outside intervention times. This highlights that the intervention and gaming material is inexpensive and accessible to most individuals. Overman and colleagues concluded that it may be feasible to administer such games within a community setting to decrease health disparities in cognitive function (46).

Furthermore, in 2011 Tesky and colleagues conducted the AKTIVA (Active Cognitive Stimulation – Prevention in the elderly) study to determine the effects of cognitively stimulating leisure activities such as role plays, games, coaching cards and reading on cognitive performance in healthy older adults (249). Information on aging and risk factors, healthy living and coping strategies for aging were also provided over the 8 weekly sessions with two booster sessions after 4 months. Participants (mean age = 72 years) were randomly allocated to 1 of 3 intervention groups: 1) AKTIVA intervention group 1 (n=126), 2) AKTIVA intervention group 2 including nutrition and exercise counseling (n=84) or, 3) no intervention control group (n=97). Pre and post cognitive measurements included the Mini-Mental-Status test, the cognitive aspect of the Alzheimer's Disease Assessment Scale (ADAS), part A and B of the Trail-Making Test and Clinical Dementia Rating (CDR). Furthermore, participants in the intervention groups were also asked to complete weekly activity logs to measure frequency of cognitively stimulating leisure activities during the intervention training program. Post intervention, both AKTIVA intervention groups showed positive effects on cognitive performance. Older adults over the age of 75 years showed significant improvements in speed of processing measured by the Trail-Making Test version A ($p<0.05$), while those older adults younger than 75 years of age showed improvements in subjective memory decline measured by the Memory Complaint Questionnaire ($p<0.05$) (249).

In addition to the above-mentioned studies, Zhu et al. 2016 concluded that combined interventions improved cognition more than physical exercise on its own but there was no evidence to suggest this for cognitive training alone (215). This may further highlight the need to conduct social sedentary and cognitively stimulating games

interventions in older adults, and to possibly compare such interventions to more interactive physical activities.

1.8 Interactive Video Gaming in Older Adults

In recent years, IVG has become popular and is widely available, even for older adults, and has been used to promote physical activity (250). IVG allows the individual to increase their energy expenditure while participating in games that were previously traditionally sedentary in nature (251). Globally, Nintendo Wii, Dance Dance Revolution and EA Sports Active combined sales equaled to 2 billion dollars in 2010 (252). In 2019, Sony's PlayStation 4 was the highest selling video gaming console with approximately 18 million units sold worldwide (253). In 2018, the estimated value of the South African video gaming market was approximately 3.5 billion South African Rands (ZAR) (approximately 260 million US dollars) (254). The price of gaming consoles such as the Nintendo Wii and Microsoft X-box 360 console with Kinect sensor ranged between R3000 and R5000 in 2017 in South Africa. The average age of a gamer was 33 years old (255), and 25% was aged 50 years and older. There has been an increased interest in participation of active games by older adults. According to the American Association of Retired Persons, the number of older adults regularly participating in interactive video games increased from 40.2 million to 50.6 million between 2016 and 2019 (255). This could be due to the fact that 84% of the games available commercially are appropriate for everyone to play (255), making IVG more accessible to people of all age groups. Products such as the Nintendo Wii and Microsoft X-box 360 Kinect combine the entertainment of video game play with physical exercise allowing one to be the actual character seen on screen. IVG requires the use of body movements to control the onscreen character's movement. Due to the player being a short distance from the screen, it also requires the player to incorporate cognitive skills in the form of visual-spatial skills, hand-eye or foot-eye coordination and quick reactions to play the specific games successfully (256). Therefore, IVG is different from traditional exercise, as it not only requires physical skill and ability, but also has a cognitive component in order to successfully play the game (256).

1.8.1 Cognitive Benefits of Interactive Video Gaming

Emerging research suggests that IVG enhances skills that may transfer to other cognitive activities. IVG has been shown to develop spatial awareness, attention, teaches a player to respond to visual feedback, plan actions, understand spatial constraints and create a cognitive map of their bodily movement in relation to the game (257). Active video gaming may also directly improve cognitive functioning, including executive control skills, by providing aerobic activity when playing (258). These improvements might be explained by increased aerobic fitness which leads to physiological changes that improve cognitive performance through increased cerebral circulation and neurotransmitter availability, as well as enhanced physiological and neurological mechanisms that occur during physical activity (259). Previous studies have illustrated benefits of IVG on cognitive performance measures such as executive control, attention, reaction time, processing speed and memory in cognitively healthy functioning older adults, with relatively little research conducted in older adults with some level of cognitive impairment (17;260;261). In this section, I will discuss the evidence from the literature on the effects of IVG on cognitive performance in cognitively healthy older adults, and in those with mild cognitive impairment, dementia and other neurological conditions.

Table 1.3: The effectiveness of supervised Interactive Video Gaming on cognitive performance in older adults

Author (Year)	Participant Characteristics				I.V.G Intervention		Comparison group	Cognitive Outcomes	Summary Results & Findings
	I.V.G n=	Control n=	Mean Age	Population	Gaming Content	Duration & Sessions			
Ackerman et al. (2010)	39	39	61yrs.	Healthy older adults	1 hour of completing the Nintendo Wii Big Brain Academy tasks	4 weeks with 5 sessions per a week	Educational reading tasks	• Executive Function • Visuospatial Skills • Processing Speed • Language	No significant changes in measures of cognition and perceptual speed abilities.
Eggenberger et al. (2015)	24	22 25	79 yrs.	Healthy older adults	1 hour of virtual reality video dance game (DANCE) on a pressure sensitive platform in response to visual cues	24 weeks with 2 sessions per a week	Treadmill walking with memory task (MEMORY) or Treadmill walking (PHYS)	• Executive Function • Working Memory • Visual Memory • Verbal Memory • Attention • Processing Speed	Significant improvements were identified in two dimensions of executive function. The DANCE and MEMORY group showed a significant time x intervention interaction compared to the PHYS group for Shifting Attention (p=0.075). Furthermore, the DANCE group showed a

									significant time x intervention compared to the MEMORY group for Working Memory (p=0.051).
Zimmerman et al. (2014)	20	19	66 yrs.	Parkinson's disease	40 minutes of IVG using the Nintendo Wii Sport Resort gaming package	4 weeks with 3 sessions per a week	Computer cognitive task (CogniPlus)	- Executive Function - Attention - Verbal memory - Visuospatial Skills - Processing Speed	Nintendo Wii patients performed better post intervention than CogniPlus patients (95% confidence interval: -1.49 to -0.11)
Kimhy et al. (2015)	16	17	37 yrs.	Schizophrenia	1 hour of IVG using the X-box 360 Kinect gaming console and Microsoft "Your Shape Fitness" exercise software as well as treadmill and cross trainer exercises.	12 weeks with 3 sessions per a week	Standard Psychiatric Treatment	MATRICES Consensus Cognitive Battery (MCCB) global cognitive composite score	12 weeks of aerobic training utilizing active gaming improved neurocognition by 15.1% vs -2% decrease in the control group.
Park et al. (2016)	36	36	74 yrs.	Healthy older adults	30 minutes of conventional exercise followed	6 weeks with 2 sessions per a week	30 minutes of conventional exercise	Global Score (Montreal Cognitive Assessment) – MoCA:	Global cognitive function improved significantly in the Kayak program

					by 20 minutes of the virtual reality kayak program			• Attention • Memory • Executive Function • Language • Calculation • Conceptual Thinking • Orientation	group compared to the control group ($p < 0.05$).
Studenski et al. (2010)	36 (<i>single group study</i>)	N/A	80 yrs.	Healthy older adults	30 minutes of an active video dance game for older adults (DanceTown™). Arrows of the game are synchronized to the rhythm of the chosen song	12 weeks with 2 sessions per a week with the goal of completing 24 sessions.	N/A	• Processing Speed • Attention • Working Memory	Completers of the video dance gaming sessions showed a trend towards better cognitive performance than non-completers
Mailott et al. (2012)	15	15	74 yrs.	Healthy older adults	60 minutes of active video gaming using the Nintendo Wii gaming console with primary controllers for the console and sensor bar. A	12 weeks with 2 sessions per a week (Total training time = 24 hours)	Waitlist control	• Executive Function • Visuospatial Skills • Processing Speed	The Nintendo Wii video gaming group improved significantly more than the waitlist control group in executive control and processing speed but not visuospatial skills.

					variety of Wii games were used such as Wii tennis, boxing, bowling, soccer headers, ski jump, hula hoop and trampoline				
Anderson-Hanley et al. (2012)	38	41	79 yrs.	Healthy older adults	45 minutes of interactive cyber-cycling video game on a stationary bicycle around a virtual reality track with the goal of out pacing a ghost rider	12 weeks with 3 sessions per a week	Stationary cycling viewing biofeedback (heart rate and mileage)	• Executive Function • Attention • Verbal Fluency • Verbal Memory • Visuospatial Skills • Spatial Memory	Cyber-cyclist achieved significantly better scores for all executive function measures compared to the traditional cyclist for the same amount of effort.
Barcelos et al. (2015)	8	9	85 yrs.	Healthy older adults	20 – 45 minutes of interactive cognitively challenging cycling around a virtual reality track	12 weeks with 3 – 5 sessions per a week	Stationary cycling with bike tour	• Executive Function	Significant improvements in executive function (Stroop test) after 12 weeks in those in the interactive cognitively demanding cycling than those in the stationary

									bicycle tour.
Hughes et al. (2014)	10	10	77 yrs.	Mild Cognitive Impairment	90 minutes of group-based IVG using the Nintendo Wii gaming console and wireless motion sensing remote devices. The Wii Sports software package was used which included bowling, boxing, tennis, baseball and golf.	24 weeks with 1 session per a week	Healthy ageing educational program.	Computerized Assessment of Mild Cognitive Impairment (CAMCI): • Executive Function • Attention • Processing Speed • Memory	No significant differences were observed for either group however, medium size effects were seen in favour of the Wii group for cognitive performance.
Rosenberg et al. (2010)	19 (<i>single group study</i>)	N/A	79 yrs.	Subsyndromal Depression	35 minutes of IVG using the Nintendo Wii gaming console and wireless motion sensing remote devices. The Wii Sports	12 weeks with 3 sessions per a week	N/A	Repeatable Battery for Assessment of Neurocognitive Status (RBANS) was used as a measure of global cognitive functioning.	Significant improvement from baseline to 12 weeks for the RBANS (p=0.032)

					software package was used which included bowling, boxing, tennis, baseball and golf.				
Karssemeijer et al. (2019)	Exergaming Group = 38 Aerobic Group = 38	39	80 yrs.	Dementia	Exergaming group: Cognitive-Aerobic cycling training developed by Bike Labyrinth. Individuals cycled around a digital environment while completing cognitive activities. Aerobic group: Cycling on a stationary bicycle for 30 – 50	12 weeks with 3 sessions per a week	Active Control Group: Flexibility and relaxations activities for 30 minutes per a session and the same frequency as the intervention groups.	• Executive Function • Episodic Memory • Working Memory • Psychomotor Speed	The exergaming and aerobic group significantly improved in psychomotor speed compared to the control group post 12 weeks. Exergame vs Control 0.33 (0.08 – 0.57) p=0.009 Aerobic vs Control 0.37 (0.10 – 0.64) p=0.007

					minutes per a session with the aim of achieving 65 – 75% heart rate reserve after 12 weeks				
Anderson-Hanley et al. (2018)	15 (<i>single group study</i>)	N/A	66 yrs.	Mild Cognitive Impairment	Interactive Physical and Cognitive Exercise System (iPACES): 20 – 40 minutes of pedaling on an under-table elliptical machine while maneuvering a joystick to control the memory game on a tablet or laptop. (For comparison analysis, individuals were	12 weeks with 3 – 5 sessions per a week	N/A	• Executive Function • Verbal Memory	Executive function (Stroop A/C: $p=0.01$) and delayed verbal memory (ADAS word list: $p=0.01$) significantly improved in those individuals ($n=10$) that had a “Complete dose” from baseline to 12 weeks. No significant changes were identified for those who had an “Inadequate dose”

					separated into “Complete dose” (=> 2 sessions per week) or “Inadequate dose” (<= 1 session per week)				
Guimaraes et al. (2018)	13	14	60 yrs.	Healthy older adults	60 minutes of active video gaming using the Microsoft X-box 360 Kinect gaming console and the Kinect Sports collection which included sports games such as table tennis, football, bowling, boxing, skiing and tennis as well as other mini games which were	12 weeks with 3 sessions per a week with the goal of completing 36 sessions	60 minutes of aerobic group exercises using treadmills and cycle ergometers in a laboratory setting. Individuals exercised at 40- 59% of their heart rate reserve to maintain a moderate intensity workout	Cognitive performance was measured using the computerized “ <i>CogState Battery</i> ” and assessed the following domain: • Executive Function • Visual Attention • Delayed Recall • Working Memory • Psychomotor Function • Short term & Visual Learning	Both groups improved significantly in various cognitive performance domains after completion of their respective 12 week programs. The active video gaming group significantly improved in executive function and delayed recall from baseline to post intervention ($p \leq 0.05$) The aerobic group also significantly improved from baseline to post 12 weeks on components of

					shorter in duration.				delayed recall, visual attention, executive function and short-term memory (p<=0.05)
Legend: yrs. = years; N/A = Not Applicable; Ex = Exercise									

1.8.1.1 Interactive Video Gaming effects on Healthy Cognitive Function

Although a relatively recent area of research, most of the studies published have focused on IVG in cognitively healthy older adults with many studies yielding positive benefits in various cognitive domains (250;260;262-267). Earlier studies by Ackerman et al. 2010 and Studenski et al. 2010 showed little effectiveness of IVG on cognition in older adults. Ackerman et al. 2010 conducted a study with 78 healthy older adults (262). Individuals participated in 60 minutes of interactive brain training using Nintendo Wii software (Big Brain Academy software) for 4 weeks, 5 times a week followed by a second month of 20 one hour reading sessions on current topics. The control group participated in educational sessions. No significant differences between both groups were identified for global cognition (262). Similarly, Studenski and colleagues conducted a study that used dance video gaming as an intervention in participants over the age of 65 years (n=36) (250). Individuals participated in 24 dance video gaming sessions over a 3 month period. This study reported an improvement in self-reported health in individual's who completed the program when compared to non-completers. In addition, Studenski et al. 2010 also measured physical function using a short physical performance battery as well as cognitive performance using the Digit Symbol Substitution test (250). Cognitive performance improved among those that completed all dance video sessions compared to non-completers. Although their study sample included healthy and high functioning older adults, improvements were seen in both physical and cognitive measures (250). One of the limitations to this study was that it was a single group study with no control group for comparison.

In contrast to the non-significant findings on global cognitive function shown by Ackerman and colleagues, a study by Park and Yim in 2016 (267) found positive effects of IVG on global cognitive function in healthy older adults. Park and Yim investigated whether active gaming in the form of a 3-D virtual reality kayak program improved cognitive function, muscle strength and balance in community-dwelling healthy older adults (267). Individuals were randomized into either the kayak program group (n=36) or the control group (n=36). Individuals in both groups participated in a conventional exercise program, and then individuals in the kayak

program group participated in an additional 20 minutes of the 3-D virtual reality kayak program, twice a week for 6 weeks. The Montreal Cognitive Assessment was used to measure global cognitive function. The arm curl and handgrip strength tests were used to measure muscle strength and standing and sitting balance was measured using the Good Balance system. Post intervention results indicated significant improvements in cognitive function ($p<0.05$), muscle strength ($p<0.05$) and standing and sitting balance ($p<0.05$). These authors proposed that 3-D virtual kayak program was a favorable intervention for differentially improving cognition, balance and muscle strength in older adults, when added to a traditional exercise training program (267).

Apart from the improvements in global cognitive function, many studies utilizing IVG have also illustrated favorable results in executive function in healthy older adults. A study by Maillot and Perrot. 2012 was conducted to evaluate the effects of Interactive video-game training on cognitive and physical function in older adults (260). Individuals in the intervention group participated in one hour of IVG twice a week using the Nintendo Wii gaming console for 12 weeks while individuals in the control group remained sedentary. Participants in the intervention group played the Wii Sports games which included tennis, boxing, bowling, soccer headers, ski jump and trampoline. Cognitive performance was measured using a wide variety of neuropsychological tests assessing executive function, attention, visuospatial function and processing speed. Participants in the intervention group improved significantly more than those in the control group in cognitive measures of executive function and processing speed, but not on visuospatial measures (260).

Similarly, Barcelos et al. 2015 and Eggenberger et al. 2015 also found positive results on executive function using IVG. Barcelos and colleagues showed significant improvements in executive function in healthy older adults who underwent a virtual cycling intervention around a virtual reality track with high cognitive demands for 12 weeks, 3 to 5 times per week (264). These cognitive effects were attributed to the added mental effort required when participating in cybercycling compared to traditional cycling as both groups exerted similar physical efforts. The added mental effort such as competing with other riders, anticipating turns and dividing attention

and decision making could partly tap on the domain of executive function (264). This result was similar for Eggenberger et al. 2015 who used interactive dance games with pressure sensitive platforms for 24 weeks, twice a week for 60 minutes as the main intervention while the control group participated in memory training for the same time period (265). The interactive dance group improved executive function in two domains namely, shifting attention and working memory while all other performance improvements were maintained in both groups at follow up (265).

Anderson-Hanley et al. 2012 also measured the effects of 3 months of cybercycling versus traditional stationery cycling on cognitive function in 79 older adults (263). Individuals were randomized into either the intervention or control group. Individuals in the intervention group (cybercycling) participated in 3 dimensional virtual reality cycling tours for 45 minutes 5 times per a week and individuals in the control group continued with cycling on stationery bicycles for the same period. Executive function was measured using the Stroop C test, Colour Trials difference and The Digit Span Backwards test. A composite executive function score was recorded. A total of 63 individuals completed the program, ranging in age from 58 to 99 years. The intention to treat analysis showed a significant group by time interaction in favour of the intervention group for the composite score on executive function ($p=0.002$). In addition, the group by time interactions were significant for all 3 measures of executive function (Colour Trials $p=0.007$; Stroop C $p=0.05$; Digit Backward Span $p=0.03$). This was interesting as there were no differences between groups with regards to exercise frequency, intensity or duration. Cybercyclist also decreased the risk for mild cognitive impairment by 23% when compared to traditional cyclist (263).

In 2018, Guimaraes et al. conducted an intervention to determine the effects of IVG and aerobic training on cognitive performance in healthy older adults (266). They found that the IVG group significantly improved executive function and delayed recall ($p\leq 0.05$), while the aerobic training group significantly improved in these same cognitive components, as well as visual attention and short-term memory ($p\leq 0.05$) after completion of their respective interventions (baseline to 12 weeks) (266). This study further illustrates the positive effect of IVG on executive function as well as delayed recall in cognitively healthy older adults.

1.8.1.2 Interactive Video Gaming effects on Mild Cognitive Impairment and Dementia

Although majority research on the effects of IVG on cognitive performance has been investigated in cognitively healthy older adults, a few studies have been conducted in older adults with mild cognitive impairment and dementia (268;269). These studies have shown potential benefits on cognitive domains such as executive function, verbal memory and psychomotor speed. Anderson-Hanley et al. 2018 found improvements in executive function and delayed verbal memory after 3 months of IVG in a single group of 15 individuals with mild cognitive impairment (268). Those individuals who completed an adequate dose ($n=10$) of interactive gaming (≥ 2 sessions per a week) had significant improvements in the Stroop test ($p=0.01$) and ADAS word list ($p=0.01$) compared to no significant changes to those individuals who had an inadequate dose of gaming (< 1 session per a week) (268). This suggests that as little as 2 sessions per a week of IVG can elicit changes in cognitive performance in older adults with mild cognitive impairment.

In contrast to the findings by Anderson-Hanley and colleagues, Hughes et al. 2014 conducted a study to identify the feasibility of IVG as well as its effects on cognitive function in 20 older adults with mild cognitive impairment (17). Individuals (mean age = 77.4) with mild cognitive impairment were randomly assigned to either an interactive gaming intervention group or health education control group. The intervention group played the Nintendo Wii Sports games which included bowling, golf, tennis and baseball (core games) on the Nintendo Wii console for 90 minutes once a week for 24 weeks. From week 7, participants were introduced to new games (Boom Blox, Wii Play and Sports Resort) to provide novel gaming conditions. The control group met for the same duration weekly and discussed age-specific health related topics with health and medical professionals. Cognitive performance was measured using the Computerized Assessment of MCI (CAMCI) which is a computer based set of cognitive tests assessing domains of attention, executive function, processing speed and memory. Gait speed was measured using a 6 metre walk to assess physical function. Neither intervention significantly impacted on cognitive

function. Medium size effects were identified for the CAMCI total score and gait speed in favour of the Nintendo Wii group.

More recently, Karssemeijer et al. 2019 conducted a 3-arm randomized controlled trial to determine the effects of IVG as well as aerobic exercise on cognitive performance in older adults with dementia (269). Individuals either participated in cognitive-aerobic cycling in a digital environment while challenged with cognitive tasks, cycling on a stationary bike or flexibility and relaxation training 3 times a week for 12 weeks. Post intervention, both the IVG group (0.33; 0.08 – 0.57, $p=0.009$) and aerobic exercise group (0.37; 0.10 – 0.64, $p=0.007$) significantly improved in psychomotor speed compared to the flexibility and relaxation control group (269). Although the study populations by Anderson-Hanley et al. 2018 (mild cognitive impairment) and Karssemeijer et al. 2019 (dementia) were different, both studies showed a common trend with both study interventions using virtual cycling on a stationary bike 3 – 5 times a week for 12 weeks. In addition, improvements in specific cognitive domains were identified in both studies. This may indicate that IVG can improve cognitive performance even in older adults with some level of cognitive impairment.

1.8.1.3 Interactive Video Gaming effects on Other Neurological Conditions

IVG research has also been conducted to determine its effects on cognitive performance in individuals with neurological conditions such as depression, Parkinson's disease and schizophrenia. While positive cognitive benefits were identified in those with depression and schizophrenia (270;271), contrasting findings were identified in individuals with Parkinson's disease (272). In 2010, Rosenberg et al. conducted a pilot study to assess the feasibility and acceptability of IVG as well as its effect on cognitive functioning in 19 older adults with Subsyndromal Depression (270). Community dwelling older adults participated in 12 weeks of IVG using the Nintendo Wii console and Wii Sports gaming package which consisted of tennis, bowling, baseball, golf and boxing. Participants gaming session lasted 35 minutes. Cognitive function was measured using the Repeatable Battery for Assessment of Neurocognitive Status (RBANS) which assesses attention, memory

and expressive language. The Quick Inventory for Depressive Symptoms (QIDS) was used to measure depression. Rosenberg and colleagues found significant improvements from baseline to 12-weeks in QIDS ($p=0.004$) and RBANS ($p=0.032$) (270). Majority of the participants reported that playing and learning the Nintendo Wii was “satisfying”. Therefore, this study suggests that IVG is feasible and accepted by older adults with depressive symptoms. It allows for an increase in physical activity, cognitive stimulation and enjoyment. Active gaming has the potential to not only alleviate sub-syndromal depression but improve overall health related quality of life in older adults (270).

Similarly, Kimhy and colleagues also found significant improvements in neurocognition and aerobic fitness in individuals with schizophrenia (271). Individuals (aged 18 – 55 years old) either participated in an aerobic training program which included two active play video gaming systems (X box 360 Kinect by Microsoft and Your Shape Fitness Evolved by Ubisoft) or received standard psychiatric treatment for 12 weeks, 3 times a week for one hour. Post testing results showed a significant improvement in the aerobic training group in the MATRICS Consensus Cognitive Battery global cognitive score by 15.1% versus -2% in the standard psychiatric treatment group. Kimhy et al. 2015 concluded that aerobic training was effective in improving neurocognitive functioning in schizophrenia individuals (271).

Table 1.4: The effectiveness of supervised Interactive Video Gaming on functional ability and physical fitness in older adults

Author (Year)	Participant Characteristics				I.V.G Intervention		Comparison group	Functional / Physical Outcomes	Summary Results & Findings
	I.V.G n=	Control n=	Mean Age	Population	Gaming Content	Duration & Sessions			
Bieryla et al. (2013)	6	6	82 yrs.	Healthy older adults	30 minutes of Nintendo Wii Fit yoga, aerobics and balance games using Wii Balance Board	3 supervised sessions per a week for 3 weeks	Normal daily activities	• BBS • FAB Scale • FR • TUG	Berg balance scale improved significantly in those that completed the Wii Fit sessions (p=0.037). In addition, BBS was significantly better in the Nintendo Wii Fit group (p<0.046) 1 month post intervention when compared to the control group. No other significant differences between groups were identified for any other balance measures.

Sato et al. (2015)	29	28	65 yrs.	Healthy older adults	40 minutes to 1 hour of 4 games namely: Apple game, Tightrope standing, Balloon popping and one-leg standing	2 to 3 times per a week for up to a total of 24 sessions	Normal daily activities	• BBS • FR • 30-CST • Gait analysis was performed using a 3D motion analysis system	Significant improvements in scores were seen for the BBS ($p<0.01$), FR ($p<0.01$), 30-CST ($p<0.01$) and double standing time ($p=0.03$) in favour of the intervention group when compared to the control group.
De Queiroz et al. (2017)	13	14	60 yrs.	Healthy older adults	60 minutes of Kinect Sports Ultimate Collection (Athletics, Bowling, Boxing, Skiing, Soccer, Tennis and Table Tennis) using the Microsoft 360 X-box console	3 times a week (alternate days) for 12 weeks	60 minutes of aerobic exercises using a cycle ergometer and electric treadmill with a aim of completing 36 sessions after 12 weeks	The Senior Fitness test (Fullerton test): • 30-CST • Arm Curl test • TUG • 2 minute step test	Exergaming and Aerobic group had above 86 % session attendance. Significant interaction effect for the arm curl test and a significant trend ($p<0.20$) for the 2 minute step test in favour of the Exergaming group. Both groups improved in the 30-CST and TUG post intervention.
Yu et al. (2020)	20	20	64 yrs.	Healthy middle-aged and older adults	50 minutes of Kinect Sports (Boxing, beach volleyball, table	3 times a week for 10 weeks	Usual daily activities	• Grip strength of dominant hand • 30-CST • Back scratch test • Chair sit and reach	Average HR = 120.13 bpm (Minimum = 100bpm and maximum = 180bpm)

					tennis, track and field, football and bowling) and Kinect Adventures games			• Force plate system • 8-foot-up-and-go test • 6 minute walk test	HHR during the active gaming session was 50.67% indicating a moderate intensity exercise. Leg strength significantly improved after 10 weeks of active gaming ($p=0.001$) while no significant change was seen for the control group ($p=0.714$). The 6 minute walk test significantly increased in the active gaming group ($p=0.001$) but was not significantly different in the control group ($p=0.350$). Significant interaction was identified between group and time for leg

									strength (p=0.012) and 6 minute walk test (p=0.025).
Legend: yrs. = years; N/A = Not Applicable; Ex = Exercise; BBS = Berg Balance Scale; FAB Scale = Fullerton Advanced Balance Scale; FR = Functional Reach; TUG = Timed Up and Go; 30-CST = 30-second Chair-Stand Test; HR = Heart Rate; HRR = Heart Rate Reserve									

1.9 Functional Ability and Physical Fitness Benefits of Interactive Video Gaming

Previous studies have shown that IVG improves functional ability and physical fitness in older adults. Bieryla and Dold in 2013 investigated the feasibility of the Nintendo Wii Fit (incorporating the Nintendo balance board) on improving balance in healthy older adults (273). Twelve older adults with a mean age of 82 years were randomly allocated to either a Nintendo Wii Fit intervention group (n=6) or a control group (n=6) that continued with normal daily activities. Individuals in the intervention group participated in a series of Wii Fit exercises including yoga, aerobics and balance games. The intervention was only 3 weeks in duration and participants engaged in 3, thirty-minute sessions per week. The Berg Balance Scale (BBS), Fullerton Advanced Balance (FAB) Scale, Functional Reach (FR) and the Timed Up and Go (TUG) were assessed at baseline, 1 week and 1 month post intervention. BBS scores significantly increased in the intervention group ($p=0.037$). Furthermore, a significant difference was identified between groups from pre intervention to one month post intervention on the BSS ($p<0.046$) in favour of the Wii Fit group. There were no other differences between groups for any of the other outcome measures. One of the reasons for the lack of improvement in dynamic balance measures could be due to the fact that the balance board requires the individual to control their centre of gravity and therefore more inclined to improve static measures of balance (273). Moreover, the lack of intervention effect could also be attributed to the intervention period only being 3 weeks and therefore not long enough to elicit any further changes.

Similarly, Sato et al. 2015 conducted a study to determine the effects of active video gaming on muscle strength and balance in healthy older persons (274). Fifty-seven healthy older adults with a mean age of 69 years were randomized into an exergaming intervention group (n=29) or a normal daily activities control group (n=28). The exergaming group participated in 4 games namely: Apple game (Participants required to grab 3D apples around them with both arms), Tightrope standing (Participants had to place their feet along a straight line and stand as if they were standing on a tight rope), Balloon popping (Participants had to pop balloons

that around their hips and buttocks by bending and squatting) and One-leg standing (Participants were required to stand on one leg and use their knee to touch a ball that appeared in front of it). Exergaming sessions lasted 40 – 60 minutes, 2 to 3 times per week for up to a total of 24 sessions. Gait analysis was performed using a 3D motion analysis system. Performance measures included the BBS, FR and the 30-CST. Post intervention analysis showed a significant decrease in double standing time ($p=0.003$). Pre-and-post intervention analysis showed significant improvements in the BBS ($p<0.01$), FR ($p<0.01$), 30-CST ($p<0.01$) in favour of the exergaming group when compared to the control group. Sato and colleagues concluded that the Kinect game used their study was effective in improving muscle strength, balance and walking in older adults (274). It is highly probable that the positive effects of IVG using the Kinect game were attributed to the intervention duration being long enough to elicit change when compared to Bierlya and Dold. Furthermore, the type of games used by Sato and colleagues were different to those used by Bierlya and Dold which could also have explained the intervention effect.

While the above-mentioned studies compared active video gaming to control groups that participated in normal daily activities, a study by De Queiroz et al. 2017 was conducted to compare the effects of aerobic exercise with active video gaming on functional fitness in healthy older adults (275). Twenty-seven participants with a mean age of 60 years (age range between 55 – 68 years) were randomly allocated to either an exergaming group ($n=13$) or an aerobic exercise group ($n=14$). The exergaming group played (in pairs) the Kinect Sports Ultimate Collection (Athletics, boxing, bowling, skiing, soccer, tennis and table tennis) during their sessions that last 60 minutes, 3 times per a week for 12 weeks. The aerobic exercise group participated in aerobic activities using a cycle ergometer and electric treadmill for the same frequency and duration as the exergaming group with the aim of completing 36 sessions at 12 weeks. Both group's sessions consisted of a warm up, a main session and a cool down, and intensity was assessed using heart rate monitors. The senior fitness test (Fullerton test) was used to assess muscle strength and endurance of the lower limbs (30-CST), upper limb strength (Arm curl test), agility and dynamic balance (TUG) and aerobic endurance (2 minute step test) at baseline and 12 weeks post intervention. There was a significant interaction effect for the arm

curl test ($p < 0.05$) and a significant trend ($p < 0.20$) for the 2 minute step test. Furthermore, significant values for the intervention time were found for the 30-CST ($p < 0.05$) and TUG ($p < 0.05$) for both groups indicating that both groups improved. The study concluded by stating that after 12 weeks, exergaming was comparable to aerobic exercise to improve areas of functional fitness such as lower limb muscle strength and endurance as well as agility and balance. In addition, exergaming was able to improve strength and endurance of the upper limbs as well as aerobic endurance (275).

More recently, Yu et al. 2020 investigated the effect of 10 weeks of X-box Kinect active games on physical fitness in healthy middle-aged and older persons (276). Forty older adults with a mean age of 64 years were randomized into either an active video gaming group ($n=20$) or a usual daily activities control group ($n=20$). Participants in the active video gaming group participated in 3 weekly gaming sessions that lasted 50 minutes. Sessions consisted of a 10 minute warm up, 30 minutes of active gaming and a 10 minute cool down. The Kinect Sports Games (Boxing, beach volleyball, football, track and field, table tennis and bowling) were played on weeks 1,3,5,7 and while the Kinect Adventures games were played on weeks 2,4,6,8 and 10. Physical fitness outcome measures included grip strength, 30-CST, back scratch test, chair sit and reach, static balance using a force plate system, 8-foot-up-and-go test and the 6 minute walk test. Post intervention analysis indicated that the average HRR during the active video gaming session equated to 50.7% indicating that participants were playing at a moderate intensity exercise level. In addition, the active video gaming group significantly improved their leg strength ($p=0.001$) and 6 minute walk score ($p=0.001$) post intervention while no significant change was shown for the control group. Yu and colleagues concluded that the Kinect Sports and Adventures exergames used provided moderate intensity physical activity for middle-aged and older persons and also was able to improve cardiopulmonary endurance and leg strength after 10 weeks (276). Besides the improvements in physical function by participating in IVG, another interesting finding from this study by Yu and colleagues was that both, Kinect Sports and Kinect Adventures games elicited an average heart rate reserve equating to moderate intensity according to the American College of Sports Medicine.

In summary, IVG is a relatively new and exciting form of physical activity; furthermore, literature suggests that the positive benefits of IVG can be gained by cognitively healthy older adults as well as those elderly persons with some level of cognitive impairment. In addition, both the Kinect Sports and Kinect Adventures gaming package can be played by older adults as a form of moderate intensity physical activity. We therefore included IVG using the X-box 360 console with Kinect sensor as the main interventions in Chapters 4 (study 3) and 5 (study 4). The choice of active video games used for each study was different. In study 3, older adults that were cognitively healthy were included in the study sample and the games that were used was the Kinect Adventures games which require many different body movements (E.g.: Bending and swaying to dodge obstacles) to play the game successful. In the Kinect Adventures game, each of the 5 games is different and each time played produces a novel experience. In study 4, older adults with some level of subjective memory impairment were included in the study sample and the games used in this study were the Kinect Sports games. The change in games from study 3 to 4 was based on the idea that the sports games package requires individuals to not only respond to novel complex situations similar to the Kinect Adventures, but it also requires the participants to remember the rules and regulations of the various sports games available. Therefore, participating in the Kinect Sports not only requires higher order executive functions such as response inhibition and task switching but also taps into one's working memory which is important for older persons.

1.10 Summary

With an ageing global population, the maintenance of quality of life and independence is becoming increasingly important for older adults. This is due to the many changes that occur with the ageing process such as a decrease in bone density, reduced muscle mass and strength and a decline in food intake and more time spent in sedentary behaviour. These lead to a reduced ability to perform activities of daily living such as walking, shopping, dressing, housework, leaning over and reaching for items. There is also a decline in one's cognitive performance in terms of reaction time, processing speed and short and long term memory.

Table 1.5 Summary of research studies conducted using different physical activity interventions and measuring physical, functional and cognitive outcomes

Outcomes	Traditional Physical Activity Interventions		Social Sedentary Card and Board Games		Interactive Video Gaming	
	Healthy Older Adults	Subjective Memory Complaints	Healthy Older Adults	Subjective Memory Complaints	Healthy Older Adults	Subjective Memory Complaints
Physical:						
1. Bicep Curls in 30 seconds	✓*	✓	?	?	✓*	?
2. 6-Minute Walk test	✓	?	?	?	✓*	?
Functional:						
1. Static Balance	✓*	✓	?	?	✓	?
2. Dynamic Balance	✓*	✓	?	?	✓*	?
3. Timed Up and Go test	✓*	✓	?	?	✓*	?
4. Sit-to-Stand test	✓*	✓	?	?	✓	?
5. Grip Strength test	✓*	✓*	?	?	✓*	?
6. Functional Reach test	✓*	✓	?	?	✓*	?
Cognitive:						
1. 6-Item Cognitive Impairment test	?	?	?	?	?	?
2. The Modified Stroop task	✓*	✓	✓	?	✓*	?
3. Mini-Mental State Examination	✓*	✓	✓	?	✓*	?
4. N-Back task	✓	?	?	?	?	?
Legend = ✓ - Intervention study conducted assessing a particular outcome; * - Significant improvement by intervention in particular outcome; ? - Unknown if Intervention study conducted assessing a particular outcome						

The above-mentioned studies in this literature review have shown positive changes through exercise and physical activity to the factors that are associated with ageing such as improvements in one's balance, strength, flexibility and a reduced risk for developing chronic disease. Since functional capacity is made up of both physiological and cognitive capacities to optimize physical performance, further investigation to identify the relationship between fitness, functional performance and cognitive ability is needed. In addition, the conventional exercise interventions have been widely studied and positive effects shown on many physical and cognitive parameters (Table 1.5).

More recently, alternative physical activities such as Tai Chi, Yoga and Active Video Gaming have become popular among older adults as a choice of exercise. This has led to increasing number of research studies being conducted over the past few years within the older adult population using IVG as physical activity interventions. These studies demonstrate the potential benefits of IVG on different aspects of cognitive performance such as executive function, attention, memory and processing speed. In addition to the cognitive benefits of IVG, other positive outcomes of IVG include improvements in physical function and functional ability such as muscle strength, balance and aerobic fitness (Table 1.5). However, there has been limited research on IVG and its association and effects on cognitive performance in older adults with subjective memory complaints in low-to-middle income countries.

1.11 Aims and Objectives

Based on the findings and previous work described in the literature review, the aim of this thesis was to determine the following:

1. To investigate the relationships between functional ability, fitness and cognitive performance in high functioning, independently-living, older South Africans. A secondary aim was to determine the extent to which physical and functional parameters predict performance in a novel cognitive task.
2. To determine the extent to which participants' perceived level of difficulty for the IVG Kinect Adventure's was related to their functional and cognitive performance. We hypothesized that IVG will increase heart rate equivalent to moderate intensity physical activity. In addition, we hypothesized that those individuals with lower functional and cognitive performance would perceive the IVG as more difficult.
3. To determine the effects of a 12-week active gaming intervention, using the X-box 360 Kinect gaming console compared with "table games" on cognitive performance and functional ability in healthy South African older adults without any known cognitive impairment. We hypothesized that participants in the intervention group would show greater improvements in physical function and cognitive performance compared to those in the table games comparison group.
4. To determine the effects of a 12-week active gaming intervention, using the X-Box 360 gaming console with Kinect Sports games, on cognitive performance in South African older adults with subjective and objective memory complaints. This intervention was compared to a conventional, multimodal supervised exercise program which served as the comparison group. We hypothesized that the individuals in the intervention group would show greater

improvements in measures of cognitive function and functional ability than the comparison group.

CHAPTER 2: THE RELATIONSHIP BETWEEN FUNCTIONAL STATUS, PHYSICAL FITNESS AND COGNITIVE PERFORMANCE IN PHYSICALLY ACTIVE OLDER ADULTS: A PILOT STUDY

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2.1 Introduction

The preservation of an individual's fitness, functional and cognitive performance, all play a role in maintaining independence with ageing (277). The relationships between these 3 domains are particularly relevant in South Africa, which has the highest proportion of older persons in southern Africa with approximately 7.6% of the population over the age of 60 years (278). As life expectancy increases in the older adult population, the prevention of disability and maintenance of functional ability and levels of independence is becoming more important (60).

Physiological changes that occur with ageing include a decrease in muscle mass (57), strength and aerobic capacity, along with a decline in cognitive function (58;59). The end result is a decline in functional ability, and ultimately result in decreased levels of independence (88). Previous research has shown that participation in physical activity also decreases with ageing and is associated with obesity and cardiovascular diseases (99). This contributes to decreased functional ability and increased need for assistance with activities of daily living. Functional ability is defined as the ability to perform activities of daily living independently without any undue pain and fatigue (89) and is linked to physical fitness. Physical fitness is defined as a general state of good somatic health that allows an individual the functional capacity to live independently in a safe and independent manner (59). A decline in function can be observed in a variety of motor abilities due to diminished muscle size, decline in strength, and a reduction in speed which can lead to the decrease in physical power, eventually leading to disability (91). A decrease in muscle size and strength, both of which influence power, can impact negatively on performance of regular daily activities (89). Examples of activities where lower body strength is important include: walking, climbing up and down stairs and rising from a seated position.

Furthermore, a decline in function and slower mobility has also been associated with reduced mental speed (119). Voelcker-Rahage et al. investigated the relationship between physical and motor fitness and cognitive performance. The researchers reported that cardiovascular fitness and muscle strength were both positively

associated with cognitive performance in German older adults. In addition, participants decreased motor fitness was associated with decreased cognitive performance in men and women older than 65 years (119).

A decline in cognitive function could also influence quality of life and independent living of older adults (279). Ageing is associated with a decrease in cognitive processes such as mental speed, short term memory, reaction time and control skills like planning (60). Previous studies have shown that a number of factors such as physical activity, education and chronic life stress can influence cognitive function as individuals age (280-282).

A wide variety of well-established test batteries have been used in other research studies to assess the different domains related to a decline in function with ageing. These include assessments such as the Continuous-Scale Physical Functional Performance test (101) and the Senior Fitness Test (90) for functional performance, while other studies have used bespoke test batteries to assess other domains (282). One example of a bespoke test battery was developed by Williamson and Colleagues, involving the Modified Stroop task to assess cognitive function (282). Much of the published research in this area has been conducted with individuals who had cognitive impairments or among those living in retirement or assisted-living care facilities (279;283;284). Other studies have been conducted in individuals who were inactive and had a sedentary lifestyle (90).

Physical fitness, functional ability and cognitive function all play an important role in maintaining the independence and quality of life of older adults. Therefore, the aim of this pilot study was to investigate the relationship between functional ability, fitness and cognitive performance in high functioning, independently-living, older South Africans. A secondary aim was to determine the extent to which physical and functional parameters predict performance in a novel cognitive task. We hypothesized that a higher level of physical activity, fitness and functional ability will be associated with higher levels of cognitive performance in high functioning independent-living, older South Africans.

2.2 Methods

2.2.1 Study Design and Participants

This was a descriptive observational study in which a convenient sample of seventy (n=70) participants (28 males and 42 females) aged 65 years and older were recruited. Participants were recruited from a commercial gym and from a community-based physical activity intervention program. The Community Health Intervention Programmes (CHIPS) aims to promote physical activity and healthier lifestyles for older adults in marginalized communities in Cape Town (285).

More than a third (39.3%) of Cape Town's total population lives below the poverty line. Low income households range from no income to earning just over R4166 (282.4\$ / 204.2£) per a month. Middle-income range from R4166 – R33741.75 (2287.6\$ / 1654.8£) per a month and high income above R33741.75 per a month. In addition, 20.8% of the population in the city of Cape Town is unemployed. Our participants were recruited from the Cape flats (Hanover Park and Lotus River) as well as the Southern suburbs (Diep River and Newlands). Half (51.1%) of the individuals living in the Cape flats fall within the low income bracket, 39% within the middle income bracket and 9.9% within the high income bracket. In the Southern suburbs, 30.5% of individuals fall within the low income bracket, 40% within the middle income bracket and 29.6% within the high income bracket. As a result, our participants were older adults who were likely to be physically active and represented both high and low socio-economic neighborhoods.

Inclusion criteria were that participants had to be older than 65 years, community dwelling and living independently. Those participants who were identified as being at a high risk for coronary artery disease, according to the American College of Sports Medicine criteria (286), required consent from a medical doctor prior to being allowed to complete the test battery. Being previously diagnosed with a stroke, myocardial infarction or uncontrolled diseases such as hypertension or diabetes were the main exclusion criteria. In addition, those with limited mobility were excluded. Three individuals were excluded as they required the use of assistive walking devices and two individuals due to previously being diagnosed with a mild stroke. Eligible

participants were further categorized into either young older adults (65 – 70 years old) or old older adults (70+ years old)

Ethical approval for this research study was obtained from the Research and Ethics Committee of the Faculty of Health Sciences, from the University of Cape Town. Written consent was obtained from each participant before the commencement of the study.

2.2.2 Measurements

2.2.2.1 Demographic and Health Status Questionnaire

An interviewer-administered questionnaire was administered to obtain information about the participant's age, occupation, self-perceived health status and highest educational achievement. Participants were also asked to report any previous disease diagnosed by a medical doctor and the associated treatment and medication received.

2.2.2.2 Yale Physical Activity Survey

DiPietro and colleagues developed and validated the Yale Physical Activity Survey (YPAS) for older adults (287) which was later validated in a South African population (288). The first part of the questionnaire assesses physical activity in five domains, namely; household, yard work, care-giving, exercise and recreational energy expenditure, representing total habitual physical activity. The time spent in each activity was summed to calculate the total physical activity time for the week. Each activity was assigned an intensity code (kcal) as described by DiPietro (287), and subsequently multiplied by the time spent to calculate kcal/week. Each individual's weekly energy expenditure was calculated for each of the activity domains and then summed to estimate total weekly expenditure.

2.2.2.3 Anthropometry

Height was measured to the nearest centimeter using a wall-mounted tape measure (Detecto). Body mass was measured using a calibrated electric scale (UWB BW-150) and recorded to the nearest 0.5kg. Body mass index (kg/m^2) was calculated as body mass (kg) divided by height (m) squared (286).

Waist circumference was recorded at the level of the umbilicus and hip circumference was measured at the largest diameter below the umbilicus or maximum circumference over the buttocks. Waist-to-hip ratio was calculated as waist divided by hip circumference (289).

A Harpenden caliper (Holtain) was used to measure skinfold thickness at four sites, namely; sub-scapular, supra-iliac, triceps and biceps. The Durnin and Womersley (1974) equation was used to calculate percentage body fat (290).

2.2.3 Fitness Measures

2.2.3.1 Bicep Curls test

This test measures upper body muscle strength and endurance (89). Participants were seated in a chair with back support for posture and given a small dumbbell (2kg's for females and 4kg's for males). They were instructed to repeat as many bicep curls as possible in 30 seconds (89).

2.2.3.2 Six – Minute Walk test

The participants walked around a 70m indoor track for 6 minutes. Two chairs were placed on the track, one at the start and the other at the 35m mark, in case participants needed to rest during the 6-minute walk. Participants were requested to walk for as long and fast as possible and advised that they could sit and rest if needed. The total distance covered was recorded in metres (291).

2.2.4 Functional Ability Tests

2.2.4.1 Static Balance test

Static balance was assessed by asking the participant to stand for as long as possible (a maximum of 30 seconds) in the tandem and semi tandem positions, with the left and then right foot leading (292). The tandem stance was performed by standing with the right foot in front of the left, with the toe of the left foot touching the heel of the right foot, and vice versa with the left foot leading. The time that the stance was maintained without taking a step or losing balance was recorded.

2.2.4.2 Dynamic Balance test

The participants were asked to walk 10 meters along a strip of tape using the tandem gait. Tandem gait involves walking heel to toe. When the left foot is in front, the right heel will move forward touching the left toe and when the right foot is in front, the left heel will move forward touching the right toe (154). The time taken to walk the first 6 steps (292) as well as the time taken to complete 10 meters was recorded.

2.2.4.3 Timed Up and Go test

This test is a measure of mobility, balance and agility. Participants started in a seated position with hands across their chest on a standard chair with no arm rests, then stood up, walked 3 meters, turned around and walked back to the chair and sat down. The time taken to complete the task was recorded (156).

2.2.4.4 Sit to Stand test

This test is a measure of lower body strength. Participants were seated on a standard chair without armrests, with their hands folded across the chest. They were then instructed to rise from the chair into a standing position and sit down again. They repeated this process for 30 seconds without using their arms for assistance. The time taken to complete 5 repetitions was recorded, as well as the total number of sit-to-stands completed in 30 seconds (142).

2.2.4.5 Grip Strength test

Grip strength was determined using a hand held dynamometer (Takei Physical Fitness Test: Grip-D, T.K.K. 5401) and measured in kilograms (kg) of isometric force. Participants were required to squeeze the hand held dynamometer inner and outer grips towards each other as hard as possible without bending the elbow, while remaining seated (172). Two attempts each for the right and left arms were recorded.

2.2.4.6 Functional Reach test

Participants were asked to stand next to a wall and reach as far forward as possible along a wall mounted yardstick (150cm vertically from the ground) without moving, taking a step or lifting their heels (153). Participants were not allowed to use the wall for support while reaching forward. Each participant was given two familiarization trials and then three performance trials. The mean value (in cm's) of the last three functional reach trials was recorded.

2.2.5. Cognitive Performance Tests

2.2.5.1 The Six–Item Cognitive Impairment Test (6CIT)

The Six–Item Cognitive Impairment test (6CIT) was developed in the United Kingdom to assess cognitive function in older adults by measuring orientation, concentration and short–term memory (193). This tool was modified for the use in South African older adults (194) and has been validated against the Bristol Activities of Daily Living Scale (293).

The first three questions assess orientation in time, by asking the participant to recall the current month and year. The latter three questions assess memory and concentration. The number of errors made for each question were scored and weighted. The scores range from 0 to 28, where a score from 0 to 7 indicates normal

cognitive function, 8 to 9 indicating mild cognitive impairment and 10 to 28 indicating significant cognitive impairment.

2.2.5.2 Modified Stroop task

The Modified Stroop task is a computer-based assessment where cues (2cm in height) appear in the centre of a computer monitor (294). The cues consisted of 4 text words (red, blue, green and yellow) which appeared every 3.2 seconds on a black background and were displayed for 600ms after which a black screen was displayed for 2600ms constituting the response period. The 4 words were presented in 5 different colour inks: red, blue, green, yellow and grey. The words were either presented in grey ink or in a colour ink incongruent with the meaning of the word: e.g. blue word presented in a red colour, or yellow word presented in a green colour, but never a green word presented in a green colour or red word presented in a red colour, etc. The participants were then asked to respond as quickly and as accurately as possible by pressing one of the four response buttons to indicate either the ink colour of the word (if the text was written in either red, blue, green or yellow ink), or the word itself (if the word was written in grey ink).

The Modified Stroop task measures three executive functions: 1) Shifting between tasks; 2) Updating and monitoring of working memory representation and; 3) Inhibition of dominant or pre-potent responses (295). The objective of the Modified Stroop task in this study was to determine the balance between speed and accuracy, which is also known as the speed accuracy trade off (187). Previous studies have shown that when subjects concentrate more on responding as fast as possible, their number of mistakes increases, thereby sacrificing accuracy for speed (187). The first Modified Stroop task administered was regarded as a familiarization trial. The outcome variables such as the number of correct responses, mistakes, missed responses and average reaction times of responses were recorded. The second Modified Stroop task was used in the data analysis.

2.3 Statistical Analysis

STATISTICA 9 software package was used for all the analyses (Stasoft, Inc., Tulsa OK, USA). Descriptive statistics were used to calculate the mean and standard deviations for the demographics, fitness, functional and cognitive results as well as weekly total physical activity time and energy expenditure. Data that were not normally distributed were log transformed. Consequently, the following variables were log transformed: Dynamic balance, 6 Item cognitive impairment test, total mistakes and missed responses on the Stroop task.

T-tests were used to determine any significant differences between men and women for anthropometrical measures. Spearman's correlation coefficients were applied to investigate the relationship between total physical activity and measures of cognitive function. Pearson's correlation coefficient was used to investigate the relationship between fitness, functional and cognitive performance. No mathematical correction or adjustment was conducted for multiple comparisons (296). In addition, a multiple regression analysis was performed to determine which of the fitness and functional performance tests had the greatest influence on cognitive performance. A backwards elimination multiple regression analysis was performed to develop a model to best predict the number of correct responses on the Stroop task. The backward elimination process started with variables that were significant in the bivariate correlation. Variables were added to the model to determine the amount of variance. Variables that gave the most statistically insignificant deterioration of the model fit were deleted. This process was repeated until no further variables could be deleted without a statistically significant loss of fit.

2.4 Results

2.4.1 Participant Characteristics

A total of 70 participants, 65 years to 84 years, volunteered to participate in the research. Comparisons between males and females for body composition, total physical activity time and energy expenditure are shown in Table 2.1. Fourteen participants were employed during the time of the study. Twenty eight participants

(40%) completed up to primary school, ten participants (14.3%) completed secondary school and thirty two participants (45.7%) completed tertiary education. The most common medical diagnosis was hypertension with thirty two participants (45.7%) being diagnosed, followed by seventeen participants (24.3%) with elevated serum cholesterol concentrations, eight participants (11.4%) with diabetes mellitus, and seven participants (10%) with asthma. A total of 47 participants (67%) were using medication for the various conditions and 18.6% were diagnosed with two or more medical conditions.

Table 2.1: Participant Characteristics (Data are represented as mean $\pm$ standard deviation)

	Total (n=70)	Men (n=28)	Women (n=42)
Age (Years)	71.0 $\pm$ 4.7	71.0 $\pm$ 4.2	70.9 $\pm$ 4.7
Body Mass Index (kg.m ²)	27.6 $\pm$ 4.2	27.5 $\pm$ 3.8	27.8 $\pm$ 4.4
Waist Circumference (cm)	92.8 $\pm$ 11.8*	97.5 $\pm$ 10.0	89.8 $\pm$ 12.0
Hip Circumference (cm)	106.3 $\pm$ 9.4	105.0 $\pm$ 7.2	107.2 $\pm$ 10.6
Waist to Hip Ratio	0.9 $\pm$ 0.1*	0.9 $\pm$ 0.1	0.8 $\pm$ 0.1
Percentage Body Fat (%)	29.6 $\pm$ 4.7*	27.6 $\pm$ 5.1	31.0 $\pm$ 4.1
Total Weekly Physical Activity (Minutes)	1450.5 $\pm$ 850.1	1380.2 $\pm$ 963.1	1497.3 $\pm$ 774.4
Total Weekly Energy Expenditure (kcal/week)	5259.6 $\pm$ 3143.3	5615.5 $\pm$ 3959.7	5022.3 $\pm$ 2481.6
Employment Status:			
1) Employed (number)	14 (20%)	7 (10%)	7 (10%)
Education Level:			
1) Primary School	28 (40%)	2 (7.1%)	26 (92.9%)
2) Secondary School	10 (14.3%)	5 (50%)	5 (50%)
3) Tertiary Education	32 (45.7%)	21 (65.6%)	11 (34.4%)
Health Status:			
1) Hypertension	32 (45.7%)	12 (37.5%)	20 (62.5)
2) High Cholesterol	17 (24.3%)	7 (41.2%)	10 (58.2%)
3) Diabetes	8 (11.4%)	4 (50%)	4 (50%)
4) Asthma	7 (10%)	5 (71.4%)	2 (28.6%)
5) Peripheral Vascular Disease	1 (1.4%)	1 (1.4%)	0 (0%)
*p< 0.01 – Significant differences between men and women Employment, Education and Health Status are represented as a number (percentage) Health status was self-reported. Individuals were asked if they were previously diagnosed with any the following medical conditions: Hypertension, High Cholesterol, Diabetes, Asthma or Peripheral Vascular Disease.			

Table 2.2: Fitness, Functional and Cognitive Performance for Men and Women(Data are represented as mean $\pm$ standard deviation)

	Total (n=70)	Men (n=28)	Women (n=42)
Physical Fitness:			
Bicep Curls in 30 seconds (Number)	18.3 $\pm$ 3.8	19.3 $\pm$ 3.4	17.7 $\pm$ 4.0
6-minute walk test (metres)	545.8 $\pm$ 109.4**	599.4 $\pm$ 118.4	510.0 $\pm$ 87.2
Functional Ability:			
Static Balance: Tandem Gait: Left Leading (seconds)	27.8 $\pm$ 6.9	29.1 $\pm$ 4.6	27.0 $\pm$ 8.0
Static Balance: Tandem Gait: Right Leading (seconds)	28.5 $\pm$ 5.5	29.2 $\pm$ 4.2	28.1 $\pm$ 6.3
Dynamic Balance: 10 metres	37.2 $\pm$ 15.3*	30.8 $\pm$ 16.5	41.7 $\pm$ 12.8
Timed Up and Go (seconds)	7.2 $\pm$ 1.5	7.3 $\pm$ 1.7	7.1 $\pm$ 1.3
Sit to Stands in 30 seconds (Number)	12.9 $\pm$ 2.3	13.4 $\pm$ 2.5	12.5 $\pm$ 2.1
Grip Strength: Left (kg)	23.8 $\pm$ 6.3**	29.7 $\pm$ 4.4	19.9 $\pm$ 3.7
Right (kg)	25.0 $\pm$ 7.0**	31.2 $\pm$ 5.2	20.9 $\pm$ 4.5
Functional Reach (cm)	81.6 $\pm$ 6.2**	86.0 $\pm$ 5.2	78.8 $\pm$ 5.2
Cognitive Performance:			
6 Item Cognitive Impairment Test (errors)	4.0 $\pm$ 4.1	3.4 $\pm$ 4.2	4.3 $\pm$ 4.0
Modified Stroop task:			
Mistakes (Number)	9.2 $\pm$ 7.3*	6.3 $\pm$ 5.1	11.1 $\pm$ 7.9
Missed Responses (Number)	3.5 $\pm$ 4.7	2.3 $\pm$ 4.4	4.3 $\pm$ 4.9
Correct Responses (Number)	19.3 $\pm$ 9.5*	23.4 $\pm$ 7.0	16.7 $\pm$ 10.0
Average Reaction Time (Seconds)	1585.0 $\pm$ 373.0	1579.0 $\pm$ 317.0	1588.0 $\pm$ 410.5
S.D of Average Reaction time of Correct Responses	454.5 $\pm$ 175.2	448.0 $\pm$ 153.1	458.8 $\pm$ 190.3
Correct Responses : Average Reaction Time (Number/ Second)	0.013 $\pm$ 0.008*	0.016 $\pm$ 0.006	0.012 $\pm$ 0.008
*p< 0.01; **p< 0.001 – Significant differences between men and women			

2.4.2 Fitness, Functional and Cognitive Test Results for Men and Women

The results of the fitness, functional and cognitive tests for men and women are presented in Table 2.2. The men ($599.4\text{m} \pm 118.4$) were able to walk significantly further in the 6-minute walk test compared to the women ($510.0\text{m} \pm 87.2$) but there was no significant difference in the number of bicep curls performed in 30 seconds. The mean static balance scores were close to 30 seconds for both men and women. The men ($29.7\text{kg} \pm 4.4$) also had a significantly higher grip strength score on the left hand compared to the women ($19.9\text{kg} \pm 3.7$) as well as on the right arm (men: $31.2\text{kg} \pm 5.2$ versus women: $20.9\text{kg} \pm 4.5$). Grip strength was higher in the right arm for the men compared to the left arm which was also the dominant arm for most of the participants. Functional reach was also significantly different between both groups with the men ($86.0\text{cm} \pm 6.2$) scoring higher than the women ($78.8\text{cm} \pm 5.2$). Most of the cognitive performance tests were similar for the men and women with the exception of number of mistakes and correct responses in the Stroop task. The men (23.4 ± 7.0) had a significantly higher number of correct responses on the Stroop task compared to the women (16.7 ± 10.0).

2.4.3 Fitness, Functional and Cognitive Test Results for Young and Old Older Adults

Table 2.3 represents the fitness, functional and cognitive test results for young older adults and old older adults. There were no significant differences in the fitness and functional variables between both age group classifications. In the cognitive domain, only standard deviation of the average reaction time of correct responses were significantly different between both groups with the young older adult group ($411.2\text{ms} \pm 153.8$) having a better score than the old older adult group ($502.9\text{ms} \pm 187.1$).

Table 2.3: Fitness, Functional and Cognitive Performance for Young and Old Older Adults (Data are represented as mean $\pm$ standard deviation)

	Young Older Adults (n=37) (65-70 years old)	Old Older Adults (n=33) (70+ years old)
Physical Fitness:		
Bicep Curls in 30 seconds (Number)	18.9 $\pm$ 4.0	17.7 $\pm$ 3.6
6-minute walk test (metres)	557.1 $\pm$ 119.5	533.1 $\pm$ 97.0
Functional Ability:		
Static Balance: Tandem Gait: Left Leading (seconds)	28.0 $\pm$ 6.3	27.7 $\pm$ 7.5
Static Balance: Tandem Gait: Right Leading (seconds)	29.1 $\pm$ 4.0	28.0 $\pm$ 6.9
Dynamic Balance: 10 metres	40.4 $\pm$ 21.3	41.5 $\pm$ 21.7
Timed Up and Go (seconds)	6.9 $\pm$ 1.5	7.4 $\pm$ 1.4
Sit to Stands in 30 seconds (Number)	13.14 $\pm$ 2.3	12.6 $\pm$ 2.2
Grip Strength: Left (kg)	24.7 $\pm$ 6.6	22.8 $\pm$ 5.8
Right (kg)	25.6 $\pm$ 7.1	24.4 $\pm$ 6.9
Functional Reach (cm)	81.4 $\pm$ 6.7	82.0 $\pm$ 5.8
Cognitive Performance:		
6 Item Cognitive Impairment Test (errors)	3.6 $\pm$ 4.0	4.3 $\pm$ 4.2
Modified Stroop task:		
Mistakes (Number)	8.2 $\pm$ 7.0	10.5 $\pm$ 7.8
Missed Responses (Number)	3.0 $\pm$ 4.6	3.7 $\pm$ 4.6
Correct Responses (Number)	20.7 $\pm$ 9.6	17.8 $\pm$ 9.2
Average Reaction Time of Correct Responses (Seconds)	1535.8 $\pm$ 417.8	1629.1 $\pm$ 325.6
S.D of Average Reaction time of Correct Responses	411.2 $\pm$ 153.8	502.9 $\pm$ 187.1*
Correct Responses : Average Reaction Time (Number/ Second)	0.014 $\pm$ 0.01	0.012 $\pm$ 0.01
*p< 0.01		

Table 2.4: Relationships between Functional Ability, Physical Fitness and Cognitive Performance

		Modified Stroop task						
	6 Item cognitive impairment test	Mistakes	Missed Responses	Correct Responses	Average Reaction Time of Correct Responses	Correct Responses : Average Reaction Time	S.D of Reaction Time	S.D : Correct Response
<u>Cognitive Performance Tests</u>								
6 Item cognitive impairment test		$r=0.47^{***}$ ($p<0.001$)	$r=0.38^{***}$ ($p<0.001$)	$r=-0.52^{***}$ ($p<0.001$)	$r=0.06$ (NS)	$r=-0.48^{***}$ ($p<0.001$)	$r=0.11$ (NS)	$r=-0.34^*$ ($p=0.048$)
<u>Functional Ability Tests</u>								
Functional Reach	$r=-0.34^*$ ($p=0.004$)	$r=-0.35^*$ ($p=0.002$)	$r=-0.35^*$ ($p=0.003$)	$r=0.44^*$ ($p=0.001$)	$r=-0.08$ (NS)	$r=0.33^*$ ($p=0.006$)	$r=0.01$ (NS)	$r=-0.16$ (NS)
Grip Strength: Right arm	$r=-0.20$ (NS)	$r=-0.36^*$ ($p=0.002$)	$r=-0.44^*$ ($p=0.002$)	$r=0.48^{***}$ ($p<0.001$)	$r=-0.11$ (NS)	$r=0.42^{***}$ ($p<0.001$)	$r=-0.12$ (NS)	$r=-0.29^*$ ($p=0.048$)
Dynamic balance	$r=0.07$ (NS)	$r=0.18$ (NS)	$r=0.30^*$ ($p=0.011$)	$r=-0.26^*$ ($p=0.039$)	$r=0.04$ (NS)	$r=-0.15$ (NS)	$r=0.03$ (NS)	$r=0.16$ (NS)
Grip Strength: Left arm	$r=-0.18$ (NS)	$r=-0.34^*$ ($p=0.004$)	$r=-0.40^*$ ($p<0.001$)	$r=0.43^*$ ($p<0.001$)	$r=-0.08$ (NS)	$r=0.35^*$ ($p=0.003$)	$r=-0.10$ (NS)	$r=-0.19$ (NS)
Timed Up and Go	$r=-0.50$ (NS)	$r=-0.10$ (NS)	$r=-0.07$ (NS)	$r=0.11$ (NS)	$r=-0.02$ (NS)	$r=0.11$ (NS)	$r=-0.07$ (NS)	$r=-0.14$ (NS)

Sit to Stands	r= -0.05 (NS)	r= 0.03 (NS)	r= 0.02 (NS)	r= -0.03 (NS)	r= -0.08 (NS)	r= -0.01 (NS)	r= -0.10 (NS)	r= -0.01 (NS)
<u>Physical Fitness Tests</u>								
Bicep Curls	r= -0.04 (NS)	r= -0.03 (NS)	r= -0.14 (NS)	r= 0.09 (NS)	r= -0.11 (NS)	r= 0.08 (NS)	r= -0.13 (NS)	r= -0.05 (NS)
6-Minute Walk Test	r= -0.13 (NS)	r= -0.12 (NS)	r= -0.29* (p=0.003)	r= 0.23 (NS)	r= 0.02 (NS)	r= 0.16 (NS)	r= -0.04 (NS)	r= -0.18 (NS)
<u>Habitual Physical Activity Level</u>								
Total Physical Activity Time	r= -0.20 (NS)	r= -0.08 (NS)	r= -0.20 (NS)	r= -0.17 (NS)	r= -0.25* (p=0.037)	r= 0.23 (NS)	r= -0.21 (NS)	r= -0.27* (p=0.024)
* p≤0.05; *** p<0.001; S.D – Standard Deviation; NS – Not Significant								

2.4.4 Correlations between Functional Ability and Cognitive Performance Tests

There were significant associations between functional ability and cognitive performance outcomes as illustrated in Table 2.4. The strongest correlation was between the right arm grip strength and the number of correct responses on the Stroop task ($r=0.48$, $p<0.001$). Right arm grip strength was also strongly associated with correct responses to average reaction time on the Stroop task ($r=0.42$, $p<0.001$). In addition there was a significant inverse association between right arm grip strength and the number of errors ($r=-0.36$, $p<0.05$). Functional reach was significantly and inversely associated with the number of errors ($r=-0.35$, $p<0.05$), and correct responses in the Stroop task ($r=0.44$, $p<0.05$). The Timed Up and Go test and the sit to stand test did not yield any significant correlations with the cognitive performance components.

2.4.5 Correlations between Cognitive Performance Tests

Associations between the 6-Item Cognitive Impairment test and the Modified Stroop task variables are illustrated in Table 2.4. The strongest associations was seen between the 6-Item Cognitive Impairment test and the number of correct responses on the Stroop task ($r = -0.520$; $p<0.001$) and the correct responses to average reaction time on the Stroop task ($r=-0.48$, $p<0.001$). This suggests that those who perform worse on the 6-Item Cognitive Impairment test produce fewer correct responses on the Modified Stroop task. This was also observed between the 6-Item Cognitive Impairment test and the ratio between standard deviation of the average reaction time of correct responses and the total number of correct responses.

Table 2.5: Regression Model with Correct Responses as dependent variable

(n=70)	b*	Standard Error of b*	b	p value
	Multiple R ² = 0.312	Adjusted R ² = 0.280		
Intercept			2.804	0.887
Age	-0.186	0.102	-0.392	0.074
Right Grip Strength	0.330	0.122	0.450	0.008*
Functional Reach	0.270	0.122	0.407	0.030*
*p < 0.05				

2.4.6 Multiple Regression Analysis to predict the best performance on the novel cognitive Stroop task

A backwards elimination multiple regression analysis was performed to develop a model to best predict the number of correct responses on the Stroop task (Table 2.5). The final model consisted of three variables including: age ($p=0.074$; $b= -0.392$), right arm grip strength ($p=0.008^*$; $b= 0.450$) and functional reach ($p=0.030^*$; $b= 0.407$) as these variables had strong independent correlations with the number of correct response on the Stroop task. This model explained 28% of the variance in performance of the Stroop task. The Timed Up and Go test, sit to stand test, total physical activity time, bicep curls in 30 seconds and 6-minute walk test were not significantly associated with correct responses on the Stroop task.

Similarly, the ratio between correct responses and average reaction time was explained using the same model. Age ($p= 0.051$; $b= -0.0004$), right arm grip strength ($p= 0.015^*$; $b= 0.0004$) and functional reach ($p=0.208$; $b= 0.0002$) were included in the model with right arm grip strength contributing significantly to the entire model. The entire model was able to predict 20% of the variance in performance of the Stroop task ratio between correct response and average reaction.

2.5 Discussion

This study explored relationships between measures of physical fitness, functional ability and cognitive performance in older adults. We hypothesized that a higher level of physical activity, fitness and functional ability would be associated with higher cognitive performance. The data from this study partially supports our hypothesis. We found that functional ability measures such as functional reach, grip strength and dynamic balance were associated with the number of correct responses, mistakes and missed responses on the Stroop task. Our research has shown that individuals with better functional reach scores had fewer incorrect responses during the Stroop task. In addition, we also found a negative association between dynamic balance and the number of correct responses on the Stroop task. This indicates that those individuals with a better dynamic balance score had more correct responses on the Stroop task.

Functional reach and dynamic balance are both proxy measures of balance in older adults (153;154). A decrease in function of the neuro-musculoskeletal system which helps to maintain balance, may increase the likelihood of falls in older adults (95). Holtzer et al. 2007 conducted a study to determine the relationship between cognitive function and falls in 127 older adults (297). Multivariate logistic regressions showed that lower scores on executive attention were associated with the increased risk of recurrent falls in older adults. Similarly, Liu-Ambrose and colleagues conducted a study to determine if executive function is independently associated with balance and mobility in community-dwelling older adults (298). Results showed that cognitive flexibility was independently associated with balance and mobility in community-dwelling older adults after accounting for age, quadriceps strength and physical activity levels. Therefore, low functional ability may be associated with increased cognitive decline (282). In addition, in a study by Liu-Ambrose and colleagues, there were improvements in cognitive performance shown in response to a 6 month intervention involving resistance and balance training in older adults (299). Executive function measured by the Stroop task improved significantly in the resistance and balance group when compared to the control group, post intervention.

Another important finding from our study was that right arm grip strength was positively associated with the number of correct responses on the Stroop task. This may indicate that individuals with greater strength also have better executive function. Our finding is in line with the previous work done in the older adult population. Alfaro-Acha et al. 2006, who measured baseline hand grip strength in older adults (n=2160) and found a significant link between reduced handgrip strength and a decline in cognitive performance over a seven year period (300). The authors reported that individuals with grip strength in the highest quartile maintained greater levels of cognitive function over the seven-year duration. Handgrip strength is considered to be a simple but important measure of functional ability in older adults and decreases with age due to factors such as a loss in muscle mass (57) (sarcopenia) and strength (301). As a result, it has been suggested that low grip strength may be an early indicator of subsequent decline in cognitive performance, regardless of education level and gender (300). Therefore, findings from our study suggests that maintenance of functional ability later in life may not only benefit an individual's functional capacity, but also play a role in attenuating cognitive decline.

The decline in strength leads to a reduced ability to perform daily tasks. In this regard, Goodpaster and colleagues illustrated that regular participation in moderate physical activity can inhibit both age-related loss of muscle strength as well as increases in muscular fat infiltration in older adults (302). This was supported by Buchman et al. who concluded that higher levels of physical activity are linked with a slower rate of strength and motor decline in older adults and therefore allow for better quality of life (283). The maintenance of functional ability over the age of 60 years is important for independence as well as improving activities of daily living such as walking, sitting and change of direction (97). Therefore, the abovementioned studies suggests that individuals who participate in regular physical activity may be able to carry out functional activities of daily living in a more relaxed and safer manner until later years of life. In addition, this may also lead to older adults being able to take care of themselves and live an independent lifestyle for longer.

In contrast, some of our findings did not support our hypothesis. The Timed Up and Go test, sit to stands and bicep curls in 30 seconds did not yield any significant

associations with cognitive performance measures. While a few variables explain a lot of variance in cognitive function, some of the coefficients for individual factors were relatively small. This is in contrast to previous research which has shown associations between the abovementioned tests and cognitive performance (303;304). McGough et al. 2011 illustrated a relationship between the Timed Up and Go test and executive function measured by the Trail Making Test part B and the Stroop Word Colour Test in older adults with mild cognitive impairment (304). These authors concluded that a poorer performance in the Timed Up and Go test was associated with inferior executive function performance on the Trail Making and Stroop Word Colour Test. In another study, Ferreira et al. 2015 illustrated the association between functional performance and executive cognitive functions in older adults which included individuals with low ankle-brachial index (303). Correlation analysis from the study showed significant associations between the 6-minute walk test and global cognition, working memory, attention span, processing speed and inhibitory control. The 6-minute walk test is often used in older adult research to assess cardiorespiratory fitness. Contrasting results between our study and Ferreira et al. 2015 could be due to our study having a high functioning study sample compared individual's with low ankle-brachial index which could impact cardiorespiratory fitness. Previous work by Kramer and colleagues have shown that improved cardiorespiratory is positively associated with cognition (305;306) Similarly, other studies have also shown associations between functional ability measured by the bicep curls in 30 seconds test and the sit to stand test and cognitive performance however, this was not shown in our research.

In the present study we also found that habitual levels of physical activity were not associated with grip strength or most of the the Stroop task variables. This could be due to most of the participants (97%) in our study reported meeting the physical activity guidelines of 150 minutes of moderate intensity exercise for most days of the week, suggesting that they are physically active and highly functioning older adults. This is in contrast to Yaffe et al. who showed that habitual levels of physical activity might partly explain the association with cognitive performance (108). Yaffe et al. recruited community-dwelling women without cognitive impairment and physical limitations for the study. Those women with higher baseline levels of self-reported

physical activity measured by distance walked and total energy expenditure per week were unlikely to experience cognitive decline (108). Therefore, the amount of physical activity and exercise engaged in by individuals may impact on one's cognitive performance.

The multiple regression analysis also showed that grip strength, age and functional reach results explained 28% of the variance in the novel Stroop task. The number of errors committed was also positively correlated with the 6-item cognitive impairment test. This may be due to a decline of inhibitory processes with ageing, that would lead to a greater error Stroop effect (307) which could promote a delayed response rate, leading an individual to become impulsive thereby creating more errors. Secondly, the stress and anxiety of performing may elicit mistakes as shown by Renaud and Blondin. (308). This finding may suggest that many attributes are interrelated and may affect more than one domain. Therefore, it could be anticipated that those individuals who are functionally independent may also conserve cognitive function.

We found a significant inverse correlation between the 6-Item cognitive impairment test and the number of correct responses produced on the Stroop task. Our finding of the relationship between the correct responses on the Stroop task and scores on the 6-item Cognitive Impairment test is confirmatory though not the primary objective of the study. We also found an inverse correlation between the correct responses: average reaction time ratio and the 6-item cognitive impairment test. Age-related alterations to the central and peripheral nervous systems cause a delay in simple and choice reaction time as well as alterations of one's capacity to integrate sensory information (58). Slow reaction time may also be connected to the reduced ability of precise control. Therefore, those individuals who are less cognitively impaired may have a faster reaction time and could be more accurate when responding to the stimuli appearing on the screen during the Stroop task than individuals with a higher degree of cognitive impairment. Although age related changes occur during an individual's later years, Grigsby et al concluded that executive functioning is an important determinant of functional status in older adults (309). In addition, Barnes et al identified cardiovascular physical activity to be positively associated with

preservation of cognitive function (107). Therefore, older adults that are physically active may be able to preserve cognitive function later in life.

One of the limitations of this research study was that some participants used a computer for the first time during the Stroop task. This may have impacted on the results obtained, as they may have felt intimidated when completing the test and therefore not given a true indication of cognitive performance. This limitation was addressed by giving each participant one full familiarization trial, and using only the second Stroop task for data analysis. Another limitation was that the results are based on a measurement taken at a single time point and as a result, we can only determine associations between variables and are only able to theorize the direction of the association. Furthermore, due to the individuals in our research study being high functioning and physically active, the sample may have been highly homogeneous in physical fitness and function to find associations in cognitive function. In addition to the limitations mentioned above, our small sample size recruited for the study as well as it being a convenient sample was another limitation to our study.

One of the strengths of this study was that the tests used to assess each domain were well established and recognized. This is also one of few studies investigating cognitive function and functional performance in older adults in low to middle income countries. In addition, the Stroop task used to measure cognitive function in this study has been widely used and recognized in this research field.

In summary, the results of this study showed that measures of physical and functional performance such as grip strength and functional reach were associated with cognitive performance variables on the Stroop task, even in highly functioning, older, South African adults. However, measures such as the Timed Up and Go, sit to stands, bicep curls in 30 seconds and the 6-minute walk test did not yield any associations. This may suggest that maintenance of one's functional ability may also impact on cognitive performance later in life thereby allowing a greater independent lifestyle. Therefore, the next step in this thesis was to identify the feasibility and

association of an acute response of a single physical activity session using IVG with functional ability and cognitive performance in older adults.

**CHAPTER 3: THE RELATIONSHIP BETWEEN PERCEIVED LEVEL
OF DIFFICULTY AND PARTICIPATION IN INTERACTIVE VIDEO
GAMING AMONG OLDER ADULTS: A FORMATIVE RESEARCH
STUDY**

3.1 Introduction

Chapter 2 evaluated the association between fitness, functional and cognitive performance in older adults and found that some measures of fitness and functional performance were associated with cognitive performance. In addition to the associations highlighted in chapter 2, ageing is also associated with physical (57), functional and cognitive (60) changes which can result in a reduced ability to perform activities of daily living and decreased levels of independence (98). According to Statistics South Africa, in terms of literacy, it was found that a higher proportion of older adult women were unable to write their name, read a newspaper in their language, fill in a form and calculate change when compared to elderly men. In terms of functional domains, a higher proportion of elderly women reported experiencing severe difficulty in performing functions such as self-care, remembering and concentrating, walking and climbing, communication, hearing and seeing when compared to elderly men. The most evident difference in the proportion of older men and women's functioning were those of remembering (2%), seeing (1.9%) and walking (1.8%), where women reported far higher levels of severe difficulty in these functions (51). These changes can be attenuated with regular physical activity.

Participation in physical activity helps to maintain and improve musculoskeletal and cardiovascular fitness as well as cognitive function in older adults (310). It is recommended that older adults participate in at least 30 minutes of moderate intensity physical activity on most days of the week (286). However, they often experience physiological and psychological limitations and environmental (311) barriers for regular physical activity. Physiological limitations include reduced muscular strength required for daily activities and reduced mobility that decreases the ability to perform many weight bearing tasks (312). These physiological limitations may be associated with lack of enjoyment for physical activity and psychological barriers including the fear of falling (313-315). Environmental barriers for regular physical activity include unsafe neighborhoods, lack of community resources such as parks and walkways and inconsistent weather (311;316). It is therefore important to find physical activities that are accessible, enjoyable and safe for the older adult population.

Previous research on the effectiveness of regular physical activity, using more conventional exercise interventions such as aerobic training, strengthening and balance exercises, found favorable results on both physical and mental functional ability (317). Indeed, the literature suggests that moderate levels of physical activity and exercise interventions lasting 3 to 6 months may have positive effects on several cognitive processes in older adults (305;306). Many of these interventions are group-based and led by an instructor, performed for one hour three times a week.

More recently, computer-generated interactive video games are being used to promote physical activity in exercise interventions (318). IVG is a term used to define video gaming that requires human interaction and physical exertion to play the game. (319). IVG allows the individual to increase their energy expenditure while participating in games that were traditionally sedentary in nature (251). Because interactive video games are played in the home, it could be one of the strategies to overcome environmental and logistical barriers to physical activity in older adults (250). The effectiveness of an IVG intervention on energy expenditure was investigated in older adults aged 65 years and older. Individuals participated in 9 different interactive video games simulating different sports (Nintendo Wii and X-box Kinect sport) twice a week for one hour per a session in a standing and seated position. There was no significant difference in energy expenditure between IVG played while standing or seated (251). However, energy expenditure was significantly greater for all game conditions when compared to rest. IVG also produces a higher energy consumption and heart rate than activities such as handheld gaming and watching television (320).

In addition, Agmon et al.2011 reported improvements in balance using the Berg Balance scale after 3 months of balance IVG for 30 minutes per session 3 times a week (321). Apart from balance and energy expenditure, a 17% improvement in leg muscle strength was observed after 10 weeks of IVG compared to a 1% decrease in the control (322). Therefore, IVG has been shown to be functionally beneficial in terms of improvements in balance and muscle strength (321;322). IVG has also recently been shown to improve parameters of cognition such as executive function

and processing speed (260). In addition, most studies that have utilized IVG as an intervention focused more on sports or exercise-based games with very little research being focused other types of stimulating interactive video games (273;320-322).

Although research in the area of IVG is growing, there are still some gaps in knowledge such as heart rate response to IVG, perceived difficulty of playing interactive video games and its association to functional and cognitive performance in older adults. Some studies have shown that interactive video gaming can be compared to conventional exercise in terms of physiological variables such as heart rate intensity and systolic blood pressure in young and older adults (276;323). A study by da Silva et al. 2021 with young adults showed that heart rate increased while playing Nintendo Wii active games and systolic blood pressure decreased post exercise. These changes were comparable to conventional exercise; however, the study was conducted in young adults (323). The Nintendo Wii utilizes an interactive hand-held device during gaming which may limit the physical on screen performance as the individuals entire body movement is not picked up by the hand-held device whereas the Kinect sensor device which picks up the participants' entire body and movement. Another study conducted by Yu et al. 2020 found that 10 weeks of playing the X-box 360 Kinect with alternating Kinect Sport and Kinect Adventure games weekly for 3 times a week yielded an average HRR of 50.7% equating to moderate intensity exercise in a small sample of Taiwanese adults (276). Furthermore, in low-to-middle income countries such as South Africa, the lack of necessary resources such as heart rate monitors to measure exercise intensity magnify the need to assess the intensity of such games for older adults to provide some indication of the level of exercise that an individual is partaking in. IVG may also overcome other barriers to physical activity that older adults may encounter on a daily basis. These barriers include unpredictable weather conditions, lack of public resources such as parks and community outdoor gym facilities as well as unsafe neighborhoods, especially in low-to-middle income countries like South Africa. Apart from the barriers to physical activity mentioned, participation in IVG will also help improve social well-being and reduce loneliness by allowing older adults to play and enjoy the games with friends and family (324).

To our knowledge, few studies evaluated the heart rate response to participating in IVG and its perceived difficulty of participating. Therefore, the aim of this formative research study was to determine the heart rate intensity during an IVG session. The second aim was to investigate whether the participants' perceived level of difficulty for the X-box Kinect Adventure games was related to their functional and cognitive performance. In addition, a secondary objective of the study was to compare functional ability and cognitive performance between men and women. We hypothesized that IVG will increase heart rate equivalent to moderate intensity physical activity. In addition, we hypothesized that those individuals with lower functional and cognitive performance would perceive the IVG as more difficult.

3.2 Methods

3.2.1 Study Design and Participants

This was a formative research study in which a convenience sample of twenty participants older than 65 years were recruited. Participants were community dwelling, from both low and high socio-economic neighborhoods and living independently. Participants were recruited via advertisement posters and flyers placed around the neighborhood which included places such as gyms (Sports Science Institute of South Africa), community noticeboards, shopping centers and day clinics as well as by word of mouth.

Participants who were identified as being at high risk for coronary artery disease according to the American College of Sports Medicine criteria (286), required consent from a medical doctor prior to participation. High risk individuals were identified by answering 'Yes' to any of the seven questions from the Physical Activity Readiness Questionnaire (PAR-Q) (286).

The exclusion criteria included any previously diagnosed stroke, myocardial infarction or uncontrolled disease such as hypertension or diabetes. Those with limited mobility, defined as requiring the use of assistive walking devices, were ineligible to participate.

Ethical approval for this research study was obtained from the Research and Ethics Committee of the Faculty of Health Sciences, from the University of Cape Town.

3.2.2 Clinical Measurements

3.2.2.1 Anthropometry

Participants height, weight, body mass index and waist circumference were measured using the same procedures as described in chapter 2, methods section 2.2.2.3 on page 136 (286).

3.2.3 Functional Ability Tests

Participant's functional ability was measured using the same procedures and selected functional tests described in chapter 2, methods section 2.2.4 on pages 137 - 138. These selected tests were Dynamic balance (154), Timed Up and Go test (156), Grip strength (172) and the Functional reach test (153).

3.2.4 Cognitive Performance Tests

Participants cognitive performance was measured using the Modified Stroop task as described in chapter 2, methods section 2.2.5.2 on page 139 (183;186).

3.2.5 Preparation for Interactive Video Gaming

Once all the above tests were completed, the participants then commenced with the IVG session. Participants were requested to wear a heart rate monitor in order to measure the intensity of the activity while playing the game.

3.2.5.1 Video Game Session

Participants were requested to play the Kinect Adventures game, which is part of the X-Box Kinect video game console. Kinect Adventures is made up of 5 different games namely: 20000 Leaks, River Rush, Rally Ball, Reflex Ridge and Halo Popper. Each game is explained in more detail in table 3.1.

Table 3.1: Description of Interactive Video Games

Name	Fitness / functional measure required	Brief Description	Game Category
20000 Leaks	Balance and Flexibility	20000 Leaks requires movements using arms, hands, legs and feet in all directions to plug water leaks created by fish at the bottom of the ocean.	Balance-Flexibility game
River Rush	Balance and Agility	This game requires the individual to control a raft by moving side to side or jumping while dodging obstacles and collecting pins	Balance-Agility game
Rally Ball	Balance, coordination and agility	Hit as many blocks as possible which are placed in front of the participant continuously as the ball bounces back off the blocks at a fast pace in various directions. Any body part may be used.	Balance-Agility game
Reflex Ridge	Balance, agility and minimal lower body strength	This game requires the individuals to dodge obstacles and	Balance-Agility game

		collect pins while travelling on a railway line. Moving side to side, jumping and bending are the most important movements.	
Halo Popper	Flexibility and agility	The aim of this game is to pop bubbles that are floating in the air. Individuals may use any body part to pop the bubbles. To fly up, the participant must flap their arms as if they are wings, to move left or right the participant needs to step in the desired direction and to come down they need to keep their arms at their sides.	Flexibility-Agility game

All games require the individual to use different body movements to try and achieve the respective targets and goals.

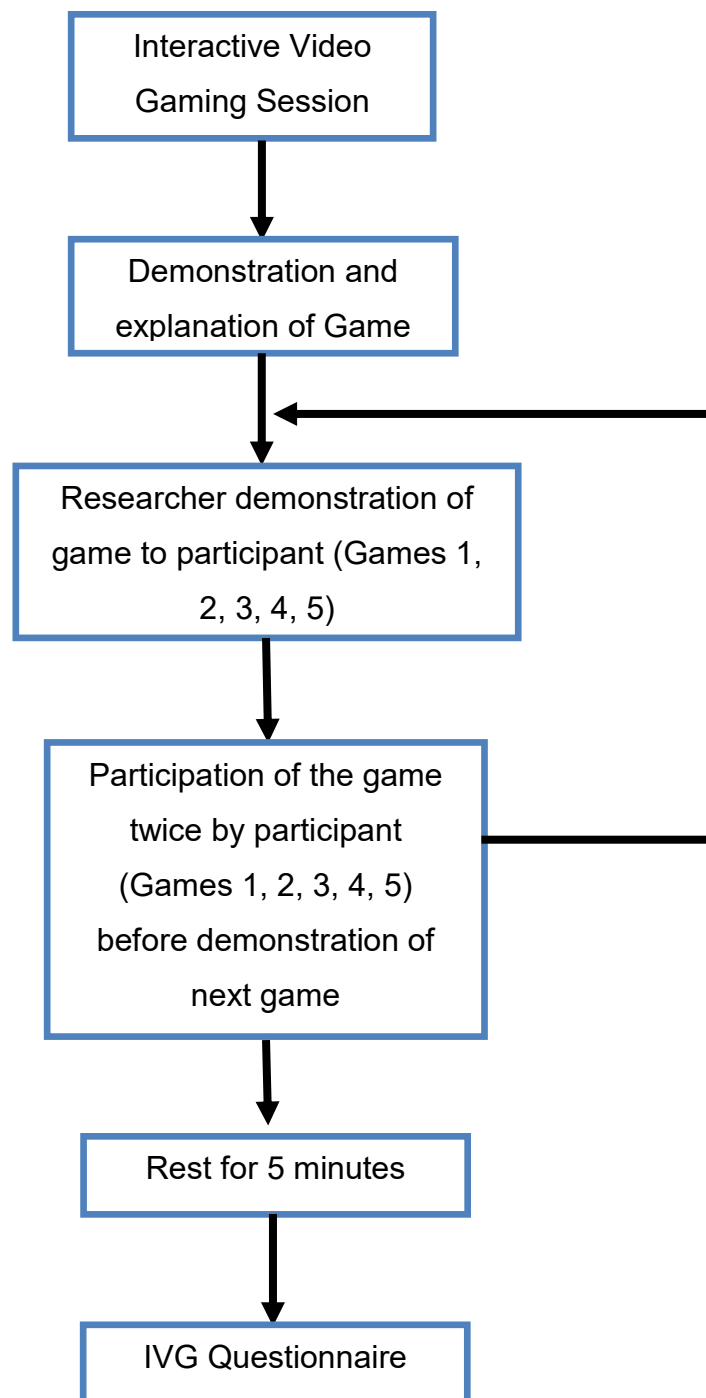
The IVG session started with the researcher demonstrating each of the games. After the explanation and demonstration, the participant was given the opportunity to play each game twice (Figure 3.1). The order of play for each of the 5 games was randomized for each participant. Each game had 3 progression levels: bronze, silver and gold levels. Progression from one level to the next was based on achieving a

specific score in the previous level according to pre-determined X-box Kinect game requirements. Although progression from one level to the next was possible for each game, participants only played the bronze level for each game to ensure the well-being and safety for all participants.

The participant's heart rate was recorded during and after each game. Heart rate was recorded to calculate the intensity of the session and to ensure that the participant's did not exceed their age predicted maximum heart rate. After each game, the participants were asked to sit down while recovery heart rate was recorded at one and two minutes. The researcher used this recovery time to explain the subsequent game and once the participant's heart rate returned to near resting values, they started playing the next round of games.

Participants played each game alone and were required to navigate from one game to the next game, as well as change settings and levels within a particular game if required. Playing time was between 5-7 minutes per a game and the total IVG session, including breaks, was between 35-55 minutes.

Figure 3.1: Flowchart Outlining IVG Session



3.2.5.2 Questionnaire

After the participants completed all five interactive video games, they were asked to complete a questionnaire in which they reported on their experiences during the gaming session. The questionnaire completed by each participant after the session was developed particularly for this study. Difficulty of the game was defined as the degree of challenge experienced by participant for each game. They reported on their perceived level of difficulty for each of the games using a Likert scale ranging from 1 to 6 (1 = Extreme Difficulty and 6 = Extremely Easy). A total difficulty score was calculated by summing the likert scale scores for each of the 5 games. Thus the maximum score that could be obtained was 30 and a minimum score of 5. The total difficulty scores were then divided into tertiles according to high, moderate and low perceived difficulty levels.

In addition, participants were asked to rank each of the 5 games according to how much they enjoyed playing the game, with 1 = most enjoyable game and 5 = least enjoyable game. A checklist was provided for participants to indicate possible reasons for future participation in interactive video games. The following reasons were included in the checklist: 1) Fun and Enjoyment; 2) Escapism (time away from work and family demands); 3) Stress reduction and relaxation; 4) Feelings of competitiveness and achievement; 5) Improved physical well-being; 6) None. Participants were asked to choose up to 3 of the above-mentioned options. Lastly, participants also reported on whether they had played any IVG prior to the research study.

3.3 Statistical Analysis

STATISTICA 10 software package was used for all the analyses (Stasoft, Inc., Tulsa OK, USA). Descriptive statistics were used to calculate the mean and standard deviation for the participant characteristics, heart rate, functional ability tests and cognitive performance tests. Data that were not normally distributed were log transformed. T-Tests were used to determine any significant differences between men and women.

Participants were divided into tertiles according to their self-reported gaming difficulty scores. One way Analysis of Variance (ANOVA) was used to compare average heart rate, functional performance, cognitive function and enjoyment scores across the tertiles for difficulty. Bonferroni post-hoc analysis were used to determine significant within group differences for non-dominant hand grip strength, correct responses on the Stroop task and average heart rate of the IVG session. The Kruskal-Wallis post-hoc analysis for non-parametric data was used to determine significant within group differences for enjoyment of IVG.

Frequency tables were used to determine the number of participants that previously participated in IVG, reasons for future participation as well as how many of them would recommend IVG to other people of a similar age.

3.4 Results

Table 3.2: Participant Characteristics (Data shown as mean $\pm$ Standard deviation)

	Total (n=20)	Men (n=11)	Women (n=9)
Age (Years)	70.5 $\pm$ 5.5	71.6 $\pm$ 6.6	69.0 $\pm$ 3.5
Height (m)	1.7 $\pm$ 0.1*	1.7 $\pm$ 0.1	1.6 $\pm$ 0.1
Body Mass Index (kg.m ²)	26.6 $\pm$ 3.4	26.8 $\pm$ 3.9	26.4 $\pm$ 3.2
Waist Circumference (cm)	90.5 $\pm$ 11.1*	95.6 $\pm$ 10.5	84.1 $\pm$ 8.6
* - Significant gender differences $p < 0.05$			

3.4.1 Participant Characteristics

Twenty older adults between the age of 65 years and 87 years (mean age 70.5 years $\pm$ 5.5) volunteered to participate. The men were significantly taller and had larger waist circumference than women (Table 3.2). However, Body Mass Index was similar for men and women, with 55% of the total sample being classified as either overweight or obese.

Table 3.3: Heart rate response for each of the games (Data shown as mean $\pm$ Standard deviation)

Game Category	Balance-Flexibility	Balance-Agility	Balance-Agility	Balance-Agility	Flexibility-Agility
Game Name	<i>20000 Leaks</i>	<i>River Rush</i>	<i>Rally ball</i>	<i>Reflex Ridge</i>	<i>Halo Popper</i>
Peak H.R (bpm)	91.3 $\pm$ 13.2	101.1 $\pm$ 19.0	99.0 $\pm$ 17.0	97.7 $\pm$ 13.3	97.6 $\pm$ 15.5
Ave. H.R(bpm)	82.6 $\pm$ 12.3	87.2 $\pm$ 15.5	88.0 $\pm$ 14.4	86.0 $\pm$ 13.8	85.3 $\pm$ 13.6
Ave.H.R% of Max H.R	55.2% $\pm$ 7.9	58.2% $\pm$ 9.8	58.7% $\pm$ 8.9	57.4% $\pm$ 8.7	56.9% $\pm$ 8.8
Rec. H.R 1 Minute (bpm)	77.1 $\pm$ 12.3	81.1 $\pm$ 15.5	88.8 $\pm$ 16.8	89.1 $\pm$ 15.7	92.2 $\pm$ 17.3
Rec. H.R 2 Minute (bpm)	72.0 $\pm$ 11.1	78.9 $\pm$ 13.6	82.7 $\pm$ 15.7	82.0 $\pm$ 12.1	90.7 $\pm$ 16.8
Legend: H.R = Heart Rate; Ave. = Average; bpm = beats per minute; Rec. = Recovery					

3.4.2 Heart rate responses for IVG

Table 3.3 presents the heart rate response for each of the interactive video games. The mean resting heart rate before the gaming session was 73.4 bpm. All 5 games had comparable peak heart rates that ranged between 91 and 101 bpm. The average heart rate for the entire gaming session was 57% of the age-predicted heart rate maximum and the average heart rate for each game ranged between 82 and 88 bpm. The average heart rate percentage of the maximum heart rate ranged between 55% and 59% for the various games.

Table 3.4: Functional Ability and Cognitive Performance Results

(Data shown as mean $\pm$ Standard deviation)

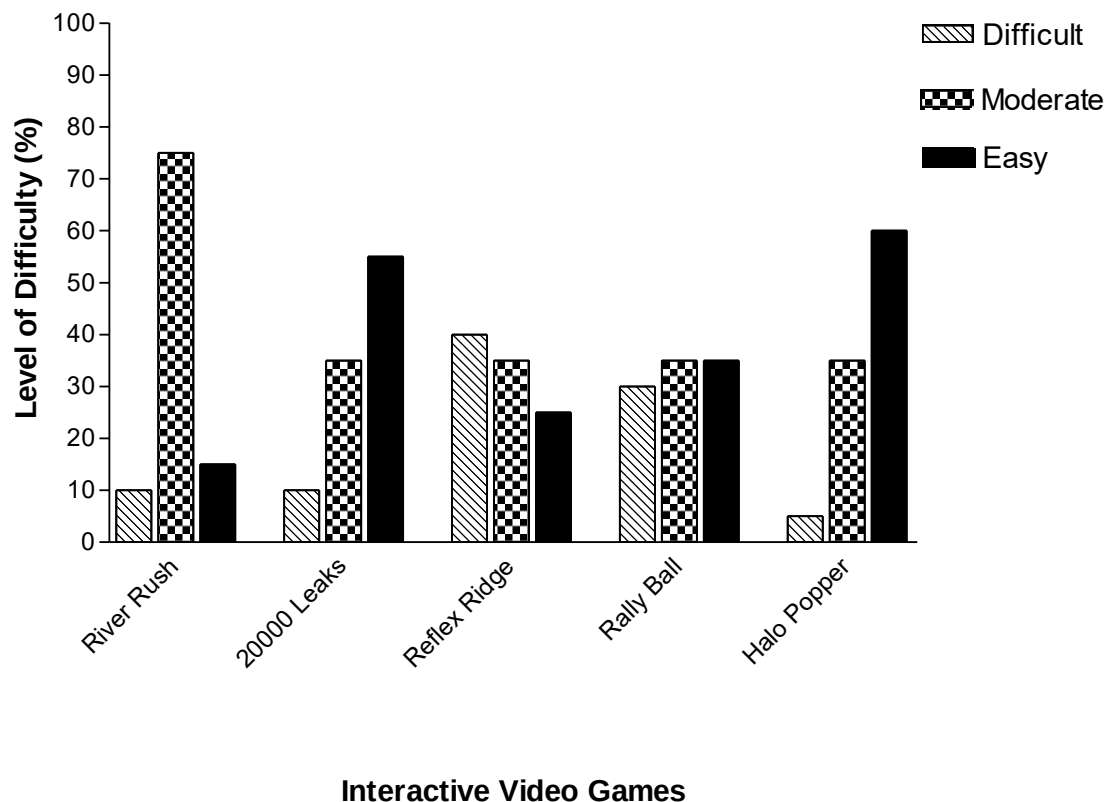
Test	Total (n=20)
Functional Ability:	
Dynamic Balance: 6 Steps (Seconds)	5.9 $\pm$ 1.9
Timed Up and Go (Seconds)	7.4 $\pm$ 3.2
Grip Strength: Dominant Hand (kg)	27.9 $\pm$ 5.8*
Grip Strength: Non-Dominant Hand (kg)	26.2 $\pm$ 6.9*
Functional Reach (cm)	84.4 $\pm$ 6.1
Cognitive Performance:	
Modified Stroop task:	
Mistakes (Number)	5.9 $\pm$ 5.1
Missed Responses (Number)	1.8 $\pm$ 3.4
Average Reaction Time of Correct Responses (m.s)	1715.8 $\pm$ 312.3
Correct Responses (Number)	26.1 $\pm$ 5.1
* - Significant gender differences $p < 0.05$	

3.4.3 Functional Ability and Cognitive Performance results

Participants had varying levels of physical fitness, which was determined using the 6-minute walk test. The men were significantly stronger than women evidenced by the higher Grip Strength for the dominant arm (31.58kg $\pm$ 4.98 versus 23.36kg $\pm$ 2.73, $p = 0.0003$) and non-dominant arm (30.60kg $\pm$ 5.39 versus 20.76kg $\pm$ 4.00, $p =$

0.0003) (Table 3.4). Besides grip strength for the dominant and non-dominant arm, there were no other significant differences between gender groups for the Functional Reach test, Timed Up and Go and Dynamic balance, suggesting that the men and women had similar functional ability. Similarly, cognitive performance was not significantly different between men and women.

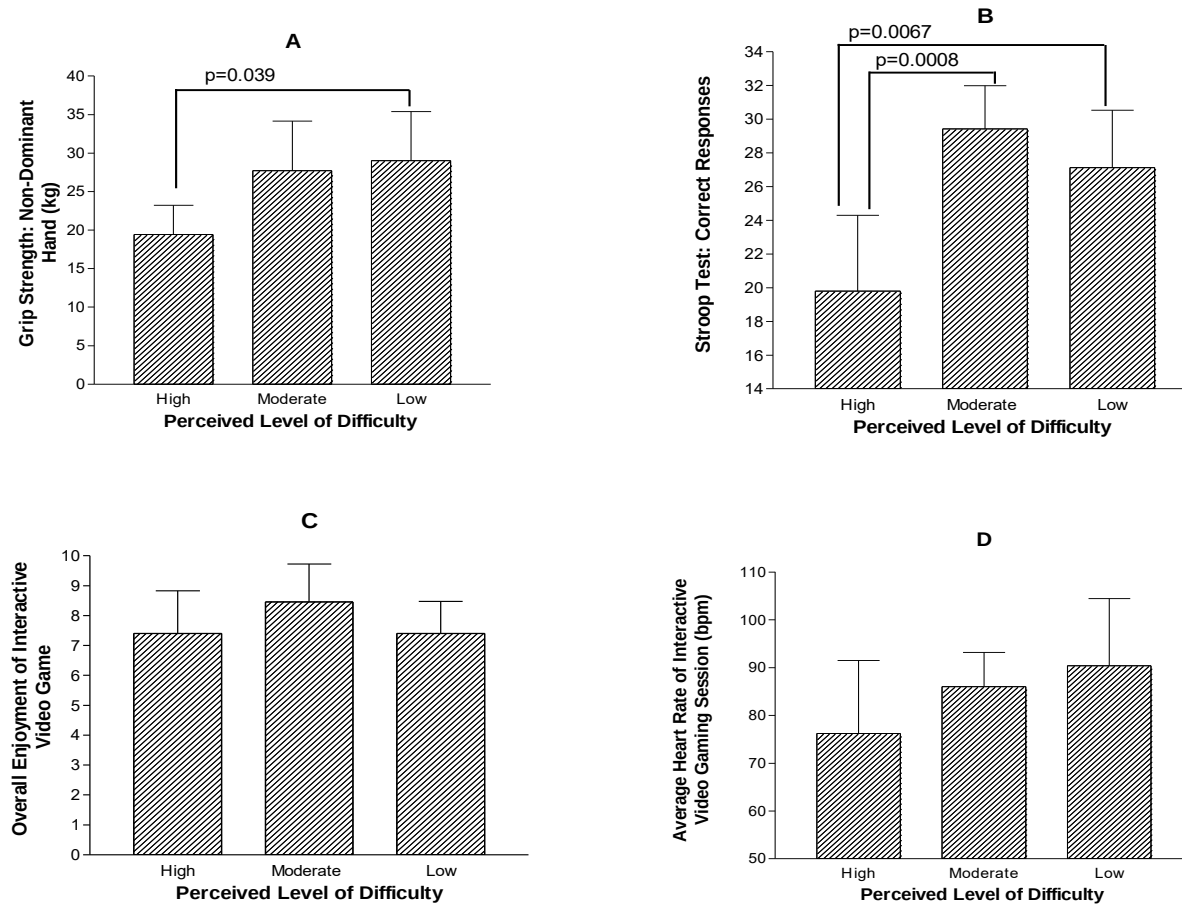
Figure 3.2: Perceived Difficulty of Interactive Video Games



3.4.4 Perceived Difficulty of Interactive Video Games

The percentage of participants that found each game easy, moderate or difficult during the video gaming session is illustrated in Figure 3.2. The game that required both flexibility and agility (Halo Popper 60%) was reported as the easiest game followed by games requiring balance and flexibility (20000 Leaks 55%) and balance and agility (Rally Ball 35%). The most difficult games were those that required both balance and agility which included Reflex Ridge (40%), followed by Rally Ball (30%).

Figure 3.3: The relationship between Perceived Level of Difficulty and (A) Non-Dominant hand grip strength, (B) Correct responses on the Stroop Task, (C) Enjoyment of the Interactive video session, and (D) Average Heart Rate of the Video gaming session.



3.4.5 Perceived Difficulty and Cognitive and Functional Outcomes

Figure 3.3A represents the association between the Perceived levels of Difficulty and non-dominant arm grip strength. Individuals who had lower grip strength scores (19.5kg) had a significantly higher perceived level of difficulty for the gaming session ($p=0.039$) than those individuals with higher grip strength scores (29.0kg). This was only significant for grip strength on the non-dominant hand.

Those individuals with lower cognitive scores on the Stroop task had significantly higher perceived level of difficulty for the gaming session than those individuals with better scores on the Stroop task. The overall enjoyment (Figure 3.3C) and the average heart rate of the video gaming session (Figure 3.3D) did not appear to be influenced by the perceived levels of difficulty of the video gaming session.

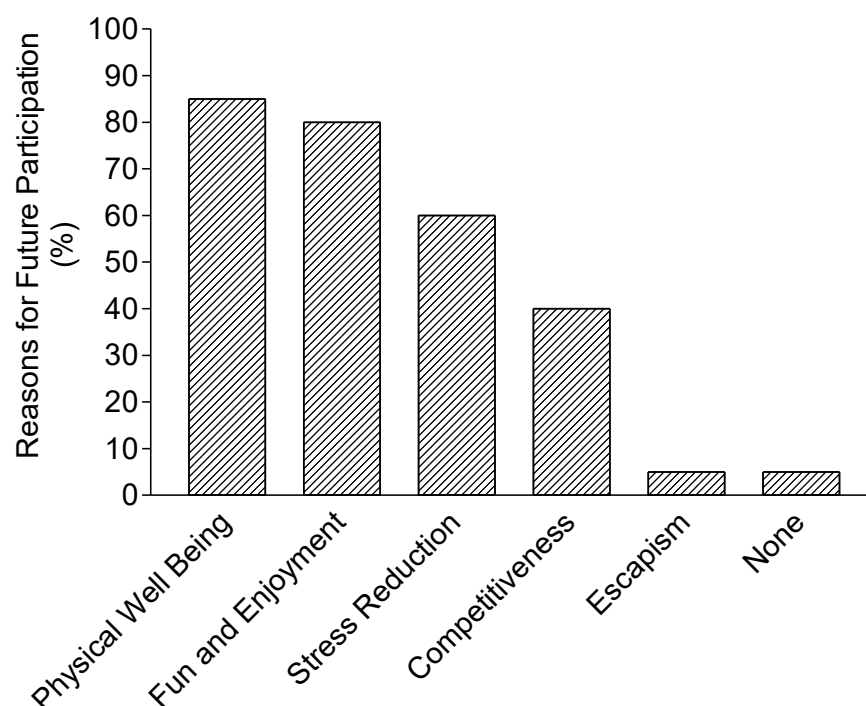
Table 3.5: Enjoyment of Interactive Video Gaming

Game Category	Game	Most Enjoyable	Least Enjoyable
		N (%)	N (%)
Balance-Agility	River Rush	6 (30)	0 (0)
Balance-Flexibility	20000 Leaks	5 (25)	3 (15)
Balance-Agility	Reflex Ridge	3 (15)	8 (40)
Balance-Agility	Rally Ball	3 (15)	5 (25)
Flexibility-Agility	Halo Popper	3 (15)	4 (20)

3.4.6 Enjoyment and Difficulty of Interactive Video Gaming

Nearly all of the participants indicated that this was the first time that they participated in IVG. Individuals rated the 'River Rush' game as the most popular and enjoyable game and the 'Reflex Ridge' game as the least enjoyable game (Table 3.5).

Figure 3.4: Reasons for Future Participation



3.4.7 Reasons for Future Participation in Interactive Video Gaming

Figure 3.4 illustrates the reasons for future participation in IVG. Improved Physical Well Being (85%) was the most common reason for future participation. Fun and Enjoyment (80%) was regarded as the second most common reason for future participation followed by Stress Reduction (60%) and Competitiveness (40%). Only 5% (n=1) indicated that they would not engage in IVG in the future.

3.5 Discussion

The aim of this formative research study was to determine the heart rate responses for each game during the IVG session. In addition, we investigated whether the participants' perceived level of difficulty for the X-box 360 Kinect Adventure games was related to their functional ability and cognitive performance. We hypothesized that those individuals with lower functional and cognitive performance would perceive the IVG as more difficult.

The first important finding of this study was that the average heart rate for the entire IVG session, 57% of age-predicted heart rate maximum, represented physical activity of a moderate intensity. This study was compared to a study conducted by Graves et al.2010 who conducted a three arm intervention program which included handheld inactive video gaming, brisk treadmill walking and the Nintendo Wii Fit as a form of physical activity (320). Both study populations had similar average heart rates during the IVG equating to ~ 57% of maximum heart rate. However, when the IVG heart rate intensity from this study was compared to the brisk treadmill walking intensity, brisk treadmill walking was seen to be higher in intensity by 5% (320). IVG has been shown to be in line with physical activity recommendations for older adults in order to achieve health benefits (286). This suggests that IVG can also be seen as a form of moderate intensity physical exercise. In addition, IVG was compared to an alternative physical activity such as Tai Chi, both IVG and Tai Chi produced similar heart rate intensities. Li et al.2001 reviewed nine studies that assessed the cardiovascular response to Tai Chi (325). It was found that these studies resulted in similar heart rate responses that were less than 60% of individual's heart rate maximum equating Tai Chi to also be considered as a moderate form of exercise.

Our second finding was that participants who had significantly fewer correct responses on the Stroop task also reported higher perceived levels of difficulty with the IVG. Previous research used the Stroop task as a performance measure in different age groups to assess individual's selective attention and response inhibition (308;326;327). As individuals age, adaptations take place in the central and peripheral nervous system that cause simple and choice reaction time to slow down, leading to a reduced capacity to integrate information (58). It is likely that ageing causes a slower reaction time to a stimulus which could cause confusion therefore leading to a higher number of mistakes than a person who has a faster reaction time and therefore more time to respond accurately and correctly to a stimulus of the same magnitude. Furthermore, those participants that performed significantly worse on the Stroop task and reported higher levels of perceived difficulty with IVG, may also suggest that people with lower cognitive function might require more instructions prior to participation. The amount of instructions given to participants before commencing IVG may play an important role in how they react to the games,

especially considering many of them had played IVG for the first time. While the ageing process may lead to a reduced capacity to integrate information, a study conducted by Baker et al. 2010 suggested that physical activity may improve executive control processes, especially in individuals with a high risk of cognitive decline (328). Cognitive performance is degraded when processing speed is slow because relevant operations cannot successfully be executed due to limited time (329). However, studies have shown that participation in physical activity can improve cognitive measures such as reaction time, attention and executive control (107;108). Therefore, due to IVG being a moderate form of physical activity, continuous participation in IVG may have positive cognitive benefits for older adults.

Similarly, those individuals who had significantly lower grip strength scores on the non-dominant arm also found the IVG session more difficult than those who rated the games as easier. Handgrip strength is considered to be a simple but important measure of functional ability in older adults and decreases as one gets older due to factors such as a loss in muscle mass (57) and strength (301). A possible mechanism for this relationship with ageing can be characterized by a general time-dependent reduction in physiological function of major systems (330). Changes that can be observed with ageing include a reduced capacity to utilize oxygen, deterioration of the nervous system through decrease in width, form and rate of conduction potential leading to a slow reaction and processing time as well as a reduction in muscle fiber diameter to produce strength (330). Ageing of the nervous system is seen by gradual changes in cognitive and motor function (59). This was supported by Salthouse et al. 1996 who showed that a slow processing time was related to a reduced cognitive function (329).

Our data shows that 95% of the participants indicated that they would participate in IVG in the future. Perceived difficulty was not associated with the overall enjoyment and average heart rate of the gaming session, even among the participants who reported higher perceived levels of difficulty. Participants who perceived the gaming session as difficult were still able to participate at a heart rate intensity and enjoyment level similar to those that found the gaming session easier. In addition, although participants rated River Rush as the most enjoyable game and Reflex

Ridge as the least enjoyable, both games produced similar heart rates that equated to moderate intensity physical activity. This is important because irrespective of the enjoyment level of each game, peak and average heart rate responses were similar indicating that each game on its own can be played at a moderate intensity level. Essentially, older adults who choose to partake in IVG in the future can decide which game they find enjoyable and participate in that particular game and still acquire the important physiological responses that is associated with good health and physical well-being. Furthermore, participants indicated that they would participate in IVG in the future as it improved their physical well-being, was fun and enjoyable and allowed for stress reduction from work. This is in line with work conducted by Mejia-Downs and colleagues who also found IVG to improve individual's health and fitness, as well as bring about fun and enjoyment, reduce stress after work, escapism and increase physical well-being (331). Graves et al. 2010 reported that older adults reported greater levels of enjoyment when playing Nintendo Wii (except Wii Yoga) compared to traditional handheld gaming (320). This suggests that older adults may participate in IVG in a safe and controlled manner facilitating social, health and personal benefits while enjoying themselves.

One of the strengths of this study was that the Stroop task used to measure cognitive performance is well established and recognized in research of older adults. This study is also the first of its kind in the South African older adult population determining heart rate response to IVG. By understanding the heart rate intensity of the IVG games, it will allow older adults to participate in an exciting and fun form of physical activity at an intensity whereby they can gain health benefits in the comfort and safety of their own residence. This may help reduce the barriers to physical activity that older adults could encounter on a daily basis. Unpredictable weather conditions, high amounts of air pollution, lack of public resources for physical activity such as parks and public outdoor gyms as well as unsafe communities are among the common barriers to physical activity experienced in low-to-middle income countries such as South Africa. Physical inactivity due to these barriers is also associated with a high strain on health care systems in low-to-middle income countries. In low-to-middle income countries, physical inactivity is a key risk factor that accounts for 80% of non-communicable diseases (332). IVG therefore has the

potential to reduce such barriers to physical activity and improve an individual's health status. Furthermore, apart from physical health benefits, individuals can participate in such interactive games with their family and friends, which will help improve their social well-being and reduce loneliness as previously shown (324). This is also one of the first studies to investigate the relationship of functional and cognitive outcomes in older adults and its association with perceived difficulty of participating in IVG.

A limitation is that some of the participants in our study did not use a computer on a regular basis. This could have influenced performance in the Stroop task results, as the participant might have felt anxious when completing the test. We addressed this limitation by allowing participants a familiarization trial before recording the final results of the test. A second limitation was the small sample size. However, this was a formative research study with the aim of determining whether a larger trial would be beneficial.

Nearly all participants indicated that they would play interactive video games in the future; however, they did represent a convenience sample that initially agreed to participate in the study. Therefore they might be more inclined to participate in future IVG.

In summary, this study has shown that the heart rate response for IVG was equivalent to moderate intensity physical activity for older adults. The heart rate response may suggest that IVG can be used to help older adults meet PA guidelines (286). Some measures of functional and cognitive performance were associated with the perceived difficulty of IVG. Even those who perceived high difficulty enjoyed the games and expressed the interest to play IVG in the future. This indicates that individuals who found the gaming session more difficult were still able to participate at an intensity and enjoyment level similar to those whom found the gaming session easier. Therefore, IVG could be a suitable form of physical activity for older adults with varying levels of ability. There are no other published studies, to the best of our knowledge, exploring the relationship between grip strength and perceived level of difficulty associated with participating in IVG.

In addition, older adults are able to enjoy themselves while meeting physical activity guidelines by participating in IVG that represents a moderate intensity. Furthermore, majority of individuals indicated that they would participate in IVG in the future. Therefore, the next step in this thesis was to determine whether continuous use of IVG may alter physical activity levels in communities as well as the effects IVG may have on functional ability and cognitive performance over a prolonged period of time in cognitively healthy older adults.

**CHAPTER 4: THE EFFICACY OF AN INTERACTIVE VIDEO GAMING
INTERVENTION ON COGNITIVE PERFORMANCE AND
FUNCTIONAL ABILITY IN OLDER ADULTS**

4.1 Introduction

The results presented in chapter 3 demonstrated that IVG represented a moderate intensity physical activity in older adults which was related to some measures of functional ability and cognitive performance. In addition, the perceived level of difficulty of participation in IVG did not affect the intensity of the physical activity. Furthermore, older adults indicated that they had fun and enjoyed the gaming session and would participate in IVG in the future. These findings highlight the ideal opportunity to increase physical activity participation in older adults using IVG as a moderate intensity physical activity.

According to the United States of America's physical activity guidelines, adults should accumulate at least 150 to 300 minutes of moderate intensity, or 75 to 150 minutes of vigorous intensity aerobic physical activity a week or an equivalent combination of moderate-and-vigorous intensity physical activity (333). These guidelines also apply to older adults with the inclusion of multicomponent physical activity that involve balance, mobility and strengthening activities (333). According to the World Health Organization more than a quarter (27.5%) of all adults are insufficiently physically active (334). Nearly half (47%) of South African adults did not meet physical activity guidelines which is more than double of the global average (335).

Physical activity can attenuate the progressive age-related decline in cognitive and functional performance in older adults (328;336). A research study using traditional physical activity interventions showed that 6 months of aerobic exercise 4 times per week improved cognitive performance. The improvements in executive function included selective attention, planning, organizing, inhibition and working memory in older adults with mild cognitive impairment (328). Similarly, a different study reported a significant reduction in cognitive decline after 6 months in participants who completed resistance training, however there were no improvements in those who participated in balance and toning exercises (336).

Because cognitive reserve is not permanent or fixed, it can be altered and enhanced (337;338). Cognitive stimulation can be regarded as engaging in a range of activities aimed at improving general cognitive function and social interaction in a non-specified manner (339). Cognitively stimulating sedentary activities such as reading, crossword puzzles and board and card games, may also attenuate the progressive decline in cognitive performance in older adults (46;241;242;247). Cognitive activities in a structured manner that focuses on concentration, attention, memory, problem solving and learning have shown improvement in cognitive reserve of older adults (339). This may highlight the need for older adults to participate in cognitively stimulating games in a structured program to improve or at least preserve their cognitive function. Observational studies have shown associations between cognitively stimulating sedentary activities and attenuation in cognitive decline among older adults (241;242;247). For example, individuals who played board games regularly had a 15% lower risk of developing dementia than those who did not play (242). This risk reduction was identified after 20 years follow up. Similarly, engaging in cognitive stimulating activities for one or more hours per day is associated with a decreased risk of incident dementia (crude overall incidence rate of 22.6 per 1000 person-years) later in life. This was observed with the participants mean baseline age of 76 years and the average follow up was 6.1 years (241). Most of the research investigating the relationship between cognitively stimulating activities and cognitive decline or risk of dementia has been cohort studies and few included novel physical activity interventions. The effect of a 10 week non-computerized, game-based cognitive intervention on cognitive performance and quality of life was conducted in senior older adults (46). This study showed no significant improvements in cognitive measures after the intervention, however, participants enjoyed playing the various games (46). In 2011, Tesky and colleagues conducted the AKTIVA (Active Cognitive Stimulation – Prevention in the elderly) study to determine the effects of leisure activities on cognitive performance in healthy older adults (249). Individuals were randomized into either one of the two intervention groups (AKTIVA intervention group or AKTIVA plus nutrition and exercise counseling group) or a no-intervention control group. AKTIVA, briefly, is a program that uses cognitive activation through cognitively stimulating leisure activities such as games

and exercise such as role plays, various games, coaching cards, and reading. In addition, information on aging and risk factors, healthy living and coping strategies for aging were also provided over the 8 weekly sessions with two booster sessions after 4 months. Post intervention, both AKTIVA intervention groups showed positive effects on cognitive performance. Older adults over the age of 75 years showed significant improvements in speed of processing measured by the Trial-Making Test version A ($p < 0.05$), while those older adults younger than 75 years of age showed improvements in subjective memory decline measured by the Memory Complaint Questionnaire ($p < 0.05$) (249). These results as well as the results from observational studies may indicate the importance of participating in cognitively stimulating activities, for at least an hour daily, on improving cognitive function later in life.

More recently, the use of IVG to encourage physical activity has become widely available and increasingly popular among older adults (250;251;320;321). IVG requires the use of body movements to control the onscreen character's movement, resulting in increased energy expenditure compared to the more traditional sedentary computer / video games (251). In addition, IVG requires the player to incorporate cognitive skills such as visual-spatial processing, hand-eye or foot-eye coordination and quick reactions. Therefore, it is different from traditional exercise as it not only requires physical skill and ability, but also requires cognitive skills in order to play the game (340).

IVG develops spatial awareness, increases attention span (amount of time an individual can concentrate on task without becoming distracted), improves responses to visual feedback, plan actions, understand spatial constraints and creates a cognitive map of bodily movement in relation to the game (257;341). Previous studies have reported benefits of IVG on cognitive performance in older adults (17;260;261). A study was conducted that used dance video gaming over a 3 month period (24 dance video sessions) in healthy high functioning participants ($n=36$) over the age of 65 years (261). Improvements in self-reported health and cognitive performance measured by the Digit Symbol Substitution test were identified among those that completed all dance video

sessions compared to non-completers. Even though improvements were seen, this was a single group study with no control group for comparison (261). Similarly, Maillot and Perrot.2012 evaluated the effects of Wii sports IVG on cognitive and physical function in older adults (260). The Wii sports group improved significantly more in all executive control measures (Trail-Making test, Stroop Colour Word Interference, Letter Sets test, Matrix Reasoning test and Digit Symbol Substitution test) and processing speed measures (Cancellation test, Number comparison test, The Reaction time test and Plate Tapping test) than in the sedentary control group (260). Although these studies have shown potential benefits of IVG on cognitive performance and aspects of physical function, different outcome measures and interactive consoles and games were utilized.

Although previous research has reported the benefits of IVG, many studies have used different types of interactive gaming consoles and a variety of games. In addition, other studies have used a wide variety of participants such as individuals from low and high socio-economic areas as well as individuals with low and high functional ability. Furthermore, some studies focused solely on determining the effects of interactive gaming on specific outcomes such as cognitive performance, physical function, quality of life and enjoyment.

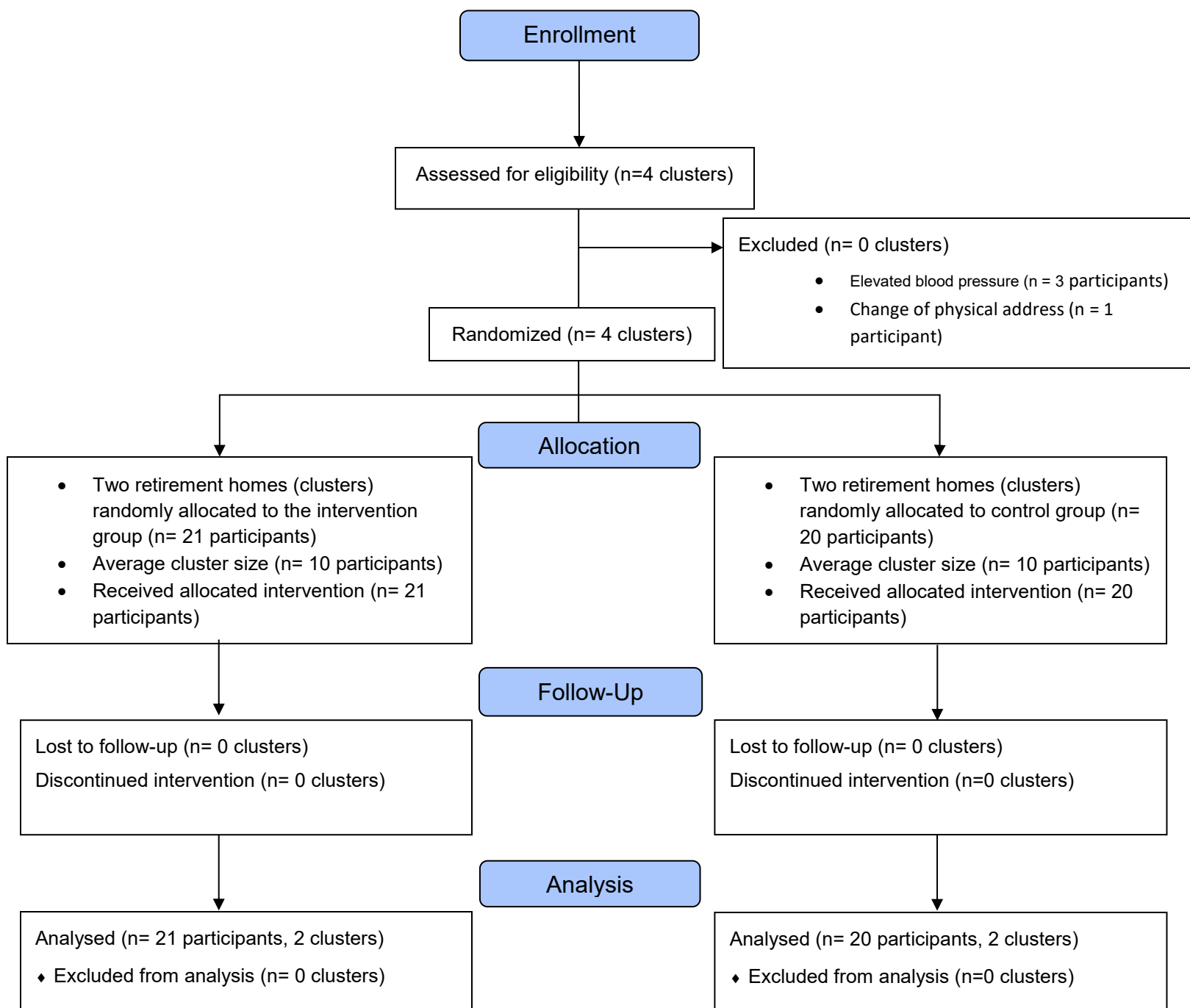
The aim of this research study was to determine the effects of a 12-week active gaming intervention, using the X-box 360 Kinect gaming console compared with cognitively stimulating table games on cognitive performance and functional ability in healthy South African older adults without any known cognitive impairment. We hypothesized that participants in the intervention group would show greater improvements in physical function and cognitive performance compared to those in the table games comparison group.

4.2 Methods

4.2.1 Study Design

Participants were recruited from four different retirement homes in Cape Town, South Africa for this cluster-randomized, exercise intervention study. Retirement homes were randomly allocated to either the intervention group (IVG) or to the comparison group (Cognitively stimulating table games) for 12 weeks. Envelopes with concealed numbers were placed into a hat with numbers 1 and 2 indicating the intervention group, and numbers 3 and 4 allocated to the comparison group. Equal number of homes was allocated to each group and an average of 10 participants was recruited per a home. Figure 4.1 below represents the Cluster Enrollment and Allocation Flowchart. All retirement homes were selected from similarly matched social and economic communities. All groups met for one hour, two days per week, for 12 weeks. Measurements were taken after cluster randomization (baseline) and at the end of the 12-week program. All measurements, IVG sessions (intervention group) and Cognitive stimulating table games (comparison group) were conducted by the same researcher. After the details of the study were explained, participants signed a written informed consent. The research was approved by the University of Cape Town, Human Research Ethics Committee (HREC REF: 220/2011).

Figure 4.1: Cluster Enrollment and Allocation Flowchart



4.2.2 Study Procedures

Participants signed a written informed consent after the details of the study were explained to them. Those who agreed to participate answered a physical activity

readiness questionnaire (PAR-Q) to determine if it was medically safe for them to participate in the research study (342). Eligible participants were invited to the Sports Science Institute of South Africa for baseline measurements.

The baseline assessment included: 1) Completion of the Demographic and Health Status Questionnaire and the Yale Physical Activity Survey; 2) Clinical measurements including height, weight, body mass index, waist circumference and body fat percentage; 3) Cognitive performance tests which included the Six-Item Cognitive Impairment Test (6CIT) and the Modified Stroop task; 4) Physical function tests which included the 6-Minute Walk test, Dynamic Balance, Timed Up and Go test, Grip Strength and Functional Reach.

The first intervention and comparison group session was conducted within a week of baseline testing. A register was used to record weekly attendance and adherence.

4.2.3 Participant Selection Criteria

4.2.3.1 Recruitment

Individuals were recruited from a senior living retirement corporation (Communicare Housing). The housing manager of Communicare Housing and Social Support was contacted via email to set up a meeting to discuss the nature of the research study. Once permission was granted, information posters and flyers detailing the research study were pinned on notice boards around the respective retirement homes inviting residents to attend an information session. A total of 45 residents showed interest and were screened for eligibility. The retirement homes were located in areas of similar socio demographic and economic status. The individuals in each program were blinded to the researchers' hypothesis. The researchers' were not blinded to the group allocation.

4.2.3.2 Inclusion and exclusion criteria

Participants older than 65 years, living in a retirement home without a known diagnosis of cognitive impairment were eligible to participate. Older adults who had been previously diagnosed with a stroke, Parkinson's disease, balance disorders, impaired vision or had uncontrolled conditions such as hypertension (blood pressure more than 160/90 and not on medication) or diabetes (not on medication) were excluded. Those with orthopaedic injuries which inhibited normal locomotion were also excluded.

The Physical Activity Readiness Questionnaire (PAR-Q) was used as the first line of screening for participant's entry into the study (286). Those who were identified as being at an increased risk for coronary artery disease, according to the American College of Sports Medicine criteria (286), required a doctor's consent prior to participation. Participants were classified as increased risk if they had more than two cardiovascular, pulmonary and / or metabolic diseases. The cardiovascular disease risk factors included: family history of death by cardiovascular disease (sudden death by father or first degree relative before 55 years of age and mother or other first degree female before 65 years of age); current smoker or those who quit within the previous 6 months and not participating in at least 30 minutes of moderate intensity physical activity for at least 3 days a week for at least 3 months. In addition, men with a waist circumference of > 102cm and women greater than 88cm; hypertension (blood pressure >140mmHg / 90mmHg on two separate occasions); total cholesterol > 5.18mmol and fasting plasma glucose > 5.50mmol (286).

4.2.3.3 Intervention Group

The intervention was comprised of interactive video games (IVG). The gaming software used for the intervention was the Kinect Adventures game which consisted of 5 games namely: 20000 leaks, River Rush, Rally Ball, Reflex Ridge and Halo Popper. The IVG games were kept the same as those used in chapter 3 due to many of the participants (80%) indicating that they had fun and enjoyment from playing these games. Each

game has previously been described in chapter 3, methods section 3.2.5.1, Table 3.1 on pages 162 – 163.

Sessions took place twice a week at the retirement homes and each participant played the IVG for one hour with the goal of completing 24 sessions over the 3-month period. The participants played 4 out of the 5 games at each session with a partner and two pairs played ($n=4$) per session. The first pair played the game for 15 minutes while the second pair rested after which the roles were reversed. Therefore, each pair played for a total of 30 minutes and had 30 minutes break per session.

Each session was supervised by an exercise physiologist who acted as a ‘spotter’ during the gaming session to minimize the risk of any injury or to help regain balance if needed. The spotter stood slightly behind and between participants during the routine. No adverse incidents, injuries and falls occurred during the 12 weeks.

4.2.3.4 Comparison Group

The comparison group met twice a week at the respective retirement homes and each session lasted one hour with the goal of completing 24 sessions over the 3-month period. Participant’s played cognitively stimulating games such as dominos, Rummikub, card games and board games including Scrabble and chess. A minimum of 10 and maximum of 20 participants attended each session. Up to 5 players were seated per gaming table and a maximum of 4 tables were set up. Participants were allowed to take breaks in between games if a game was completed or if they were waiting for another gaming table to complete their game. These sessions were coordinated and supervised by the researcher.

4.2.4 Measurements

Participant’s demographic, health and physical activity information was assessed using the Demographic and Health Status Questionnaire and Yale Physical Activity Survey (287;288) described in chapter 2, methods section 2.2.2.1 and 2.2.2.2 on page 135 .

4.2.5 Clinical Measurements

4.2.5.1 Anthropometry

Participant's height, weight, body mass index, waist circumference and skinfold thickness to assess body fat were measured using the same procedures as described in chapter 2, methods section 2.2.2.3 on page 136 (286;290). All clinical measurements were conducted at baseline and post intervention.

4.2.6 Cognitive Performance Tests

Participant's cognitive performance was measured using the Six-Item Cognitive Impairment test (6CIT) (193;293) and the Modified Stroop task as described in chapter 2, methods section 2.2.5 on pages 138 – 139 (183;186).

4.2.7 Physical Function Tests

Participant's physical function was measured using the same procedures and selected fitness and functional ability tests described in chapter 2, methods section 2.2.3 and 2.2.4 on pages 136 – 138. These selected tests included the 6-Minute Walk test (291), Dynamic balance (154), Timed Up and Go test (156), Grip strength (172) and the Functional reach test (153).

4.3 Statistical Analysis

STATISTICA 10 software package was used for all the analyses (Stasoft, Inc., Tulsa OK, USA). Data that were not normally distributed were log transformed and presented as medians and interquartile ranges. Descriptive statistics were performed for the intervention and comparison groups separately and the data that were normally distributed were represented as means and standard deviations. Frequency tables were used to determine baseline demographic and health variables percentages. T-tests

were conducted to identify significant differences between groups for baseline demographic and health characteristics.

Analyses of variance for repeated measures (ANOVA) were used to detect differences between groups for changes in continuous variables (cognitive performance and physical function) at baseline and post intervention. All models were adjusted for site level clustering applicable for an experimental cluster-randomized intervention study. The level of significance for all statistical analyses was set as $p < 0.05$. Partial η^2 , defined as the proportion of variance accounted for by an effect and that effect plus its related error variance within an ANOVA study (343), was presented as measures of effect size for each physical and cognitive variable.

The required sample size was determined using G*Power software (Version 3.1.9.2) (344;345). The sample size was determined using a priori calculation (repeated measures, within-between interaction, medium effect size = 0.5, power of 0.80, 2-sided α -error, 2 groups, 2 measurements) based on the California Older Adult Stroop Test (COAST) from a comparable study (346). The California Older Adult Stroop test is a computer-based test tapping the domains of attention, executive function, memory and processing speed which is similar to the domains measured in this study. The required sample size calculated with an additional 20% increase per a group taking into account drop outs was 15 participants per a group.

4.4 Results

4.4.1 Participant Demographic and Health Characteristics at Baseline

There were 25 participants in the intervention group and 20 in the control group at baseline. Four participants from the intervention group were unable to continue after baseline testing (did not participate in any IVG intervention sessions) due to elevated blood pressure readings observed at their routine district hospital visit (3 participants) and a change of address (1 participant). The final number of participants in the

intervention group and comparison group was 21 and 20 participants respectively. Both groups had high attendance rates with all participants completing all sessions.

There were no statistically significant differences between intervention group and comparison group in terms of age, height, waist circumference and body fat percentage at baseline (Table 4.1). However, mean Body Mass Index was significantly higher in the intervention group. Most of the participants in the intervention group were married, whereas most of those in the comparison group were widows. The highest level of formal education achieved for most participants was primary school. Hypertension was the most frequently reported medical condition in both the intervention and comparison group. More than half of the participants were taking medication for their various medical conditions.

Table 4.1: Participant Demographic and Health Characteristics at Baseline

	Total (n=41)	Intervention (n=21)	Comparison (n=20)
Age (Years)	72.7 (±6.6)	72.2 (±7.1)	73.4 (±6.1)
Height (m)	1.6 (±0.1)	1.6 (±0.1)	1.6 (±0.1)
Body Mass Index (kg.m ²)	29.7 (±5.4)*	31.2 (±5.6)	27.8 (±4.8)
Waist Circumference (cm)	91.0 (±11.9)	93.1 (±11.8)	88.5 (±11.9)
Percentage Body Fat (%)	34.8 (±3.7)	35.2 (±3.5)	34.3 (±3.9)
Total Physical Activity per week (Minutes)	1275.7 (714.8)	1161.7 (599.3)	1418.1 (831.4)
Total Energy Expenditure per week (kcal)	4053.2 (2117.0)	3653.1 (1811.5)	4553.4 (2399.8)
Marital Status			
Married	18 (40%)	13 (52%)	5 (25%)
Single	5 (11.1%)	2 (8%)	3 (15%)
Divorced	5 (11.1%)	3 (12%)	2 (10%)
Widowed	17 (37.8%)	7 (28%)	10 (50%)
Highest Level of Education			
Primary School	33 (73.3%)	18 (72%)	15 (75%)
Secondary School	12 (26.7%)	7 (28%)	5 (25%)
Medical Conditions			
Hypertension	25 (55.6%)	14 (56%)	11 (55%)
High Cholesterol	14 (31.1%)	7 (28%)	7 (35%)
Diabetes Mellitus	5 (11.1%)	4 (16%)	1 (5%)

Asthma	5 (11.1%)	4 (16%)	1 (5%)
Peripheral Vascular Disease	1 (2.2%)	0 (0%)	1 (5%)
None	10 (22.2%)	8 (32%)	2 (10%)
<i>Prescribed medication</i>	32 (71.1%)	17 (68%)	15 (75%)
Legend: S.D =Standard Deviation. Values are shown as mean ($\pm$ standard deviation); Marital status, Education and Health status are represented as a number (percentage), * p<0.05			

Table 4.2: Functional Ability Scores at Baseline and 12-week follow up

Variable	Assessment Period	Intervention (n=21)	Comparison (n=20)	Group Effect (p-value)	Time Effect (p-value)	Group by Time Effect (p-value)	Partial eta ²
		Mean (± S.D)	Mean (± S.D)				
Functional Reach Test (cm)	Baseline	71.8 (±7.2)	71.4 (±6.6)	0.276	<0.001*	0.049*	0.0960
	12 Weeks	77.3 (±6.3)	73.3 (±7.8)				
6-Minute Walk Test (m)	Baseline	475.6 (±95.4)	463.5 (±74.8)	0.815	0.015*	0.288	0.0287
	12 Weeks	483.8 (±93.6)	483.8 (±63.2)				
Dynamic 10m Walk Test (s)	Baseline ^a	42.4 (±16.0)	55.8 (±23.4)	0.025*	0.001*	0.587	0.0076
	12 Weeks	37.0 (±11.2)	48.4 (±19.5)				
Timed Up & Go Test (s)	Baseline ^a	7.8 (±2.0)	9.2 (±2.2)	0.013*	<0.001*	0.593	0.0074
	12 Weeks	6.6 (±1.0)	8.2 (±2.1)				
Grip Strength – Left (kg/m²)	Baseline	19.1 (±5.5)	18.3 (±5.7)	0.453	0.150	0.382	0.0197
	12 Weeks	20.3 (±5.1)	18.6 (±5.6)				
Grip Strength – Right (kg/m²)	Baseline	21.2 (±4.9)	19.3 (±5.3)	0.136	0.346	0.130	0.0577
	12 Weeks	22.0 (±5.0)	19.1 (±5.1)				
Legend: S.D =Standard Deviation, Values are shown as mean (± standard deviation), *p<0.05, ^a - Significant Difference between intervention group and comparison group at baseline (p<0.05)							

Table 4.3: Log Transformed Cognitive Performance Scores at Baseline and 12-week follow up

Variable	Assessment Wave	Intervention (n=21)	Comparison (n=20)	Group Effect (p-value)	Time Effect (p-value)	Group by Time Effect (p-value)	Partial eta²
		Median (IQR)	Median (IQR)				
Modified Stroop Task							
Average reaction time of all Correct Responses (m.s)	Baseline ^a	3.18 (3.10-3.23)	3.26 (3.18-3.35)	0.029*	0.106	0.028*	0.1179
	12 Weeks	3.17 (3.12-3.22)	3.15 (3.11-3.26)				
Average reaction time of Correct Colour Words (m.s)	Baseline	3.16 (3.06-3.22)	3.26 (3.21-3.37)	0.084	0.675	0.082	0.0753
	12 Weeks	3.17 (3.10-3.21)	3.17 (3.11-3.24)				
Total Correct Responses (%)	Baseline ^a	1.70 (1.45-1.93)	1.45 (1.42-1.61)	0.027*	<0.001*	0.409	0.0176
	12 Weeks	1.91 (1.80-1.96)	1.76 (1.64-1.87)				
Correct Grey (Neutral) Words (%)	Baseline ^a	1.88 (1.59-2.00)	1.50 (1.13-1.71)	0.024*	<0.001*	0.257	0.0328
	12 Weeks	2.00 (1.88-2.00)	1.95 (1.50-2.00)				
Average reaction time of Correct Grey (Neutral) Words (m.s)	Baseline	3.20 (3.14-3.23)	3.19 (2.88-3.34)	0.428	0.020*	0.367	0.0209
	12 Weeks	3.21 (3.10-3.25)	3.18 (3.10-3.34)				
Correct Colour Words (%)	Baseline	1.71 (1.13-1.93)	1.48 (1.29-1.65)	0.218	<0.001*	0.914	0.0003
	12 Weeks	1.88 (1.74-1.95)	1.76 (1.54-1.86)				
6 Item Cognitive Impairment Test	Baseline	0.48 (0.00-0.85)	0.77 (0.48-1.04)	0.055	<0.001*	0.666	0.0048
	12 Weeks	0.00 (0.00-0.48)	0.48 (0.00-0.83)				
Legend: IQR = Interquartile Range, Log transformed values are shown as median (IQR), *p<0.05; ^a - Significant difference between intervention group and comparison group at baseline (p<0.05).							

4.4.2 Functional Ability Scores at baseline and 12-week follow up

The changes in functional ability scores from baseline to post intervention (12 weeks) are displayed in Table 4.2. The intervention group had significantly better scores for Dynamic Balance and the Timed Up and Go test than the comparison group at baseline. There were no other significant differences between groups at baseline.

The only functional measure that improved significantly over time was the functional reach test in favour of the intervention group. All the other functional measures improved in both groups from baseline to post testing.

4.4.3 Log Transformed Cognitive Performance Scores at baseline and 12-week follow up

The changes in cognitive performance scores from pre to post intervention are shown in Table 4.3. The intervention group had a significantly faster average reaction time of all correct responses on the Modified Stroop task at baseline. However, the comparison group significantly improved their average reaction time of all correct responses on the Stroop task post intervention when compared to the intervention group. There were no other significant differences between groups in cognitive performance variables post intervention.

4.5 Discussion

The aim of this research was to determine the effects of a 12-week active gaming intervention, using the X-box 360 Kinect gaming console compared to table games, on cognitive performance and functional ability in healthy South African older adults, without any known cognitive impairment. We hypothesized that participants in the IVG intervention group will show greater improvements in cognitive performance and functional ability than the comparison group. One of our main findings was Functional Reach improved significantly in the intervention group, compared to no changes in the comparison group. The Functional Reach test is a dynamic test which is used to assess and measure individual's stability as well as balance in older adults (347). As described in Table 1, four out of the five Kinect Adventures games require balance and agility. Some of the movements required when playing the games included stretching the arm forward while maintaining one's balance and not falling forward, which is similar to what is measured in the Functional Reach test.

Our finding on the significant improvement in Functional Reach is in line with Sato et al. 2015, who conducted a study to determine the effects of active gaming (twice a week with the aim of completing 24 sessions) on muscle strength and balance in healthy older adults (274). Sato et al. 2015 found that balance, measured by the Functional Reach test and other measures, improved significantly in the intervention group compared to the control group. Furthermore, Suttanon et al. 2012 demonstrated the effects of 6 months of an individually tailored, home-based exercise program (balance, strengthening and walking) on balance, mobility and reducing falls risk in older adults (348). They showed that the Functional Reach improved significantly in the exercise group compared to the home-based educational control group. Although improvements were seen, Suttanon and colleagues used a traditional exercise intervention which is different to the IVG used in our study and by Sato et al. 2015 (274). This may indicate that IVG interventions result in comparative improvements in balance when compared to traditional exercises interventions.

Another possible reason for improvements in balance is due to participants being required to complete 24 sessions over the 12-week period as Szturm et al. 2011 found significant improvements in balance after just 8 weeks (16 sessions) of an active computer game (349). Significant improvements in the experimental group were identified on measures of the Berg Balance Scale, activities-specific balance confidence scale and the modified clinical test of sensory interaction and balance. This may suggest that our study duration and sessions per a week were adequate to show improvements in balance as our IVG intervention was of a slightly longer duration compared to Szturm et al. Maintaining balance and stability is important especially for older adults as both components are required in daily activities such as standing still and walking. Improvements and maintenance of balance and stability later on in life will decrease the risk of falls, which reduces the risk of injuries such as fractures thereby decreasing functional disability (350;351). There were no significant improvements in any other physical function measures. This could be due to our participants being active high functioning older adults and therefore were less inclined to show improvements in functional measures post intervention.

Cognitive performance improved significantly in the comparison group for the average reaction time of all correct responses measured during the Stroop task post intervention. The Stroop task requires mental flexibility and the ability to inhibit a dominant response therefore providing a measure of cognitive inhibition (178). Our study findings are similar to that of Tesky et al. 2011 who investigated the effects of cognitively stimulating leisure activities such as board and card games on cognitive performance (249). Individuals participated in either one of three interventions: AKTIVA intervention (group 1), AKTIVA intervention plus nutrition and exercise counseling (group 2) or a non-intervention control group (group 3) for 8 weekly sessions. Post intervention, the AKTIVA intervention group (group 1) significantly improved in executive control while the AKTIVA intervention plus group (group 2) showed a trend towards improvement with no changes to the waitlist control (249). Tesky et al. found significant improvements in cognitive performance after 8 weekly 1 hour sessions of cognitively stimulating leisure activities with 2 booster sessions 4 months later. In our study, participants in the comparison group participated in cognitively stimulating table games for 12 weeks and participated in 2 weekly hour

sessions. This is double the amount of weekly intervention contact time compared to Tesky et al. with a 4-week longer intervention period. Therefore, the more time spent playing the table games by our study participants could explain the significant improvements in cognitive performance on variables of the Stroop task. Furthermore, the cognitively stimulating table games used in our study required complex thinking skills and strategies that may have an impact on one's cognitive function. The higher improvement rate in the average reaction times from the comparison group might be due to the participation in the cognitively stimulating games that may have had a positive effect on their executive function and selective attention. Abilities such as planning and decision making are required when playing the table games which are categorized under executive function. Therefore, by participating in cognitively stimulating table games, an individual may be able to enhance certain cognitive functions. The comparison group also had a greater margin for improvement compared to the IVG group as they had a significantly slower average reaction time at baseline.

Davidson et al. 2003 found a reduction in colour-word interference effect with practice of the Stroop task (352). Although the older adults showed a reduction in colour-word interference with practice, they continued to show larger interference effects throughout practice compared to younger adults (352). These findings are in line with previous work conducted by Vakil et al. 1996 as well as Verhaeghen and De Meersman. 1998 who also showed greater increase in reaction time and errors in naming of colours incongruent to the words than younger adults (353;354). This may be due to the difference in neural activity associated with Stroop performance. Milham et al. 2002 found differences in fMRI neural activity patterns on the Stroop task associated with less extensive activity in the dorsolateral prefrontal cortex in older adults compared to younger adults (355). In addition, this pattern changed with practice indicating that parietal areas were more active than earlier in the task in the older group suggesting that Stroop practice is associated with increased recruitment of parietal areas. The findings from the above-mentioned studies are important for older adults as it confirms that as one ages, there is a decrease in executive function which is associated with frontal lobe activity. This could have a negative impact on

an individual's daily cognitive ability to accurately plan, schedule and coordinate tasks.

One of the strengths of this study was the cluster-randomization of the retirement homes as it avoids contamination between the intervention and control groups.

A limitation to this study was that the same researcher conducted the intervention and administered the assessments, although all efforts were made to decrease any form of bias. This was done by making sure that all procedures of testing and data collection throughout the study were conducted stringently. Furthermore, the effect sizes found in our study were smaller than the study the power calculation was based on which could indicate insufficient power to detect differences. A potential reason could be the choice of formula used for the power calculation. As participants were assigned to groups, it would have been better to use a formula for statistical power taking potential clustering effect into account. The proposed sample size calculated assuming individual randomization can be expanded by a Design Effect (DE) to get to the required level of statistical power under cluster randomization (356;357). The DE is utilized to further inflate the sample size calculated by individual randomization.

This study contributes to the literature as it is one of the few studies focusing on IVG as a form of physical activity compared to cognitively simulating sedentary activities on cognitive performance and physical function in older adults. In addition, our study had a low dropout rate with only four participants in the intervention group not being able to continue after baseline testing. During the IVG intervention, there were no falls or adverse outcomes which may indicate that IVG may appear to be a safe form of physical activity for older adults.

In summary, our study showed that most of the functional ability and cognitive performance outcomes improved in both groups even though many did not reach a level of significance. IVG resulted in significant improvements in balance and stability, measured with the Functional Reach test. Poor balance is also associated with the increase in gait instability which is related to dependence in older adults (350). The decrease in gait instability and fall risk can reduce the incidents of

fractures and other musculoskeletal injuries in older adults. Therefore, improvements in balance allow for enhanced functional ability and individuals are able to live in an independent manner. IVG programs of this nature and duration could be sustainable for healthy older adults to meet their physical activity requirements in a safe and stable manner if retirement home caretakers as well as other individuals in the community volunteer and are trained to conduct such sessions. The IVG program may also assist older persons to preserve certain fitness components such as balance and stability in apparently healthy older adults. This is especially important for older adults as balance and stability are required in everyday activities such as standing on uneven ground, walking up and down stairs and reaching out for an item on a high shelf. Therefore, IVG might be a suitable option for older adults to preserve functional ability.

Moreover, IVG can be played indoors which alleviates environmental barriers to exercise such as inclement weather. It also allows for a variety of options which may promote sustainability of participation and adherence to physical activity. Cognitively stimulating table games have shown to be beneficial in improving cognitive performance measured by the Modified Stroop task. The cognitively stimulating table games significantly improved performance on reaction time measures of the Stroop task.

The findings from this study show potential benefits of IVG as a safe and reliable form of physical activity in older adults. In addition, IVG showed improvements to balance and stability which is vital for everyday function, especially in elderly persons. Many other functional and cognitive outcomes improved but lacked statistical significance which could be attributed to our participants in this study being healthy and high functioning, however, level of function was not measured in this study. Therefore, taking into account the outcomes and findings presented in this study as well as the previous studies (chapters 2, 3 and 4), it may possibly be that IVG could be effective in showing significant cognitive benefits in older adults with some level of memory complaints.

**CHAPTER 5: EFFICACY OF INTERACTIVE VIDEO GAMING IN
OLDER ADULTS WITH MEMORY COMPLAINTS: A CLUSTER-
RANDOMIZED EXERCISE INTERVENTION TRIAL
[PACTR202008547335106]**

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5.1 Introduction

The previous studies (chapters 2, 3 and 4) in this thesis explored the relationship between fitness, functional ability and cognitive performance. Findings from the formative study showed that IVG represented a moderate intensity physical activity irrespective of the perceived level of difficulty of IVG and was associated with measures of functional ability and cognitive performance. These findings led us to determine the effects of IVG on functional ability and cognitive performance in older adults without any known cognitive impairment. Functional ability partially improved after 12 weeks of IVG in healthy older adults. Cognitive performance measures improved, however, did not reach a level of significance. This study was conducted to determine the effects of IVG on cognitive performance in older adults with memory complaints. Decreases in cognitive performance that occurs with ageing leads to decreased health status and quality of life, and may lead to older adults experiencing memory complaints, associated with poor executive function and delayed recall (37). Memory complaints, which may later lead to mild cognitive impairment or dementia have been shown to be mitigated or reduced by multifactorial interventions which include a change in diet, stress reduction techniques such as meditation and participation in regular exercise (358).

Previous research has shown minor improvements, as a function of participation in physical activity and exercise, in cognitive and brain health in older adults (328;359). Research on conventional exercises has also shown benefits for physical function in older adults (360), however, to our knowledge, minimal research studies have been conducted identifying the effects of conventional multimodal supervised exercises on cognitive performance in older adults with memory complaints. Rieping and colleagues conducted a 3-arm intervention to determine the effects of chair-based exercise programs on physical fitness among other outcomes over 14 weeks (361). Both chair-based exercise groups participated in their respective interventions for 45 minutes per a session, twice a week. Post intervention, the chair-based aerobic group significantly improved in lower and upper strength, agility-dynamic balance as well as a decrease in fear of falling ($p < 0.05$) (361). More recently, Furtado et al. 2021 also conducted a study to identify the effects of 14 weeks of combined chair-based

exercise on functional fitness and mental well-being in older women (362). Functional ability improved significantly in the chair-based group (362). The above-mentioned studies by Rieping et al. 2019 and Furtado et al. 2021 emphasize the benefit of chair-based exercises to improve functional performance and fitness after a 14-week period, 2-3 times per a week, for a duration of 45-60 minutes per session in older adults.

Similar to the benefits of chair-based exercises on functional performance, seated exercise improved cognitive performance in older adults (363). Results from a meta-analysis showed that seated exercise was more favorable than usual care to improve cognition in older adults with health concerns (363). Further, recent studies have identified that a combination of physical and mental exercises can improve cognitive function in healthy older adults. Shah et al. 2014 showed that the combination of home-based physical activity and computerized cognitive stimulation over 16 weeks improved verbal episodic memory in healthy older adults (364). Similarly, Nishiguchi and colleagues showed significantly greater improvements in executive function and memory in community-dwelling older adults after 12 weeks of a combined physical and cognitive intervention compared to the usual care control group (365).

Emerging research suggests that IVG may enhance physical characteristics such as postural balance and muscle strength that may transfer to other cognitive domains (260;366). In addition, It also has the ability to teach the player to respond to visual feedback and create a cognitive map of their bodily movement in relation to the game (367). Active video gaming may also directly improve cognitive functioning, especially those related to executive control skills, by providing aerobic activity when playing. These improvements can be explained by physiological changes that occur with increased levels of physical fitness which improves cognitive performance due to increased cerebral circulation and neurotransmitter availability (259).

This is a growing area of research investigating the effects of an IVG intervention on cognitive performance and functional ability in individuals with various cognitive conditions such as mild cognitive impairment and dementia (17;263). In 2019, Palac

and colleagues conducted a study to evaluate the feasibility and efficiency of an iPad-enhanced aerobic intervention over 10 weeks in 27 individuals aged 45 to 62 years (368). Individuals were either randomized into an Ipad-enhanced aerobic exercise group (n=14) or an aerobic exercise control group (n=13). The experimental group participated in virtual reality tours twice a week which was administered via an iPad positioned on the aerobic machine (bike, elliptical or treadmill) while the control group completed aerobic training only for the same frequency. Post intervention, the iPad experimental group significantly improved on an attentional-control cognitive task compared to the control group ($p<0.05$) (368). Although Palac et al. 2019 found improvements on a cognitive task between groups post intervention, the iPad intervention used in their study may differ to other IVG consoles such as the X-box Kinect or Nintendo Wii as well as their respective gaming software.

Previous studies have also illustrated benefits of IVG on cognitive performance measures such as executive control, attention, reaction time, processing speed and memory in healthy functioning older adults as well as older adults diagnosed with mild cognitive impairment (17;260). However, few studies have investigated whether active gaming can improve cognitive function in individuals with subjective memory complaints. There are no other studies to our knowledge, comparing the benefits of active video gaming to conventional multimodal supervised exercise in older adults with self-reported and objectively measured memory complaints.

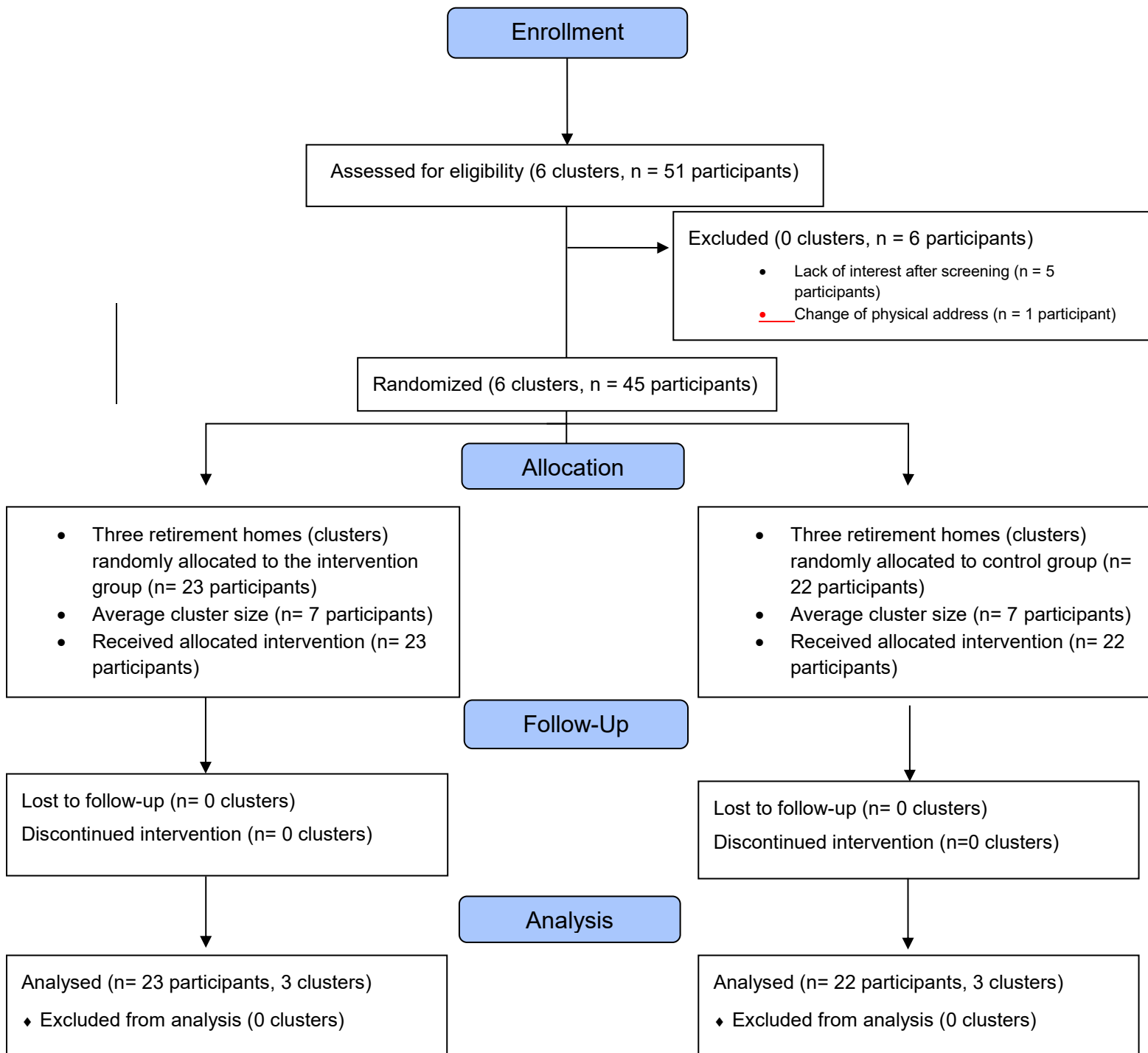
Therefore, the aim of this research study was to determine the efficacy of a 12-week active gaming intervention, using the X-Box 360 gaming console with Kinect Sports games, on cognitive performance in South African older adults with subjective and objective memory complaints. This intervention was compared to a conventional, multimodal supervised exercise program which served as the comparison group. We hypothesized that the individuals in the intervention group would show greater improvements in measures of cognitive function and functional ability than the comparison group.

5.2 Methods

5.2.1 Study Design

Participants were recruited from six different retirement homes in Cape Town, South Africa for this cluster-randomized exercise intervention trial. Homes were randomly allocated to either the intervention group (IVG) or to the comparison group (Conventional multimodal supervised exercise program) for 12 weeks. Envelopes with concealed numbers were placed into a hat with numbers 1 – 3 indicating the intervention group, and numbers 4 – 6 allocated to the comparison group. Equal number of homes was allocated to each group and an average of 7 participants was recruited per a home. Figure 5.1 below represents the Cluster Enrollment and Allocation Flowchart. All retirement homes were selected from similarly matched social and economic communities. All groups met for one hour, two days per week, for 12 weeks. Measurements were taken after cluster randomization (baseline) and at the end of the 12-week program. All measurements, IVG sessions (intervention group) and conventional multimodal supervised exercise sessions (comparison group) were conducted by the same researcher. After the details of the study were explained, participants signed a written informed consent. The present study was approved by the University of Cape Town, Human Research Ethics Committee (HREC REF: 529/2015). In addition, the study has been registered with the Pan African Clinical Trial Registry (Trial identification number: PACTR202008547335106)

Figure 5.1: Cluster Enrollment and Allocation Flowchart



5.2.2 Study Procedures

An information session was conducted for each participant prior to baseline testing to explain the procedure of the testing routine as well as to describe the nature of the

physical activity that was administered over the 12-week period. During the first session, potential participants went through a cognitive screening criterion and answered a physical activity readiness questionnaire (PAR-Q) to determine if they were eligible to participate in the research study. Eligible participants for the research study were subsequently invited to the Sports Science Institute of South Africa for baseline measurements. The baseline visit included: 1) Completion of the demographic, health and wellness questionnaire; 2) Clinical measurements including height, weight, body mass index, waist circumference and body fat percentage; 3) Cognitive performance tests which included the Mini-Mental State Examination (MMSE), the Modified Stroop task and the “N-Back” test and; 4) Physical Function test which included the 6-Minute Walk test, Dynamic balance, Timed up and go and Functional Reach. All clinical measurements, cognitive performance and physical function tests were completed at baseline and post intervention. The first intervention session was conducted within a week of baseline testing. The intensity of the IVG and conventional multimodal supervised exercise sessions were monitored using the Borg’s RPE scale (1 – 10; 1 = Very light effort, 10 = Maximal effort). Individuals were asked to provide feedback during their respective program sessions on their rate of perceived exertion on a scale from 1 to 10 and the researchers ensured that the RPE was between 2 and 5 at most times. If an individual indicated an RPE of greater than 5 at any given time during the session, they were requested to slow down until they felt their rate of perceived exertion decrease to the recommended intensity. The rate of perceived exertion feedback from the participant’s during the respective sessions was not recorded for data analysis.

5.2.3 Participants Selection Criteria

5.2.3.1 Recruitment

Individuals were recruited from the Cape Peninsula Organization for the Aged (CPOA) retirement homes. The housing manager of the Cape Peninsula Organization for the Aged was contacted via email to set up a meeting to discuss the nature of the research study. Once permission was granted for the study, information posters and flyers about the study were pinned on notice boards around the respective retirement homes. Participants used the contact details provided on the

information posters and flyers to contact the researcher while other participants attended an information briefing meeting. A total of 51 residents showed interested in the research study and were screened for eligibility. All individuals resided in retirement homes of similar socio-demographic and economic status. The individuals in each program were blinded to the researchers' hypothesis.

5.2.3.2 Inclusion and exclusion criteria

Individuals aged 65 years and older with subjective and objective memory complaints and residing in a retirement home were eligible. We adapted the Petersen criterion for MCI to determine subjective and objective memory complaints in older adults not clinically diagnosed with MCI (69). Individuals were eligible to participate in the study if they met all 5 of the criteria (Subjective memory complaints (369), Objective memory impairment (370), Intact daily function (371), Normal cognitive function (Adapted Telephone Interview for Cognitive Status (TICS)) and Non-demented (372)) described in table 5.1:

Table 5.1: Cognitive Function Screening Criteria

Criteria	Assessment Questions	Scoring
1) Subjective Memory Complaint (369)	1.1 Do you have a memory complaint?	1) Yes 2) No
	1.2 Strawbridge scale of cognition assessment questions: a) Do you have difficulty paying attention b) Do you have trouble finding the right word c) Do you have difficulty remembering things d) Do you forget where things are put	Participants selected one possible answer from the list below for each question: 1) Rarely or never had the problem in the last 12 months 2) Sometimes had the problem 3) Often had the problem 4) Very often had the problem Participants were classified as having a self-reported memory complaint if reported that they have memory complaints (Yes) in addition to answering ' Sometimes had the problem ' in at least of two questions on the Strawbridge scale of cognition.
2) Objective Memory Impairment (370)	2.1 10 Word Learning Test a) Trial 1 b) Trial 2 c) Trial 3 d) Trial 4 Delayed Recall (5 minutes later)	Scoring based on the number of words recalled per a trial with a minimum score of 0 and a maximum score of 10 Objective Memory Impairment = Scored less than or equal to 5 on the 10 word learning test delayed recall
3) Intact Daily Function (371)	3.1 Groningen Activity Restriction Scale was used to assess activities of daily living (ADL) (11 questions were administered)	Participants selected one possible answer from the list below for each question:

		POINTS Yes I can do it fully independently without any difficulty (1 point) Yes I can do it fully independently but with some difficulty (2 points) Yes I can do it fully independently but with great difficulty (3 points) No I cannot do it fully independently. I can only do it with someone's help (4 points) No I cannot do it at all. I need complete help (4 points) Intact ADL function if they reported no disabilities on the ADL items except for "Care of feet and toe nails"	
4) Normal Cognitive Function (372)	4.1 Telephone Interview for Cognitive Status (TICS) was used to assess mental status, orientation, concentration, calculation, memory, judgment and reasoning. We adapted the TICS so that it could be administered face-to-face.	Score Range: 0 – 41 Score greater than or equal to 19 on the TICS was categorized as normal cognitive status	
5) Non-Demented		Individuals regarded non-demented with a score of greater than or equal to 19 on the TICS	

Older adults who had been previously diagnosed with a stroke, Parkinson's disease, balance disorders, impaired vision or had uncontrolled conditions such as hypertension (blood pressure more than 160/90 and not on medication) or diabetes (not on medication) were excluded from the study. Those with orthopaedic injuries which inhibited normal locomotion were also excluded.

The Physical Activity Readiness Questionnaire (PAR-Q) was used as the first line of screening for participant's entry into the study (286). Those who were identified as being at an increased risk for coronary artery disease, according to the American College of Sports Medicine (ACSM) criteria, required consent from a doctor to allow them to participate (286). Participants were classified as increased risk if they had more than two cardiovascular risk factors and were symptomatic for or diagnosed with cardiovascular, pulmonary and / or metabolic disease. The cardiovascular disease risk factors have previously been described in chapter 4, methods section 4.2.3.2 on page 187 (286).

5.2.3.3 Interactive Video Games (IVG) Group

Participants in the intervention group attended two, one hour interactive video game (IVG) sessions per week. The IVG sessions took place at the respective retirement homes for the duration of the 12-week program. The X-Box Kinect Sports video gaming software was used and comprises of 6 games namely: ten-pin bowling, boxing, track and field, table tennis, beach volleyball and soccer. Each game is described in the Table 5.2. The Kinetic Sports games are different to the Kinect Adventures games used in chapters 3 and 4 (study 2 and 3) as they require the participants to learn and remember the rules and regulations of the various sports in addition to being able to adapt to the complexity and novelty of each sports game. Apart from the physical function required for the various sports games, remembering rules of the sport (memory) and strategically planning responses to competitors (executive function) requires the participant to multitask using different cognitive domains. The Kinect Sports gaming package also has an extra sports game compared to the Kinect Adventures games which has 5 games.

The participants played each of the 6 games at each session with a partner and two pairs played (n=4) per session. The first pair played the game for 15 minutes while the second pair rested after which the roles were reversed. Therefore, each pair played for a total of 30 minutes and had 30 minutes break per session.

Each session was supervised by an exercise physiologist who acted as a 'spotter' during the gaming session to minimize the risk of any injury or to help regain balance if needed. The spotter stood slightly behind and between the individuals during the gaming routine. An attendance register was used to record the number of sessions each participant attended over the 12-weeks to determine adherence. No adverse incidents and no falls occurred during the 12 weeks.

Table 5.2: Description of Interactive Video Games

Name	Fitness Component	Brief Description
Ten-pin bowling	Shoulder flexibility and balance	Individuals were required to reach either to the left or right hand side to pick up a ball before swinging their arm forward to bowl. This game will require good mobility and balance. The aim of this game was to knock over as many pins as possible
Boxing	Bilateral arm flexibility, agility, endurance and balance	The game required individuals to move in all directions, use both hands to punch forward and block, both at head and body height. The aim was to either score more points than the opponent during the fight or to knock the opponent out.
Track and Field	All-round flexibility, endurance, agility lower body strength and balance	The track and field is a collection of 5 separate events namely: sprint, javelin, long jump, discus and hurdles. Individuals jogged on the spot to run / sprint, jump up to clear hurdles or jump forward for long jump as well as performed the relevant arm movements to throw a javelin or discus. The aim was to score as many points in each of the respective events.
Table Tennis	All-round flexibility and agility	Individuals were required to reach either to the left or right hand side to pick up a paddle. They then mimicked the movements of table tennis to hit the ball. The aim was to score 11 points first.
Soccer	Lower body strength and agility	In this game, individuals played as attackers and defenders. As an attacker, the individual was required to kick the ball in order to pass or shoot. As a defender, the individual needed to move side to side to block passes and use their body to block shots. The aim was to score more goals than the opponent.
Beach Volleyball	Upper body strength and flexibility	This game required the use of both hands. To serve, the participant made an upward throwing motion with one hand and then a swinging motion with the other hand. Passing, returning or spiking the ball was done by mimicking volleyball movements. The aim was to score 7 points first.

5.2.3.4 Comparison Group

The comparison group met for one hour, twice per week, for 12 weeks and participated in group-based low intensity conventional multimodal supervised exercise sessions.

The exercise program consisted of a combination of standing and seated exercises. The exercise sessions comprised of a 10-minute warm up, 30 minutes of strength training, followed by 10 minutes of proprioceptive exercises and 10 minutes of cooling down. All exercises were performed using body weight during the first 6 weeks. The intensity of the upper body strength training exercises for weeks 7 to 12 were increased by using plastic soft drink bottles (500ml) filled with sand as weights. Participants enjoyed a 45-second break after each set of exercises for the duration of the 12 weeks. Participants were also allowed to take additional breaks during the sessions if they felt the need to do so. Each set consisted of 15 repetitions per an exercise. The sessions were supervised and coordinated by an exercise physiologist. An attendance register was used to record each session to determine adherence. Table 5.3 describes the exercise program in more detail.

Table 5.3: Exercise Program

Program Component	Duration	Type of Exercises
1) Warm Up	10 minutes	1) Chair marching while seated 2) Lateral circular arm movements while standing
2) Strength Training	30 minutes (Two sets of 12 repetitions were performed for each strength exercise)	<u>Lower body exercises :</u> 1) Seated straight leg raise 2) Standing heel raises 3) Standing knee raises 4) Seated ankle circles 5) Seated alphabet tracings <u>Upper body exercises:</u> 1) Seated bicep curls 2) Frontal arm raises (Standing) 3) Lateral arm raises (Standing) 4) Single arm shoulder press (Standing) 5) Seated horizontal chest press
3) Proprioceptive Exercises	10 minutes	1) Double leg balance with eyes open and then with eyes closed 2) Supported single leg balance with eyes open and then closed
4) Cool down	10 minutes	1) On the spot slow walking 2) Stretching

5.2.4 Measurements

5.2.4.1 The Demographic, Health and Wellness Questionnaire

An interviewer-administered questionnaire was conducted to obtain information on demographics and health (section 1) and weekly physical activity (section 2). The first section was used to obtain information about the participant's age, gender, marital status, past and present occupation, perceived health status and highest level of educational achievement. Participants were also asked to report any previous disease diagnosed by a medical doctor including the treatment and medication received.

The second section of the questionnaire was based on Part One of the Yale Physical Activity Survey for older adults (287) and was used to assess physical activity in five domains, namely, household, yard work, care giving, recreation and exercise. Participants were required to recall the amount of time spent in each of these five domains for various activities. Each activity was assigned an intensity (kcal) as described by DiPietro (287), and subsequently multiplied by the time spent to calculate kcal/week. Individual weekly energy expenditure was calculated for each of the activity domains and then summed to estimate total weekly energy expenditure. This questionnaire was only administered at baseline to determine habitual physical activity levels amongst participants both groups.

5.2.5 Clinical Measurements

5.2.5.1 Anthropometry

Participant's height, weight, body mass index, waist circumference and skinfold thickness to assess body fat were measured using the same procedures as described in chapter 2, methods section 2.2.2.3 on pages 136 (286;290). All clinical measurements were conducted at baseline and post intervention.

5.2.6 Cognitive Performance Tests

Participant's cognitive performance was measured using the Modified Stroop task as described in chapter 2, methods section 2.2.5.2 on page 139 (183;186). In addition to the Modified Stroop task (183;186), The Mini-Mental State Examination (MMSE) (199) and 'N-Back' task (206) were also administered to assess global cognitive function and working memory respectively at baseline and post intervention. The MMSE and 'N-Back' task are described below:

5.2.6.1 The Mini-Mental State Examination (MMSE)

The MMSE is an interview administered cognitive outcome measure of global cognitive function and was used to assess cognitive impairment (199). This test consists of 11 questions concerning orientation, registration, attention and calculation, recall and language. The test takes between 5 – 10 minutes to administer and the score obtained can range from 0 to 30 (199).

5.2.6.2 The 'N-Back' task

The *N*-Back task ("n" represents the level number; example: 1-back, 2-back) has previously been used to assess working memory (WM) (206). During the *n*-back task, participants were presented with a sequence of letters, one at a time, on an Apple I-pad screen and requested to compare the current letter to the one presented "*n*-back" in the sequence. Participants used the index finger of their dominant hand to respond by pressing the middle of the Ipad screen when the current letter matched the letter that was *n*-back in the sequence. The letter sequence was presented randomly in a fixed location in the centre of the computer screen for duration of 600m.s with a 2600m.s inter-stimulus interval.

Individuals started with the 0-back task. In the 0-back condition, individuals were required to respond when an "X" appeared on the screen only. When performing the 2-back task, the current letter is a target when it matches the letter presented two positions ago. For example, in the sequence "R-I-T-A-?" the individual should respond by pressing the middle of the screen if the 5th letter in the sequence is a "T"

because it would match the letter occurring two places prior. During this study, only the 0-back, 1-back and 2-back task were used. Individuals were allowed one familiarization trial (0-back task) and one final trial for each *n*-back task (1-back and 2-back). All trials were be recorded and used for data analysis.

5.2.7 Physical Function Tests

Participant's physical function was measured using the same procedures and selected fitness and functional ability tests described in chapter 2, methods section 2.2.3 and 2.2.4 on pages 136 – 138. These selected tests included the 6-Minute Walk test (291), Dynamic Balance (154), Timed Up and Go test (156), and the Functional Reach test (153).

5.3 Statistical Analysis

STATISTICA 10 software package for Windows 10 was used for all the analyses (Stasoft, Inc., Tulsa OK, USA). Descriptive statistics were performed for the IVG and CM groups separately and data were represented as means and standard deviations. Frequency tables were used to determine demographic, health and wellness variables percentages. T-tests were conducted to identify significant differences between groups for baseline screening, ADL and demographic and health characteristics.

Analyses of variance for repeated measures (ANOVA) were used to detect differences between groups for changes in continuous variables (cognitive performance and physical function) at baseline and post intervention. ANCOVA was conducted before and after the intervention with age being included as a covariate in the analysis. All models were adjusted for site level clustering appropriate for an experimental cluster-randomized intervention study. The level of significance for all statistical analyses was set at $p < 0.05$. Partial η^2 , defined as the ratio of variance accounted for by an effect and that effect plus its related error variance within an ANOVA study (343), was displayed as measures of effect size for each cognitive and physical function outcome variable.

The sample size was estimated using G*Power software (Version 3.1.9.2) (344;345). The sample size was determined using a priori power calculation (repeated measures, within-between interaction, medium effect size = 0.6, power of 0.80, 2-sided α -error, 2 groups, 2 measurements) based on the primary outcome of the Mini-Mental State Examination from a comparable study (373). The required sample size calculated with an additional 20% increase per a group taking into account dropouts was 12 participants per a group.

5.4 Results

Table 5.4: Baseline Screening: Cognitive Ability and Activities of Daily Living (ADL) Characteristics

	Total (n=45)	Intervention (n=23)	Comparison (n=22)	p-value
	Mean ($\pm$ S.D)	Mean ($\pm$ S.D)	Mean ($\pm$ S.D)	
Strawbridge Scale of Cognition (Score)	1.8 ($\pm$ 0.3)	1.9 ($\pm$ 0.3)	1.8 ($\pm$ 0.2)	0.090
10 W.L.T (Number)				
1) Immediate Recall 1	4.6 ($\pm$ 1.2)	4.4 ($\pm$ 1.3)	4.8 ($\pm$ 1.1)	0.301
2) Immediate Recall 2	5.5 ($\pm$ 1.1)	5.4 ($\pm$ 1.2)	5.6 ($\pm$ 1.1)	0.563
3) Immediate Recall 3	6.0 ($\pm$ 1.1)	6.1 ($\pm$ 1.0)	5.9 ($\pm$ 1.2)	0.488
4) Average Immediate Recall of 3 attempts	5.4 ($\pm$ 0.9)	5.3 ($\pm$ 0.9)	5.4 ($\pm$ 0.8)	0.642
5) Delayed Recall	2.9 ($\pm$ 1.7)	3.3 ($\pm$ 1.6)	2.5 ($\pm$ 1.7)	0.111
GARS (Score)	11.6 ($\pm$ 1.1)	12.0 ($\pm$ 1.4)	11.2 ($\pm$ 0.4)	0.009*
TICS (Score)	29.3 ($\pm$ 3.2)	29.3 ($\pm$ 3.4)	29.3 ($\pm$ 3.1)	0.990
Legend: 10W.L.T – 10 Word Learning Test; GARS – Groningen Activity Restriction Scale; TICS – Telephone Interview for Cognitive Status; S.D =Standard Deviation, Values are shown as mean $\pm$ standard deviation, * $p < 0.05$				

5.4.1 Baseline Screening Characteristics

Fifty-one people volunteered to participate and were initially screened. All individuals met the inclusion criteria to participate, however, 6 participants dropped out due to a lack of interest after screening (n=5) and change of address (n=1). The 6 participants that dropped out did not complete any IVG or conventional multimodal sessions. The final sample size for the study was then reduced to 45 participants. All 45 participants presented for all tests and sessions throughout the study.

Participant baseline screening cognitive and ADL characteristics are presented in Table 5.4. All participants in both groups answered 'Yes' to having a memory complaint. The only difference between the two groups was the Groningen Activity Restriction Scale score, which was significantly better in the comparison group, suggesting that the comparison group had better function for activities of daily living than the IVG intervention group. All the participants scored more than 19 on the adapted version of the TICS and were therefore considered to be non-demented.

5.4.2 Participant Baseline Demographic and Health Characteristics

Participant's demographic and health characteristics are presented in Table 5.5. The mean age of the participants was 72.4 ± 5.4 years with the comparison group being significantly older; therefore the analysis included age as a covariate. Majority of participants in the intervention (65.2%) and comparison (77.3%) group's highest level of education was completing primary school education. Hypertension was the most frequently reported medical condition in the intervention (78.3%) and comparison (68.2%) groups. Almost all of the participants were taking prescribed medication for a chronic disease.

Table 5.5: Baseline Demographic and Health Characteristics

	Total (n=45)	Intervention (n=23)	Comparison (n=22)
	Mean (±S.D)	Mean (±S.D)	Mean (±S.D)
Age (Years)	72.4 (±5.4)*	70.8 (±4.5)	74.1 (±5.8)
Body Mass Index (kg·m ²)	29.1 (±5.7)	29.0 (±5.5)	29.2 (±6.0)
Waist Circumference (cm)	88.8 (±11.8)	89.3 (±11.5)	88.2 (±12.4)
Percentage Body Fat (%)	34.4 (±3.1)	34.4 (±3.4)	34.4 (±2.6)
Total Weekly Physical Activity (Minutes)	1143.6 (±975.3)	1149.0 (±1099.7)	1138.0 (±852.1)
Total Weekly Energy Expenditure per (Kcal / Week)	3467.8 (±2547.9)	3382.2 (±2392.9)	3557.2 (±2754.4)
Marital Status			
1. Married	11 (24.4%)	4 (17.4%)	7 (31.8%)
2. Single	3 (6.7%)	2 (8.7%)	1 (4.6%)
3. Divorced	10 (22.2%)	4 (17.4%)	6 (27.3 %)
4. Widowed	21 (46.7%)	13 (56.5%)	8 (36.4%)
Highest Level of Education			
1. Primary School	32 (71.1%)	15 (65.2%)	17 (77.3%)
2. Secondary School	2 (4.4%)	2 (8.7%)	-
3. Tertiary	11 (24.4%)	6 (26.1%)	5 (22.7%)
Health Status			
1. Hypertension	33 (73.3%)	18 (78.3%)	15 (68.2%)
2. High Cholesterol	24 (53.3%)	13 (56.5%)	11 (50.0%)
3. Diabetes Mellitus	14 (31.1%)	10 (43.5%)	4 (18.2%)
4. Asthma	3 (6.7%)	3 (13.0%)	-
5. Peripheral Vascular Disease	1 (2.2%)	1 (4.4%)	-
6. None	3 (6.7%)	2 (8.7%)	1 (4.6%)
Legend: S.D =Standard Deviation, Values are shown as mean ± standard deviation, , Marital status, Education and Health status are represented as a number (percentage), *p<0.05			

Table 5.6: Changes in Cognitive Performance in the Intervention and Comparison Groups

Variable	Assessment Wave	Intervention Group (n=23)	Comparison Group (n=22)	Group Effect (p-value)	Time Effect (p-value)	Group by Time Effect (p-value)	Partial eta ²
		Mean (± S.D)	Mean (± S.D)				
Modified Stroop task							
Total Correct Responses (%)	Baseline	64.2 (±19.9)	70.8 (±19.9)	0.956	0.970	0.028*	0.1095
	12 Weeks	80.7 (±21.0)	74.8 (±21.0)				
Average reaction time of all Correct Responses (m.s)	Baseline	1717.5 (±226.5)	1635.5 (±226.7)	0.886	0.736	0.092	0.0660
	12 Weeks	1594.7 (±238.0)	1660.3 (±238.2)				
Correct Grey (Neutral) Words (%)	Baseline	60.0 (±32.2)	61.7 (±32.3)	0.631	0.432	0.725	0.0029
	12 Weeks	74.3 (±25.4)	79.7 (±25.5)				
Average reaction time of Correct Grey (Neutral) Words (m.s)	Baseline	1713.2 (±661.8)	1702.3 (±662.6)	0.787	0.877	0.901	0.0003
	12 Weeks	1770.3 (±419.0)	1725.6 (±419.5)				
Correct Colour Words (%)	Baseline	65.7 (±22.1)	73.8 (±22.1)	0.897	0.718	0.011*	0.1436
	12 Weeks	82.9 (±21.9)	73.2 (±22.0)				

Average reaction time of Correct Colour Words (m.s)	Baseline	1692.8 (±240.7)	1570.5 (±241.0)	0.744	0.516	0.024*	0.1161
	12 Weeks	1533.3 (±261.3)	1613.8 (±261.6)				
<i>N-Back Task</i>							
0-Back Score (%)	Baseline	97.1 (±2.6)	96.6 (±2.6)	0.164	0.901	0.409	0.0163
	12 Weeks	98.6 (±1.8)	97.5 (±1.7)				
1-Back Score (%)	Baseline	93.7 (±6.8)	93.5 (±6.8)	0.640	0.436	0.527	0.0096
	12 Weeks	96.0 (±5.7)	94.6 (±5.7)				
2-Back Score (%)	Baseline	59.8 (±27.2)	51.9 (±27.3)	0.511	0.896	0.286	0.0270
	12 Weeks	73.8 (±18.1)	73.7 (±18.2)				
<i>Mini-Mental State Examination</i>	Baseline	24.6 (±2.7)	25.0 (±2.7)	0.242	0.285	0.005*	0.1751
	12 Weeks	27.3 (±2.5)	25.3 (±2.5)				
*p≤ 0.05							
ANOVA for repeated measures (Age included as covariate in analysis)							

5.4.3 Cognitive Performance Scores at baseline and 12-week follow up

Table 5.6 shows the cognitive performance changes after 12 weeks in the intervention and comparison group. The total number of correct responses on the Stroop task was significantly superior in favour of the intervention group when compared to the comparison group ($p=0.028$). The intervention group showed significantly greater improvements for the correct colour word percentage ($p=0.011$) and average reaction time of correct colour words ($p=0.024$) on the Stroop task after 12 weeks when compared to the comparison group. The intervention group had significantly greater improvements in the Mini-Mental State Examination compared to the comparison group ($p=0.005$). Results from the ANOVA showed no significant group or time main effects or interaction effects for any of the other cognitive performance variables. Age as a covariate in the analysis did not change the interpretation of results, nor differences between groups.

5.4.4 Functional Ability Scores at baseline and 12-week follow up

Displayed in Table 5.7 are the functional ability changes after 12 weeks between the intervention and comparison group. There was an interaction effect for the 6-minute walk test, with significantly greater improvements in the intervention group compared to the comparison group ($p=0.017$). Dynamic balance also improved significantly in the intervention group in when compared to the comparison group ($p=0.030$). In addition, significant improvements in the intervention group were also identified for the timed up and go test ($p<0.001$) and the functional reach test ($p<0.001$). The results from the ANOVA showed no significant group by time effects for any of the other variables. However, a main effect of time was identified for the 6-minute walk test, indicating that both groups improved significantly at 12-weeks. An attendance register was taken at each session for both groups. All participants ($n=45$) in both groups completed 24 one hour sessions over the 12 week intervention period.

Table 5.7: Changes in Functional Ability in the Intervention and Comparison Groups

Variable	Assessment Wave	Intervention (n=23)	Comparison (n=22)	Group Effect (p-value)	Time Effect (p-value)	Group by Time Effect (p-value)	Partial eta²
		Mean (± S.D)	Mean (± S.D)				
6-Minute Walk Test (m)	Baseline	466.7 (±79.1)	491.8 (±79.3)	0.694	0.039*	0.017*	0.1283
	12Weeks	513.7 (±83.5)	507.7 (±83.5)				
Dynamic Balance 10m Test (s)	Baseline	46.4 (±13.9)	46.5 (±14.1)	0.246	0.916	0.030*	0.1070
	12 Weeks	35.7 (±11.0)	43.8 (±11.3)				
Timed Up & Go Test (s)	Baseline	7.4 (±1.4)	7.2 (±1.4)	0.212	0.945	<0.001*	0.3507
	12 Weeks	6.2 (±1.2)	7.4 (±1.3)				
Functional Reach Test (cm)	Baseline	80.8 (±6.5)	83.3 (±6.5)	0.651	0.520	<0.001*	0.3471
	12 Weeks	85.9 (±4.6)	82.0 (±4.6)				
*p≤ 0.05							
ANOVA for repeated measures, (Age included as covariate in analysis).							

5.5 Discussion

The aim of this research study was to determine the effects of a 12-week active gaming intervention, using the X-box 360 gaming console with Kinect Sports games, on cognitive performance in South African older adults with subjective and objective memory complaints. We hypothesized that participants in the IVG group would show significantly greater improvements in measures of cognitive performance and functional ability compared to the comparison group. Our main finding supports this hypothesis as the data show that both the Stroop task and the Mini-Mental State Examination scores improved significantly in the IVG group, while there were no changes in the comparison group.

In our study, the video gaming intervention group showed significant improvements over time in the total correct number of responses on the Stroop task as well as the total correct colour word responses and average reaction time of correct colour words. Previous studies have shown that various forms of exercise training such as cardiovascular training, resistance training and balance training can alter brain plasticity which is associated with improvements in cognitive performance (374;375). The increase in availability of oxygen for cerebral activity could be accountable for the improvement in neurocognitive performance that arises with fitness training. Therefore in our study, we speculate that the improvement in executive function on the Stroop task with IVG may be due to the improvements in cardiovascular fitness with consistent participation. This may indicate that older adults who participate in IVG two or more times a week may be able to improve their cardiovascular fitness and thereby assist in improving their cognitive performance. Although there was a significant difference between both groups in the total correct responses on the Stroop task, the comparison group showed an improvement post intervention compared to baseline. In the past, studies have shown that exercise training can improve cognitive performance; however, not many studies have utilized IVG to show improvements in executive function over duration of 12 weeks in individuals with subjective memory impairment.

Our findings are supported by Maillot and Perrot. 2012 who evaluated the effects of Interactive video-game training on cognitive and physical function in older adults (260). Individuals participated in IVG for an hour twice a week using the Nintendo Wii gaming console and Wii sport games for 12 weeks while individuals in the control group remained sedentary. Cognitive performance was assessed using a wide variety of neuropsychological tests such as the Stroop task, Digit Symbol Substitution test and Trail-making test to measure executive function as well as other cognitive tests to assess attention, visuospatial function and processing speed. Participants in the intervention group improved significantly more than those in the sedentary control group in cognitive measures of executive function and processing speed (260).

Another study by Anderson-Hanley et al. 2012 also found similar results to our study by illustrating the effects of 3 months of either 3 dimensional virtual reality cycling tours versus traditional stationery cycling, on cognitive function in older adults (263). Individuals (n=79) were randomized and participated in either 3 dimensional virtual reality cycling tours (cyber-cycling) for 45 minutes 5 times per a week or stationery cycling for the same period. Executive function was measured using the Stroop C test, Colour Trials difference and The Digit Span Backwards test. Intention to treat analysis showed a significant group by time interaction in favour of the intervention group for the composite score on executive function ($p=0.002$). In addition, group by time interaction were significant for all 3 measures of executive function. This was interesting as there were no differences between groups with regards to exercise frequency, intensity or duration. Cybercyclist also decreased their risk for mild cognitive impairment by 23% when compared to traditional cyclist (263). The post intervention results regarding executive function in this study are similar to our study, however, the Stroop task in both studies were the only common outcome measure. These cognitive effects could be due to the added mental effort required when participating in cybercycling compared to traditional cycling as both groups exerted similar physical efforts. The added mental effort such as competing with other riders, anticipating turns and dividing attention and decision making could partly tap on the domain of executive function.

The above-mentioned studies have drawn similar conclusions to our study indicating that IVG does have the potential to improve executive function in ways similar to traditional moderate intensity exercise in older adults. One of the reasons for this could be due to the added mental effort required such as remembering movement sequences or instructions of a particular game when participating in IVG, in addition to the physical exertion. By participating in IVG as a means of meeting weekly physical activity guidelines, it may also allow older adults the opportunity to improve their executive function capabilities which is important for daily living such as making decisions, planning one's day to day activities and being able to successfully switch between different tasks. Executive function capabilities could be important for daily situations such as cooking when one has to concentrate and switch between essential tasks such as preparing ingredients, making sure the cooking temperature is optimal and being careful with certain utensils in order to successfully complete the task in an independent manner. Similarly, planning one's daily life such as running a list of errands, doing financial calculations while shopping and being able to manage one's time and money also requires higher level executive function. It therefore might be possible that participating in such active video games may not only help increase physical activity levels but also have the added benefit of improving executive function in older adults with some level of memory impairment.

In addition to significant improvements in executive function, our study also demonstrated that IVG resulted in significant improvements in global cognitive function measured using the Mini-Mental State Examination over 12-weeks compared to the conventional multimodal supervised exercise group. The Mini-Mental State Examination has been widely used as a screening tool for dementia (199) and also in research to measure change in cognition over time (229;235). A study by Suzuki and colleagues 2013 demonstrated the effects of 6 months of multicomponent exercise on memory function and general cognitive function in older adults with mild cognitive impairment (229). Participants in the multicomponent exercise program participated in 90 minutes of exercise twice a week. The control group attended educational classes regarding health three times a week for the duration of the study. The Mini-Mental State Examination ($p<0.04$), logical memory ($p<0.04$) and reduced whole brain cortical atrophy ($p<0.05$) improved significantly in

the multicomponent exercise group (229). Similarly, Kwak et al. 2008 showed the effects of exercise on cognitive function in 30 females with senile dementia (235). Individuals in the exercise group participated in stretching, walking and upper and lower extremity exercises 2 – 3 times a week for 12 months with each session lasting between 30 – 60 minutes. After 12 months, the exercise group improved significantly ($p < 0.01$) on the Mini-Mental State Examination compared to the control group (235). Although Kwak et al. 2008 found similar results to our study on the Mini-Mental State Examination, participants in their study were more impaired than our participants with evidence of memory complaints. However, contrasting results to the above-mentioned studies have also been observed.

Christoforetti et al. 2008 conducted a study whereby 54 individuals with mixed dementia (more than one type of dementia occurring simultaneously) were allocated into one of three groups namely: 1) An interdisciplinary therapy and education program; 2) a physiotherapy program; and 3) a non-active control group (236). Groups 1 and 2 completed the intervention 5 and 3 times a week respectively for 6 months. Global cognitive function was measured using the Mini-Mental State Examination and The Brief Cognitive Screening Battery at baseline and post intervention. Global cognitive function did not improve through treatment however, attenuation was observed in the decline of global cognition on two specific domains in The Brief Cognitive Screening Battery for the interdisciplinary therapy group. The results indicate that exercise may slow the dementia related decline in cognitive symptoms, but lack statistical significance.

Functional ability outcomes improved significantly in our IVG participants. To our knowledge, few studies have shown improvements in cardiorespiratory measures such as the 6-minute walk test in older adults participating in IVG. A study by Lund and Jessen. 2014 showed a significant improvement in the 6-minute walk test after 12 weeks using interactive modular stepping tiles as an intervention program (376). The modular stepping tiles connect together to form a pressure-sensitive area of varying size and shape that allow the individuals to step on during the game and thereby providing feedback of the individuals movement. Individuals in this study participated in 9 sessions (1 -1.5 hours per session) of modular interactive tiles over

12 weeks. The intervention group had a mean difference improvement of 22.4 percent when pre and post test scores were compared. Although an improvement was seen in the study conducted by Lund and Jessen.2014, there was no control group for comparison (376).

One of the possible reasons for the improvement in the 6-minute walk test scores in our study could be due to the intensity and movement during each game compared to the comparison group's conventional multimodal standing and seated exercise. The interactive gaming package used for our study requires many fitness components such as flexibility, agility, balance, lower body strength and endurance. Although our study measured subjective intensity of the active gaming using RPE, a previous study by Graves et al. 2010 using Nintendo Wii Fit concluded that active gaming stimulated a light (Wii yoga, muscle conditioning and balance games) to moderate (Wii aerobics) intensity activity for young and older adults (320). Therefore, the IVG sessions over 12 weeks could possibly have had a significant impact on individual's cardiorespiratory fitness. The maintenance of cardiorespiratory fitness for older adults is especially important for independent living as most daily activities require endurance and stamina (377). Older adults often have to walk long distances such as walking from their place of residence to a public bus stop which could be a fair distance away (377). Furthermore, activities such as running shopping errands will also require a certain level of stamina, especially if going from one shop to another or various different shops that are spaced apart (377). A recent systematic review showed that cardiorespiratory fitness was positively associated with memory function in older adults (378). If participating in IVG has the potential to improve cardiorespiratory fitness in older adults, it may be a means of also improving memory function, particularly in older adults with some level of memory complaints.

Our study showed that balance and mobility improved significantly for the intervention group in the functional reach, dynamic balance, and timed up and go test. The interactive gaming group had significantly better scores on all of the above mentioned proxy measures of balance and mobility when compared to the conventional multimodal supervised exercise comparison group after 12 weeks. Previous studies have identified IVG as a means to improve balance and mobility in

older adults (273;379). Bieryla and Dold. 2013 illustrated significant improvements in balance for individuals participating in Nintendo Wii Fit 3 times a week for 3 weeks compared to the control group who continued with normal activities. This is particularly important as an individual's balance is coordinated by different physiological systems within the body. If this system is diminished, there is known to be an increased risk of falling in older adults (95). In addition, falls have severe consequences that are accompanied by pain and decreased mobility for daily tasks such as walking up and down stairs. An improvement in balance may help reduce the risk of falling and thus indirectly improve an individual's quality of life.

Similarly, Chien-Hung et al. 2013 also found positive effects of IVG on balance in older adults (379). Group A participated in IVG for 6 weeks followed by no gaming for the next 6 weeks and Group B received no intervention for the first 6 weeks followed by gaming for the next 6 weeks. 12 weeks post intervention both groups improved significantly in balance measured by the Berg balance scale, Modified falls efficacy scale and the Timed up and Go test (379). The results from our study were similar to the above mentioned studies however; our study consisted of participants with some level of memory complaints while the previously mentioned studies included individuals with higher cognitive function. We must acknowledge that, although our study illustrated significant differences in balance between both groups in favour of the IVG group, the type of activities performed by both groups varied in nature. The intervention group performed active games in a standing position for most of their session (unless on a break in pairs) and therefore participated in more weight bearing compared to the comparison groups combination of standing and seated exercise. Participation in activities that are more weight bearing inclined may have a positive influence on balance. Maintenance of balance and mobility in the later years of one's life is of particular importance as a worsening of either balance or mobility is associated with an increased risk of injury through falls (351). Older adults that experience falls in their 6th and 7th decades of their life often incur fractures (380). The increased risk of injury through falls coupled with an inactive lifestyle may further reduce independency and quality of life. 80% of all fall-related deaths occur in low-and-middle income countries with death rates highest among the elderly aged 60 years and older (381). Furthermore, a reduction in mobility may also lead to

diminished physical activity levels which could further lead to a sedentary lifestyle. South Africa is a low-to-middle income country, with a lack of safe community resources to promote physical activity and well-being in older adults. Therefore, participating in IVG as a form of physical activity may also promote and improve certain components of functional ability such as balance and mobility in older adults and therefore allow for better quality of life.

Several strengths of this study are notable. Firstly, the high adherence rate by participants in the IVG and CM groups. All participants included in the final statistical analysis completed all physical function and cognitive assessments as well as attended 100% of their respective session. Secondly, to our knowledge, this study addresses the gaps in the literature as it is the first study to show cognitive and physical function benefits of IVG (X-box 360 gaming console with Kinect Sports software package) in older adults from a low-to-middle income country with subjective and objective memory complaints, in comparison to conventional multimodal exercise. Thirdly, the retirement homes in this study were cluster-randomized into either the intervention or control group which helps to avoid contamination between groups. Furthermore, the IVG console and software used in this study are portable and therefore may be easily transported and set up in individuals home to promote physical activity.

A limitation of this study was that it was conducted in a single blind manner, although efforts were made to decrease bias on re-assessment. Another limitation to this study was that the rate of perceived exertion for each session measured by the Borg Scale was not formally recorded for data analysis.

In summary, a low to moderate intensity IVG program improves executive function and global cognitive function in older adults with subjective memory complaints. This intervention resulted in greater improvements in cognitive function than conventional multimodal supervised exercise. Participants in the IVG group experienced improvements in balance and mobility at 12-weeks, measured by the functional reach, timed up and go and dynamic balance tests.

Consequently, low to moderate IVG has the potential to increase physical activity in older adults as it may overcome many physical activity barriers for older adults such as built up suburbs and cities that may not be suitable for activities such as walking and cycling, inclement weather and social isolation. Interventions of this nature will be sustainable and beneficial to older adults should volunteer workers be trained to conduct sessions at retirement homes and community centres. Further investigations on the long-term effects of IVG in individuals with subjective memory complaints should be conducted with a larger sample size and a longer intervention period. A larger sample and longer IVG intervention may be able to identify the optimal prescription of IVG for individuals with subjective memory complaints in the future.

CHAPTER 6: DISCUSSION AND CONCLUSION

Discussion

The percentage of older adults is increasing worldwide (46;48). The life expectancy of elderly people around the global is also on the increase due to improvements in health, safety, technology and overall standard of living (50;51). The ageing process is inevitably associated with a decrease in cognitive and functional performance that may later lead to a dependent lifestyle (382). It has been widely accepted that exercise can improve cognition in older adults (359). Specifically, aerobic exercise enhances cognitive performance by maintaining cerebral blood flow and increasing the amount of oxygen transported to the brain (359). In addition, aerobic exercise has the ability to improve the function of cerebral neurotransmitters by stimulating nerve cell regeneration (359). A vast amount of the literature has focused on the positive benefits of conventional exercise interventions on cognitive and functional performance with a relatively limited amount of research showing the benefits of less traditional forms of physical exercise such as Yoga, Pilates and more recently, IVG in older adults (133;213;214;219;328;346). In addition, research on physical activity and exercise in older adults with memory complaints are limited.

Consequently, the main aim of this thesis was to determine the effects of a 12-week intervention in the form of interactive, sport and adventure video gaming on cognitive performance in South African older adults with memory complaints. Importantly, the participants were naïve to video gaming. We hypothesized that the IVG intervention would show greater enhancements in measures of cognitive performance and functional ability than the conventional multimodal standing and seated exercise intervention. The thesis was undertaken in a stepped manner, firstly to establish the relationship between physical capacity and cognitive performance in highly functioning older adults, in part, to test our tools for measurement. Our next study, examined the feasibility and acceptability of such a gaming intervention in older adults, living in residential homes, compared to more conventional “table games”. Our final study was a controlled, cluster-randomized intervention, comparing video gaming to more conventional forms of therapist-led chair exercise.

The first study (chapter 2) of this thesis examined the relationship between fitness, functional ability and cognitive performance in independent living, high functioning older adults. In addition, we aimed to determine which fitness and functional tests best describe the variance in cognitive function. We found that functional ability measures such as Functional Reach, Dynamic Balance and Grip strength were significantly related to the number of correct responses, mistakes and missed responses on the Modified Stroop task. Our findings indicated that individuals who scored higher on the Functional Reach test produced fewer incorrect responses on the Modified Stroop task. Furthermore, there was an inverse relationship between Dynamic Balance and the number of correct responses on the Modified Stroop task.

These findings are important as both Functional Reach and Dynamic Balance are measures of balance (153;154). A decline in balance with age may be due to a decrease in function of the neuro-musculoskeletal systems that help to maintain balance (95). Previous research showed that physical exercise is effective in improving physical function in older adults (383). In addition, regular physical activity and enhanced fitness has been shown to improve cognitive performance in older adults (384). Due to our study participants comprising of high functioning, healthy older adults, it could be speculated that they may be more inclined to be physically active or participating in levels of physical activity which may have a positive effect on functional ability measures such as balance. Furthermore, improvements in balance through physical activity and exercise may stimulate the vestibular system by inducing changes in the hippocampus and areas of parietal lobe through direct pathways (385). The parietal lobe plays an important role in the integration of spatial awareness and proprioception. Moreover, various areas of the parietal lobe are involved in the processing of language and writing which are cognitive constructs (386). The associations identified between measures of balance and cognitive performance could be due to individual's being high functioning and physically active and therefore allowing for enhancement of these brain areas.

Another finding from study 1 (chapter 2) was that Grip strength was positively associated to the number of correct responses of the Modified Stroop task. This could indicate that individuals with greater strength may also have superior executive

function. Our finding is in line with previous research conducted by Alfaro-Acha et al. 2006 who stated that older persons with grip strength in the highest quartile maintained higher levels of cognitive function over a seven year period (300). As a result, it might suggest that individuals who are stronger and better balanced do more physical activity, and this overall improvement in functional measures is associated with retention in cognitive performance in older adults. This suggests that maintenance of one's functional capacity may also play a role in cognitive performance in one's later years which will help maintain an independent lifestyle. Exercise interventions targeting various functional components should be conducted to improve one's functional capacity and indirectly reduce cognitive decline.

The second study (chapter 3) aimed to determine the feasibility and acceptability of IVG in older adults. We had some concerns that the perceived level of difficulty might decrease and inhibit the level of participation. The first finding of interest was that the average heart rate of the entire IVG session equated to approximately 57% of the age-predicted maximal heart rate which represents moderate intensity physical activity. Compared to previous research conducted by Graves et al. 2010 who determined the physiological cost and enjoyment of the Nintendo Wii fit, the average heart rate of our IVG session was significantly higher than inactive handheld video gaming but 5% lower than brisk treadmill walking (320). Although our average heart rate of the IVG session was lower than the treadmill walking, IVG elicited intensities high enough to meet the recommendations of moderate intensity physical activity and thereby achieving health benefits according to the American College of Sports Medicine (ACSM). This suggests that this form of IVG can also be implemented as a form of moderate intensity physical exercise for older adults.

The second finding from study 2 (chapter 3) was that individuals who reported having higher levels of difficulty with IVG had significantly fewer correct responses on the Modified Stroop task. One of the reasons for this could possibly be due to the adaptations that occur in the central and peripheral nervous system with age. A reduction in function of the central and peripheral nervous system has been shown to slow down simple and choice reaction time which leads to a reduced capacity to integrate information (58). It is probable that the ageing process leads to slower

reaction times to a stimulus which may cause confusion thus leading to more mistakes. An individual who has a faster reaction time has more time to respond precisely and correctly to a stimulus of the same magnitude than an individual with a slower reaction time. Similarly, individuals who found the IVG session more difficult also had lower grip strength scores on the non-dominant arm. Interestingly, perceived difficulty of IVG was not associated with overall enjoyment and average heart rate of the session. Even in those who reported higher perceived levels of difficulty, more than 90% of participants indicated that they enjoyed the games and would play IVG in the future, as a means to improve physical well-being. These findings suggest that even those individuals who had greater levels of perceived difficulty were still able to play the IVG at intensities and enjoyment levels similar to those that found the IVG session easier. All games had similar peak and average heart rate responses indicating that older adults can choose the particular game that they enjoy, and still be able to acquire the physiological health benefits of playing. Older adults can gain health benefits of physical activity by participating in IVG in the comfort and safety of their own homes. Furthermore, IVG can be played with family and friends and can increase their social interaction and reduce loneliness. IVG also has the potential to reduce various barriers to physical activity such as unpredictable weather, lack of public resources and facilities as well as unsafe communities, especially in South Africa. Consequently, IVG could be an appropriate form of physical activity for older adults with varying levels of ability.

In the third study (chapter 4), we aimed to determine the effectiveness of a 12-week IVG intervention, compared with 'table games' on cognitive performance and functional ability in healthy older adults. The main finding of the study was that the intervention group demonstrated an improvement in functional reach, thus, partially supporting our hypothesis. However, there was no other group by time effects for physical function. Our finding is supported by Sato et al. 2015, who also found improvements in balance measured by the functional reach test in healthy older adults who participated in active gaming twice a week for 24 sessions (274). We speculated that the improvement in functional reach in the IVG group was a consequence of the movements used during the game, as most of the games required components of balance and agility. Although balance improved, no other

significant effects were identified for physical function. This may be due to our participants being highly functioning individuals and therefore less inclined to show improvements post intervention. Based on the improved balance in our intervention participants, IVG might be a suitable intervention for older adults to preserve their functional ability. IVG programs of this nature and duration might be a safe and stable way for older adults to meet physical activity guidelines. The IVG program may also further allow or at least assist older adults to preserve certain components of fitness such as balance and stability. Retirement homes can train caregivers to administer IVG programs to residents, especially those that are at an increased risk for falls and those that have balance and stability concerns. Older adults may benefit from their participation in IVG, in helping to maintain functional independence. Older adults can perform everyday activities such as walking or standing on uneven ground, walking up and down stairs and reach out for items in various directions in a more controlled and relaxed manner without the fear of falling and getting injured.

Another finding from study 3 (chapter 4) was that the comparison group demonstrated significant improvements in average reaction time for correct responses measured during the Modified Stroop task. These improvements may have been related, at least in part, to their participation in cognitively stimulating games. Previous work has shown that participation in cognitive stimulating sedentary activities such as reading, board and card games and puzzles are associated with a reduced risk of cognitive impairment and dementia in older adults (241;242). A study by Hughes et al. 2010 found that individuals who participated in higher number of sedentary leisure activities and games for longer periods of time were less susceptible to developing dementia and that participation in such activities for more than one hour per a day may protect individuals from the onset of dementia in one's later years (241). Similarly, Dartigues et al. 2013 found that individuals who played board games on a regular basis were less likely to develop dementia than individuals who did not participate in any board games (242). They concluded that board games stimulate the brain and motivates decision-making and competition as well as adds a social component that encourages participation. Partaking in cognitively stimulating sedentary games may positively affect areas of the brain responsible for executive function and processing speed in ways different to physical activity and exercise.

Exercise has been shown to physiologically mediate enhancements in cognitive performance through improved cerebral blood flow and oxygen supply to the various areas of the brain. Due to the nature of the cognitively stimulating sedentary games compared to exercise, the improvement in cognitive performance may occur via different mechanisms. Cognitive stimulating table games were identified as a possible means to improve components of cognitive performance as it requires individuals to plan, utilize complex thinking skills as well as make decisions. In addition, sedentary table games including cards, rummikub, dominos and various board games such as scrabble and chess might be feasible for older adults as most of the games allow for multiple players, does not require a specified period of time to complete and are inexpensive to purchase.

Centred on the results and outcomes from the previous studies (chapters 2, 3 and 4) within this thesis, we established that physical function is related to cognitive performance in healthy independent living older adults. In addition, IVG was regarded as a fun and enjoyable activity that can be used to improve physical well-being as it equates to moderate intensity physical activity. Furthermore, 12 weeks of IVG was effective in improving balance in healthy older adults. Most other functional and cognitive outcomes improved after 12 weeks of IVG but many did not reach a level of significance.

These findings led us to our fourth study (chapter 5) which determined the effectiveness of IVG in older adults with memory complaints. The aim was to determine the effectiveness of a 12-week IVG intervention, using the X-Box 360 gaming console with Kinect Sports games, on cognitive performance in South African older adults with subjective and objective memory complaints. This intervention was compared to a conventional multimodal supervised exercise program which served as the comparison group. We hypothesized that the IVG group would illustrate significantly greater improvements in cognitive performance and functional ability compared to the comparison group. The results from our study supported our hypothesis as the Modified Stroop task and the Mini-Mental State Examination significantly improved post intervention in the IVG group with no changes to the conventional multimodal supervised exercise comparison group.

The IVG group showed improvements on the Modified Stroop task for the total number of correct responses, total correct colour word responses as well as the average reaction time of correct colour words. Various forms of traditional exercise training such as cardiovascular, resistance and balance are associated with enhanced cognitive performance (133;209;346). One of the reasons could be due to the increase in oxygen availability for cerebral activity which aids neurocognitive performance that arises from fitness training (359). We speculated that improvements in executive function on the Modified Stroop task may be due to improvements in aerobic fitness from consistent participation in IVG. Our results are supported by Maillot and Perrot. 2012 who found that participation of Nintendo Wii Sports games over 12 weeks significantly improved executive function and processing speed when compared to sedentary counterparts (260). Similarly, Anderson-Hanley et al. 2012 also found significant improvements in executive function after 3 months of virtual reality cycling (Cyber-cycling) compared to traditional cycling (263). The results from our study, along with Maillot and Perrot. 2012 and Anderson-Hanley et al. 2012 indicate that IVG can improve executive function in ways similar to traditional exercise. The improvement in executive function could be due to the intellectual effort required such as remembering sequences or instructions when playing a specific game, in addition to the physical exertion required. Executive function capabilities are essential to successfully carry out everyday life activities such as cooking. An individual needs to be able to concentration and switch between important tasks' including preparing ingredients, making sure the cooking temperature is optimal and making sure one is particularly careful with certain utensils. Similarly, executive function capabilities such as planning, complex thinking and decision making are needed on a daily basis when driving. Older adults may improve and maintain functional independence by participation in IVG, in terms of both fitness and executive cognitive function.

Further to the improvements in executive function, we also demonstrated a significant improvement in global cognitive function measured by the Mini-Mental State Examination in favour of the IVG group. The Mini-Mental State Examination is a widely and frequently used tool to assess change in cognitive function over time

(199). Research studies by Suzuki and colleagues. 2013 and Kwak et al. 2008 support our finding on the Mini-Mental State Examination; however, both studies used multiple component traditional exercise programs as opposed to our IVG intervention (229;235). In addition, both study populations were more impaired than our study participants.

We also identified significant improvements in functional ability. Cardiorespiratory fitness, measured by the 6-minute walk test significantly improved in the IVG group post intervention. To our knowledge, few studies have illustrated improvements in cardiorespiratory fitness in individuals participating in IVG. A recent study by Lund and Jessen. 2014 found similar results to our study by showing a significant improvement in the 6-minute walk test after 12 weeks of using interactive modular stepping tiles as an intervention program (376). Although results were similar, Lund and Jessen. 2014 did not have a control intervention for comparison. The improvement in 6-minute walk test scores in our study could potentially be due to the movement and intensity required for IVG, compared to conventional multimodal supervised exercise. In the present study, the IVG required various fitness components such as agility, balance, endurance, lower body strength and flexibility. Maintaining cardiorespiratory fitness in older adults is vital as most everyday activities require some level of endurance and stamina. An activity such as going out shopping generally requires an individual to walk long distances such as walking from their home to the public bus stops. In addition, running shopping errands will also need an individual to have a certain level of stamina, especially if one has to visit various shops that are spaced apart. Furthermore, a review by Ridgon and Loprinzi, 2019 concluded that cardiorespiratory fitness is associated with memory function (378). Therefore, if IVG can be played to improve cardiorespiratory, it may also assist in improving memory function in older adults, especially those that have some level of memory impairment.

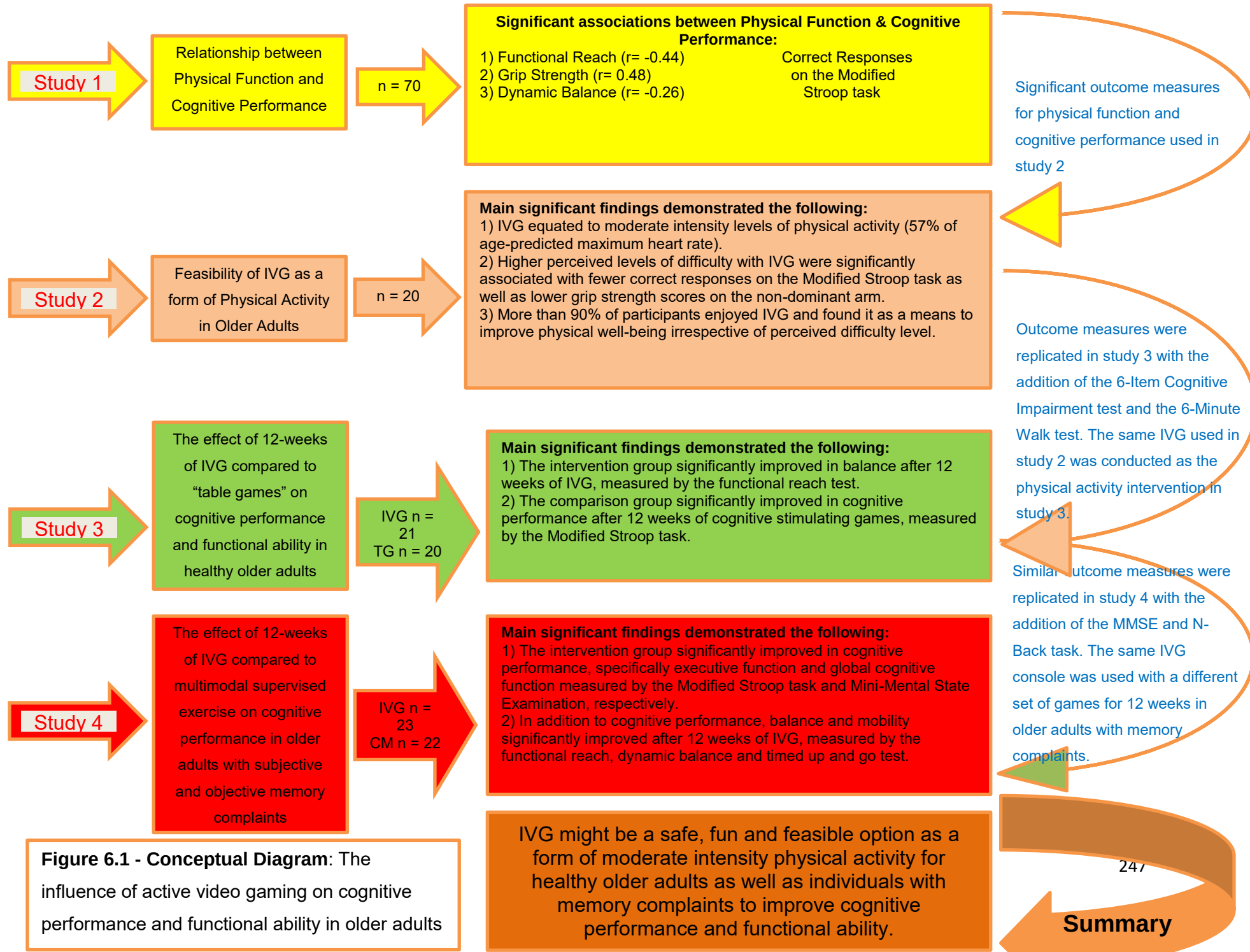
Furthermore, our study also showed significant improvements in balance and mobility in favour of the IVG group for functional reach, dynamic balance and the timed up and go test. Balance is coordinated by various physiological systems. A decline in the function of these systems may increase the risk of falls which

consequently leads to reduced mobility for daily activities. In this regard, improvements in an individual's balance may lead to a better quality of life. All above-mentioned proxy measurement scores for balance and mobility were significantly better in the IVG group when compared to the conventional multimodal supervised exercise comparison group. Our findings are similar to those by Bieryla and Dold. 2013 and Chien-Hung et al. 2013 who also illustrated positive effects of IVG on balance after 3 weeks and 12 weeks (6 weeks of IVG followed by 6 weeks of normal activity / no gaming) of participation respectively (273;379). Although our study found similar results to the above-mentioned studies, they found significant improvements in balance over a shorter intervention period. While this may be true, the studies conducted by Bieryla and Dold. 2013 and Chien-Hung et al. 2013 excluded individuals with any cognitive impairment therefore including higher cognitive functioning individuals. This may indicate that the duration required to demonstrate effects of IVG on balance may vary depending on the cognitive functioning of the individual. This is important as physical fitness and functional ability are known to be associated with cognitive function in older adults. Maintenance of balance and mobility later on in one's life is especially important as a decline in either balance or mobility is known to be associated with increased risk of injury through falls (351). In addition, a decrease in balance and mobility may lead to reduced physical activity levels which could then also subsequently lead to a sedentary lifestyle. According to the WHO, most fall-related deaths occur in low-to-middle income countries such as South Africa with the highest fall-death rates among the elderly aged 60 years and older (381). This may further highlight the benefit of IVG as a form of physical activity to promote and improve certain components of functional ability in older adults and therefore allow for better quality of life.

Taking both studies 3 and 4 into consideration as described above, from a methodological perspective, one may question the choice of control conditions as an inactive control group is missing for studies 3 and 4 (chapters 4 and 5). From a logistical perspective, it was not possible to include both an inactive and an active control group. We chose to include an active control group based on the rationale that including an active control group that receives a different treatment

contemporaneously with the experimental group is regarded to be a stronger study design than including just a passive control group (387;388). One of the reasons for this is the potential of overstating the outcome of the experimental intervention because most interventions are more effective in changing cognitive outcomes or certain behaviors than passive control groups and the mere passage of time (389;390). Furthermore, the choice of the different active control groups in these chapters could be questioned. Although it may have been preferred to have the same control group for both studies for comparative purposes, we also had a clear rationale for the choices. The choice of the control condition described in chapter 4 was based on evidence from previous research. In 2013, Dartigues and colleagues concluded that playing board games is a cognitively stimulating sedentary activity as it allowed planning, decision-making and competition (242). Another study by Nouchi et al. 2012 used digital sedentary games that required participants to either read aloud and do simple arithmetic calculations (Brain age intervention group) or play Tetris (Tetris active control group) for 15 minutes, 5 times a week for 4 weeks (244). Results showed that the effects of brain age training significantly improved executive function measured by the Frontal Assessment Battery at bedside and the Trail-Making Test-B compared to the Tetris group. Krell-Roesch et al. 2017 showed that after a 4 year follow up, participation in mentally stimulating activities such as playing games was associated with a reduced risk of MCI (246). Based on these previous studies, playing cognitively stimulating games has shown positive effects on cognitive function in older adults. Although the above-mentioned studies have shown benefits of cognitively stimulating table games on cognitive performance in older adults, a review study found no significant differences between combined physical and cognitive interventions and single stand-alone cognitive interventions in older adults for various cognitive domains (215). This observation by Zhu et al. 2016 may further warrant the need to compare an intervention such as IVG with cognitively stimulating table games in older adults. Therefore, the rationale behind the control condition in chapter 4 was to identify how IVG (cognitive stimulation with physical exercise) compared to cognitively stimulating table games in terms of both cognitive function and functional capacity in older adults.

After the completion of chapter 4 comparing IVG (cognitive stimulation with physical exercise) with cognitively stimulating table games on cognitive and functional capacity in healthy older adults, the change in control conditions from chapter 4 (cognitively stimulating table games) to chapter 5 (conventional multimodal supervised exercise) was to identify if IVG was as or more effective than exercise alone to improve both cognitive performance and functional capacity in older adults with memory complaints. The rationale behind the change in control conditions was based on previous research on physical activity and cognitive performance. Research on conventional exercise has shown positive effects of exercise on physical function (360) and cognitive performance in older adults (391), with minimal research being conducted identifying the effects of conventional multimodal exercise on cognitive performance in older adults with memory complaints. Moreover, research on IVG compared to conventional multimodal supervised exercise on cognitive performance in older adults with memory complaints is lacking.



Strengths and Limitations

One of the strengths of this thesis was the use of IVG as a form of physical activity in healthy older adults as well as older adults with memory complaints with positive effects been shown in both populations (chapter 4 and 5). This is one of few research studies comparing IVG to a traditional seated exercise regime (chapter 5) and cognitively stimulating sedentary games (chapter 4) in South African older adults. Moreover, chapter 3 of this thesis is one of the first studies investigating heart rate response to IVG as well as the perceived difficulty of IVG and its relationship to functional ability and cognitive performance in South African older adults. Lastly, the outcome measures for functional ability and cognitive performance used in all studies within this thesis have been widely used and recognized.

A limitation within this thesis was the significant difference in cognitive performance characteristics at baseline, specifically for the Modified Stroop task in Study 3. The table games control group had a significantly slower average reaction time for all correct responses and correct colour words compared to the IVG intervention group. Due to these significantly slower reaction times at baseline, it may have allowed the table games group a greater margin for improvement compared to the IVG group post intervention.

Conclusion

In conclusion, my thesis explored the hypothesis that IVG would offer significantly greater improvements in cognitive performance and functional ability compared to conventional multimodal exercise in older adults with memory complaints. A further hypothesis within this thesis was that higher levels of physical fitness and functional ability would be related to higher levels of cognitive performance in older adults.

The main finding from this thesis was the improvement in cognitive performance and functional ability induced by the IVG intervention after 12 weeks. We found positive intervention effects on cognitive performance in study 4 (chapter 5) as well as positive intervention effects on functional ability in studies 3 and 4 (chapters 4 and 5). In these studies, the effects of IVG were examined in healthy older adults (chapter 4) and older adults with memory complaints (chapter 5). This indicates that

the IVG intervention might be feasible for older adults with memory complaints as well as healthy individuals. Furthermore, the positive effects of the active gaming intervention may indicate the potential for IVG as a low to moderate intensity form of physical activity in older adults which is considered to be fun and enjoyable that will produce health benefits similar to that of supervised multimodal exercise. IVG may also help reduce and overcome physical activity barriers such as robust and busy built up suburbs and cities, unsafe neighborhoods for walking and cycling as well as inclement weather and social isolation. On the basis of these results, it can be concluded that IVG is favourable for improving cognitive function and functional ability in older adults with subjective and objective memory complaints.

In low-to-middle income countries such as South Africa, the implementation of structured IVG programs in retirement homes and community centers may be of benefit to the older adult population. By training volunteers and caregivers to administer and conduct IVG programs in communities, it will allow a fair number of senior older adults to become physically active in a fun and enjoyable manner which will have positive benefits on their functional and cognitive performance. Furthermore, implementation of low-to-moderate intensity IVG programs within communities will also reduce and overcome many barriers to physical activity. Although IVG showed some positive effects on cognitive performance and functional ability in older adults with and without memory complaints, the optimal dosage of such programs needs to be further researched. Future research should also focus on measuring cognitive and functional outcomes at regular time points to best understand the effects of IVG on these parameters.

CHAPTER 7: REFERENCES

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CHAPTER 8: APPENDICES

Appendix A1: Participant Informed Consent and Information Sheet (Chapter 2)



Department of Human Biology

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DISCOVERY HEALTH PROFESSOR OF EXERCISE AND SPORTS SCIENCE

Healthy ageing: developing a protocol for evaluating ageing functional capacity

Background and Purpose of Research Study:

Many physiological capacities such as muscle strength, aerobic capacity, co-ordination and flexibility deteriorate with ageing, which could lead to functional limitations and possibly the loss of independence. Physical function is made up of both physiological and cognitive capacities to optimize physical performance in daily function. Declined function and slower mobility has also been associated with cognitive (mental) performance resulting in reduced mental speed and flexibility. These cognitive declines then contribute to the impaired functional abilities leading to an increase in formal and informal service use among older adults. However, most of the research studies investigating the role of fitness and cognitive performance only considered cardiovascular fitness, where strength, endurance and flexibility muscle were seldom included.

Aim:

Therefore the aim of this study is to develop a battery of tests to assess the fitness, functional performance and cognitive ability in independently living South African older adults. In addition, we would like to determine which fitness parameters and functional performance tasks are closest associated with cognitive ability, and whether this relationship is influenced by level of fitness.

Methods:

Each participant will be invited to attend the testing at the Sports Science Institute in Newlands. All the testing will be completed on the same day and will take approximately 2 hours. Light refreshment will be served after an hour.

Questionnaires

Before starting any of the testing, the researchers need to ensure that it is medically safe for you to participate, by asking you to complete a health risk assessment form. If you are at high risk for coronary artery disease, we will require a letter of consent from your health care provider before commencing with the testing.

The Yale Physical Activity Survey (Part 1) is a questionnaire that was developed for older adults. This questionnaire requires the participant to recall the amount of time spent in household, yard-work, recreation, care-giving and exercise-related activities.

Fitness:**6-Minute Walk test:**

The aim of this test is to see how far an individual can walk in 6 minutes. You will be requested to walk as far as possible for 6 minutes, around a 70m indoor track. You can choose your own pace and are free to take a break during the 6 minutes if needed. In addition, you can stop the test before at any time if you feel too tired to continue.

Biceps Curls

Men will receive a 5kg dumbbell and women a 2kg dumbbell. You will be requested to complete as many biceps curls in 30 seconds. This test measures endurance, and similar to the first test, you can stop before the 30 seconds have elapsed.

Functional Ability:

This component comprises of 6 tests.

Static balance

The left foot will be positioned directly behind the right foot so that the left toe is touching the right heel. Participants will be requested to maintain this stance without holding onto any support, for up to 30 seconds. The test will be repeated with the left leg in front.

Dynamic balance

Participants will be requested to walk 6m using the tandem gait, which entails walking heel to toe, so that if stepping forward with the left foot, it goes directly in front of the right foot so that the left heel is touching the right toe. The time taken to cover this distance will be recorded.

Timed up and go

Participants will start in a seated position on a standard chair, then stand up, walk 3m, turn around, walk back to the chair and sit down. The time taken to complete the task will be recorded.

Grip Strength

Participants are requested to squeeze a hand held dynamometer as hard as possible without bending the elbow, while remaining seated. The maximum value of four attempts; comprising of two attempts for each of left and right arms, will be recorded.

Sit to stand

Participants will sit in a standard chair with no arm-rests, with their hands folded across the chest. They will then be instructed to rise from the chair and sit down again five times as fast as possible, without using their arms for assistance. The time taken to perform the task will be recorded

Functional Reach

A yard-stick or tape-measure will be mounted at shoulder height on a wall. Participants will stand next to the wall (sideways) and be requested to reach as far forward as possible along the yardstick without moving / taking a step.

Cognitive performance:*The six-item cognitive impairment test (6CIT)*

You will be asked six questions related to memory and cognitive performance. This assessment includes questions assess memory and concentration. The number of errors made by the participant for each question will be scored and weighted. The scores range from zero to 28.

Modified Stroop test

This test is completed in a small, quiet room. You will be required to identify colours and words that appear on a computer screen. You will need to identify the colour of the letters as opposed to the word being spelt. The colour words will either be presented in grey ink or in a colour ink incongruent with the meaning of the word, i.e. blue in red colour, or yellow in green colour, but never green in green colour or red in red colour, etc.

Benefits and risks*Benefits:*

Participants will gain insight into to their levels of functional ability, and identify areas that may need improvement. Furthermore, they will have a cognitive ability assessment, which is not readily accessible to older adults. This will give them an idea of their own cognitive performance and how it is correlated with functional ability and physical fitness.

Risks:

The overall risk of participating in this research study is very low. All the functional and fitness assessment protocols are at a sub-maximal workload, thus reducing the risk of injury or an event during testing. Furthermore, the tests will be conducted at the SSISA facilities, where a 'crash cart' is kept on the same floor as testing. There is also a Sports Medicine practice in this facility, thus a doctor will be present if needed. Finally, SSISA has an agreement with emergency medical services that they will respond within four minutes of the panic alarm being activated.

The researchers do however feel that the intensity of these tests is of a very low intensity, and it is highly unlikely that these services will be required.

Freedom of Consent:

Your participation in this test is voluntary and you have the freedom to withdraw at any stage.

Please note that this study will be conducted in accordance with the Declaration of Helsinki, Good Clinical Practice as well as the laws of the Republic of South Africa.

Inquiries:

Please feel free to contact Dr Tracy Kolbe-Alexander (021 650 5126 or tracy.kolbealexander@uct.ac.za) if you need any further information or points of clarity. Please feel free to ask about any aspects of the research.

Head, Research Ethics Committee, Faculty of Health Sciences Professor Mark Blockman Room E52-24 Groote Schuur Hospital Old Main Building, Observatory 7925; Telephone [021] 406 6338 . Facsimile [021] 406 6411

Consent Form:

Healthy ageing: developing a protocol for evaluating ageing functional capacity

Declaration by Participant:

I the undersigned _____, hereby agree that I have fully read and understood the information sheet and that I understand the nature, purpose and procedures of this research study. My agreement to participate in this study is voluntary and I am aware that I can withdraw at any stage that I feel appropriate. On the basis of the above, I hereby agree to participate in this study being conducted by the UCT/MRC Research Unit of Exercise Science and Sports Medicine.

Name of Participant: _____

Participant Signature: _____ Date: _____

Name of Researcher: _____

Researcher Signature: _____ Date: _____

Name of Witness: _____

Witness Signature: _____ Date: _____

Principal Investigator:

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Appendix A2: Participant Informed Consent and Information Sheet (Chapter 5)



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Participant Information Sheet and Consent Form

Effects of 12 weeks of Interactive Video Gaming on Cognitive Performance in Older Adults with evidence of both objective and subjective memory complaint

What is this study about?

Decreases in muscle strength, breathing capacity, flexibility and coordination have been observed with increasing age. In addition changes in mental function like decreased short-term memory and slower reaction times also take place. These changes may impact on older adults' ability to carry out their daily activities, and can reduce their levels of independence.

The aim of this study is to measure the effects of 12 weeks of interactive video gaming on mental function in older adults with evidence of both objective and subjective memory complaint.

We are particularly interested in establishing whether or not physical activity will have similar beneficial effects on physical and mental capacity in older adults with memory impairment.

Why have I been invited to participate?

You have been invited, because you are an adult over the age of 65 years and the results of your screening suggest that you have subjective and objective memory complaints.

If I choose to participate, what is involved?

You will be asked to participate in interactive video gaming twice per week, for 12 weeks at your community centre. One of the researchers will be present to conduct each of these gaming sessions and to ensure that you are exercising at not more than a low-to-moderate intensity. This will also give you an opportunity to speak to the researcher about any questions that you might have as the research study progresses.

In addition, we will invite you to have some physical measurements taken and to complete a survey at our research unit, which based at the Sports Science Institute of South Africa (SSISA) in Newlands before starting the 12 week program. Transport will be arranged for you from your residential address to the SSISA facility and back for specific testing days.

All the testing will be completed on the same day and will take approximately 2 hours. Light refreshment will be served at each testing session. All tests and measurements are explained below.

Questionnaires:

Screening Criteria:

You will be required to undergo a screening process to determine if you have subjective and objective memory complaints. This will be done by asking you a few simple questions related to any memory complaints as well as objective memory impairments. We will also ask you questions related to your activities of daily living and mental function.

Health status:

The researchers need to ensure that it is medically safe for you to participate; by asking you to complete a health risk assessment form. If you are at high risk for coronary artery disease, we will require a letter of consent from your health care provider before commencing with the testing and be allowed to participate in the research study. The health risk assessment form will be administered to you at baseline only.

Demographic, Health and Wellness Questionnaire

You will be asked questions about your age, gender, marital status, occupation, health status and past education. The second group of questions are related to the amount of time you spend in household, yard-work, recreation, care-giving and exercise-related activities during the past week (YPAS Part 1).

Body measurements

The researcher will measure your height, weight and waist and hip circumferences. We will also measure your body fat and muscle mass. The researcher will use a small caliper to measure the fat at the back and front of your arm, the back of your shoulder and on your hip. One of our researchers will gently pinch the skin between a thumb and forefinger and measure the thickness of this skinfold using a blunt metal caliper. This procedure is painless and may only cause some slight discomfort. All your body measurements will be taken at baseline and after 12 weeks of the exercise programme.

Physical Function Tests

Dynamic balance

You will be asked to walk 10m on a straight line, heel to toe. (If you stepping forward with the left foot, it goes directly in front of the right foot so that the left heel is touching the right toe). We will record the time it takes you take to complete 10m.

Timed up and go

You will begin this test in a seated position on a standard chair, then stand up, walk 3m, turn around, walk back to the chair and sit down. The time taken to complete the task will be recorded.

Grip Strength

You will be asked to make a fist and squeeze a meter which is held in your hand, to measure your 'grip'. You will be asked to do this twice on each side, and the best score will be recorded for both right and left hands.

Functional Reach

This test begins by you standing alongside a wall mounted yard-stick or tape measure at shoulder height. You will then be required to reach as far forward as possible along the yardstick without moving or taking a step.

6-Minute Walk test

You will be asked to walk as far as possible in six minutes around a 70m indoor track with one chair positioned at the start and one at 35m, to give you an opportunity to sit and rest if needed. The total distance covered will be recorded in meters.

You will be requested to complete all physical function tests at baseline and after 12 weeks of the exercise programme.

Cognitive Performance Tests

Mini-Mental State Exam

You will be required to answer 11 questions concerning orientation, registration, attention and calculation, recall and language. The test will take between 5-10 minutes to administer.

Modified Stroop Task

You will be required to identify colours and words that appear on a computer screen. You will need to identify the colour of the letters as opposed to the word being spelt. The number of correct and incorrect responses will be recorded.

The “N-Back” Task

During this task, you will be presented with a sequence of letters one at a time in the centre of a computer screen. You will be required to compare and respond to the specific letter on the computer screen with a letter that was either presented one place before or two places before. The number of letters correctly and incorrectly identified and responded will be recorded.

The Clock Drawing Task

During this task, you will be presented with a sheet of paper with a pre-drawn circle. You will be required to write the numbers on the clock.

You will be requested to complete all cognitive performance tests at baseline and after 12 weeks of the exercise programme.

Intervention

The gaming sessions will be conducted twice a week and each session will last one hour and each session will be supervised by a biokineticist. Intensity of the session will be monitored via an exertion scale ranging from 0 (Easy) to 10 (Difficult).

Benefits and risks

Benefits:

You may gain insight into your levels of cognitive performance and functional ability, and identify areas that require improvement. You will experience and enjoy the interactive video games that have been recently designed for the older adult population in a social setting with people of similar ages. We will minimize inconvenience to you by conducting all gaming sessions where you live, in your community centre or village.

Risks:

All functional assessment protocols are at a sub-maximal workload, thus reducing the risk of injury during testing. The tests that will be conducted are similar to daily activities that you do (walking, balancing, reaching, sitting and standing) and replicate similar movements that will be self-paced according to you. All of these tests have been previously administered in older adults, including previous research in our unit, where we had no adverse events.

All testing at baseline and 12 weeks will take place at the SSISA facilities, where an emergency medical cart is kept on the same floor as testing. A doctor will also be available from the Sports Medicine Practice should the need arise. Sports Science Institute of South Africa also has an agreement with emergency medical services that they will act in response within four minutes of the panic alarm being activated.

You are only eligible for the study, if you are considered low risk to participate in low-to-moderate intensity exercise, and where necessary, cleared for participation by a medical doctor. "Low risk" means that you have less than two risk factors (high blood pressure, high cholesterol or blood fat, diabetic or high glucose, family history, obesity and/or a large waist circumference, smoking, and inactivity).

All interactive gaming sessions will be supervised by a biokineticist who will monitor your heart rate and ensure that the intensity of the session remains at a low to moderate. You can determine the pace and intensity of each session and stop whenever you are tired or don't feel like continuing. You will be 'spotted' by the biokineticist to reduce the risk of falling. You will also be allowed to stop at anytime to take a break if required.

The University of Cape Town has public liability insurance, should anything untoward occur, as the result of your participation in this research trial.

Confidentiality and Freedom of Consent:

Your participation in this test is voluntary and you have the freedom to withdraw at any stage. All of your results will be kept strictly confidential. You will not be identified by name in any reports or results of this study, and all of your data will be kept in locked files, and unlinked to your personal identifying information.

Inquiries:

Please feel free to contact Udhir Ramnath (073 800 0973 or RMNUDH001@myuct.ac.za) or Prof. Estelle Vicki Lambert (021 650 4571 or vicki.lambert@uct.ac.za) if you need any further information or points of clarity. Please feel free to ask about any aspects of the research.

Head, Research Ethics Committee, Faculty of Health Sciences

Professor Mark Blockman

Room E52-24 Groote Schuur Hospital Old Main Building,

Observatory 7925;

Telephone [021] 406 6338.

Facsimile [021] 406 6411

Consent Form:

Declaration by Participant:

I the undersigned _____, hereby agree that I have fully read and understood the information sheet and that I understand the nature, purpose and procedures of this research study. My agreement to participate in this study is voluntary and I am aware that I can withdraw at any stage that I feel appropriate. On the basis of the above, I hereby agree to participate in this study being conducted by the UCT/MRC Research Unit of Exercise Science and Sports Medicine.

Name of Participant: _____

Participant Signature: _____ Date: _____

Name of Researcher: _____

Researcher Signature: _____ Date: _____

Name of Witness: _____

Witness Signature: _____ Date: _____

PhD. Student: Udhir Ramnath
Tel: 0216504564
Email: RMNUDH001@myuct.ac.za

Thesis Supervisor: Prof. E.V Lambert
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Appendix B1: Yale Physical Activity Survey (Part 1)

YALE PHYSICAL ACTIVITY SURVEY (PART 1)

Record of appointment and time	Date:	Time:

This questionnaire was developed for the use on older adults. We are using this questionnaire to calculate the amount for physical activity you participate in during a week and what is your total energy expenditure from the activities you participate in. The questions are based on 5 categories such as: work, yard work, care taking, exercise and recreation.

Code: _____

Name: _____

Address: _____

Telephone: _____

Date of Birth: _____

Age: _____

Date: _____

ACTIVITY	TIME		Days	INTENSITY CODE
	hours	minutes		
WORK				
Shopping (eg, clothes, groceries)				3.5
Stair Climbing while carrying a load				8.5

Laundry: unloading/loading machine, hanging, folding only, washing clothes by hand				3.0
				4.0
Light housework: tidying, dusting, sweeping, collecting rubbish in the home, polishing, ironing.				3.0
Heavy housework: vacuuming, mopping, scrubbing floors and walls, moving furniture, boxes or rubbish bins				4.5
Food preparation: chopping, stirring, moving about to get food items and pans.				2.5
Food services: setting table, carrying food, serving food				2.5
Dish washing: clearing the table, washing/drying dishes, putting dishes away.				2.5
Light home repairs. Small appliance repairs light home				3.0

maintenance / repair.				
Heavy home repairs: painting, carpentry, washing/polishing car.				5.5
Other:				

ACTIVITY	TIME			INTENSITY CODE
	hours	minutes	days	
YARD WORK				
Gardening, pruning, planting, weeding, digging, hoeing				4.5
Lawn mowing (walking only)				4.5
Clearing walks / driveways : sweeping, shovelling, raking				5.0
Other:				

ACTIVITY	TIME			INTENSITY CODE
	hours	minutes	days	
CARE TAKING				
Older or disabled person (lifting, pushing wheelchair)				5.5
Child care (lifting, carrying, pushing pram)				4.0

ACTIVITY	TIME			INTENSITY CODE
	hours	minutes	days	
EXERCISE				
Brisk walking				6.0
Pool exercises, stretching, yoga				3.0
Vigorous calisthenics, aerobics				6.0
Cycling				6.0
Swimming (laps only)				6.0
Other				

ACTIVITY	TIME			INTENSITY CODE
	hours	minutes	days	
RECREATION				
Leisurely / slow walking				3.5
Needlework: knitting, sewing, needlepoint etc.				1.5
Dancing: line, ballroom, tap, square etc.				5.5
Bowling				3.0
Golf				5.0
Racquet sports: tennis, squash				7.0
Billiards				2.5
Other				

Appendix B2: Physical Activity Readiness Questionnaire (PAR-Q)

PAR-Q & YOU

Physical Activity Readiness Questionnaire

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: Check YES or NO

YES	NO	
		1. Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?
		2. Do you feel pain in your chest when you do physical activity?
		3. In the past month, have you had chest pain when you were not doing physical activity?
		4. Do you lose your balance because of dizziness or do you ever lose consciousness?
		5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
		6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
		7. Do you know of any other reason why you should not do physical activity?

IF YOU ANSWERED:

YES to one or more questions
Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the

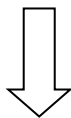
PAR-Q and which questions you answered YES.

- You may be able to do any activity you want – as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- Start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- Take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.



DELAY BECOMING MUCH MORE ACTIVE:

- If you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- If you are or may be pregnant – talk to your doctor before you start becoming more active

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should changes your physical activity plan.

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

NAME: _____

SIGNATURE: _____ DATE: _____

SIGNATURE OF PARENT or GUARDIAN: _____

WITNESS: _____

NOTE: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

Appendix B3: Demographic and Health Status Questionnaire

DEMOGRAPHIC & HEALTH STATUS INTERVIEWER QUESTIONNAIRE

<u>Name:</u>	<u>Surname:</u>
<u>Age:</u>	<u>Date of Birth:</u>
<u>Code:</u>	<u>Date:</u>

1)	1. Male		2.	
Sex:			Female	

2) Are you currently employed?			
1. Yes		2. No	
If yes, what job do you do?			

3) What is your current marital status?	
1. Married	
2. Single	
3. Divorced	
4. Widowed	

4) How many years of education did you complete?	

5) How long are you living at this current address / retirement village?

6) What is your highest level of education obtained?	
1. Primary School Education	
2. Secondary School Education	
3. Tertiary Education	

7) How would you rate your current health status?	
1. Very poor	
2. Poor	
3. Average	
4. Good	
5. Excellent	

8) Do you think your health is Better, the Same or Worse than/as others the same age as you?	
1. Better	
2. Same	
3. Worse	

9) Has your doctor previously diagnosed you for any of the following medical conditions:		Are you on medication?	
		Yes	No
1. Hypertension		Name:	
		Dosage:	
2. High cholesterol		Name:	
		Dosage:	
3. Diabetes mellitus		Name:	
		Dosage:	
4. Asthma		Name:	
		Dosage:	
5. Peripheral vascular disease		Name:	
		Dosage:	
6. None			

Appendix C1: The 6-Item Cognitive Impairment Test

1

APPENDIX 2: THE 6 ITEM COGNITIVE IMPAIRMENT TEST (6CIT)

Participant Code: _____ Date: _____

Time of test: _____

	Answers	Maximum Error	Score	Weight	Weighted Score
What year is it now		1		*4	
What month is it now?		1		*3	
Memory phrase (Address) - repeat after me					
Sports Gear, Unit 9, Sable Road, Newlands, Cape Town					
About what time is it now? (within 1 hour)		1		*3	
Count backwards 20-1		2		*2	
Say months in reverse order		2		*2	
Repeat the memory phrase		5		*2	

Total

Score 1 for each incorrect response.

- Write down answers to:

.....

- Count backwards:

.....

- Months in reverse order:

.....

- Memory phrase:

.....

Appendix C2: The Mini-Mental State Examination

Mini-Mental State Examination (MMSE)

Patient's Name: _____

Date: _____

Instructions: Ask the questions in the order listed. Score one point for each correct response within each question or activity.

Maximum Score	Patient's Score	Questions
5		"What is the year? Season? Date? Day of the week? Month?"
5		"Where are we now: State? County? Town/city? Hospital? Floor?"
3		The examiner names three unrelated objects clearly and slowly, then asks the patient to name all three of them. The patient's response is used for scoring. The examiner repeats them until patient learns all of them, if possible. Number of trials: _____
5		"I would like you to count backward from 100 by sevens." (93, 86, 79, 72, 65, ...) Stop after five answers. Alternative: "Spell WORLD backwards." (D-L-R-O-W)
3		"Earlier I told you the names of three things. Can you tell me what those were?"
2		Show the patient two simple objects, such as a wristwatch and a pencil, and ask the patient to name them.
1		"Repeat the phrase: 'No ifs, ands, or buts.'"
3		"Take the paper in your right hand, fold it in half, and put it on the floor." (The examiner gives the patient a piece of blank paper.)
1		"Please read this and do what it says." (Written instruction is "Close your eyes.")
1		"Make up and write a sentence about anything." (This sentence must contain a noun and a verb.)
1		"Please copy this picture." (The examiner gives the patient a blank piece of paper and asks him/her to draw the symbol below. All 10 angles must be present and two must intersect.) 
30		TOTAL

(Adapted from Folstein & Folstein, 1987)

Instructions for administration and scoring of the MMSE

Orientation (10 points):

- Ask for the date. Then specifically ask for parts omitted (e.g., "Can you also tell me what season it is?"). One point for each correct answer.
- Ask in turn, "Can you tell me the name of this hospital (town, county, etc.)?" One point for each correct answer.

Registration (3 points):

- Say the names of three unrelated objects clearly and slowly, allowing approximately one second for each. After you have said all three, ask the patient to repeat them. The number of objects the patient names correctly upon the first repetition determines the score (0-3). If the patient does not repeat all three objects the first time, continue saying the names until the patient is able to repeat all three items, up to six trials. Record the number of trials it takes for the patient to learn the words. If the patient does not eventually learn all three, recall cannot be meaningfully tested.
- After completing this task, tell the patient, "Try to remember the words, as I will ask for them in a little while."

Attention and Calculation (6 points):

- Ask the patient to begin with 100 and count backward by sevens. Stop after five subtractions (93, 86, 79, 72, 65). Score the total number of correct answers.
- If the patient cannot or will not perform the subtraction task, ask the patient to spell the word "world" backwards. The score is the number of letters in correct order (e.g., dlrow=5, dlrow=3).

Recall (3 points):

- Ask the patient if he or she can recall the three words you previously asked him or her to remember. Score the total number of correct answers (0-3).

Language and Praxis (2 points):

- Naming: Show the patient a wrist watch and ask the patient what it is. Repeat with a pencil. Score one point for each correct naming (0-2).
- Repetition: Ask the patient to repeat the sentence after you ("No ifs, ands, or buts."). Allow only one trial. Score 0 or 1.
- 3-Stage Command: Give the patient a piece of blank paper and say, "Take this paper in your right hand, fold it in half, and put it on the floor." Score one point for each part of the command correctly executed.
- Reading: On a blank piece of paper print the sentence, "Close your eyes," in letters large enough for the patient to see clearly. Ask the patient to read the sentence and do what it says. Score one point only if the patient actually closes his or her eyes. This is not a test of memory, so you may prompt the patient to "do what it says" after the patient reads the sentence.
- Writing: Give the patient a blank piece of paper and ask him or her to write a sentence for you. Do not dictate a sentence; it should be written spontaneously. The sentence must contain a subject and a verb and make sense. Correct grammar and punctuation are not necessary.
- Copying: Show the patient the picture of two intersecting pentagons and ask the patient to copy the figure exactly as it is. All ten angles must be present and two must intersect to score one point. Ignore tremor and rotation.

(Folstein, Folstein & McHugh, 1975)

Interpretation of the MMSE

Method	Score	Interpretation
Single Cutoff	<24	Abnormal
Range	<21	Increased odds of dementia
	>25	Decreased odds of dementia
Education	21	Abnormal for 8 th grade education
	<23	Abnormal for high school education
	<24	Abnormal for college education
Severity	24-30	No cognitive impairment
	18-23	Mild cognitive impairment
	0-17	Severe cognitive impairment

Sources:

- Crum RM, Anthony JC, Bassett SS, Folstein MF. Population-based norms for the mini-mental state examination by age and educational level. *JAMA*. 1993;269(18):2386-2391.
- Folstein MF, Folstein SE, McHugh PR. "Mini-mental state": a practical method for grading the clinician. *J Psychiatr Res*. 1975;12:189-198.
- Rovner BW, Folstein MF. Mini-mental state exam in clinical practice. *Hosp Pract*. 1987;22(1A):99, 103, 106, 110.
- Tombaugh TN, McIntyre NJ. The mini-mental state examination: a comprehensive review. *J Am Geriatr Soc*. 1992;40(9):922-935.

Appendix D1: The Strawbridge Scale of Cognition

Strawbridge Scale of Cognition

This scale consists of four questions concerning perceived cognitive function.

Individuals will be asked the following questions:

Do you have memory complaints?		YES		NO

Question:	Rarely or never had the problem in the last 12 months	Sometimes had the problem	Often had the problem	Very often had the problem
1. Do you have difficulty paying attention?				
2. Do you have trouble finding the right word?				
3. Do you have difficulty remembering things?				
4. Do you forget where things are put?				

Appendix D2: 10 Word Learning Test

10 Word Learning Test

Below is the list of words used to assess individual's objective memory impairment:

1. Arm
2. Bed
3. Plane
4. Dog
5. Clock
6. Bike
7. Ear
8. Hammer
9. Chair
10. Cat

Immediate Recall			Delayed Recall (5 minutes later)		
Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
			Percentage Saving		

Reference:

Spreen. O., Strauss. E., Sherman. E.M.S. *Memory. In: A Compendium of Neuropsychological Tests*, 2nd Ed. Oxford, England: Oxford University Press, 1998: 260 - 422

Appendix D3: The Groningen Activity Restriction Scale

Groningen Activity Restriction Scale (GARS)

Overview: The Groningen Activity Restriction Scale (GARS) is general disease independent instrument for measuring disability. It can be used to monitor a patient over time and to identify potential interventions. The authors are from the University of Groningen in the Netherlands.

For the purpose of this study, only the first 11 questions will be used to identify individuals Activities of Daily Living function

Statements about Activities of Daily Living (ADL) – Can you independently:

	Yes I can do it fully independently without any difficulty	Yes I can do it fully independently but with some difficulty	Yes I can do it fully independently but with great difficulty	No I cannot do it fully independently. I can only do it with someone's help	No I cannot do it at all. I need complete help
1. Dress yourself?					
2. Get in and out of bed?					
3. Stand up from sitting in a chair?					
4. Wash your face and hands?					
5. Wash and dry your whole body?					
6. Get on and off the toilet?					
7. Feed yourself?					
8. Get around in the house (if necessary with a cane)?					
9. Go up and down the stairs?					
10. Walk outdoors (if necessary with a cane)?					
11. Take care of your feet and toenails?					

RESPONSE (based on what the patient is able to do)	POINTS
Yes I can do it fully independently without any difficulty	1
Yes I can do it fully independently but with some difficulty	2
Yes I can do it fully independently but with great difficulty	3
No I cannot do it fully independently. I can only do it with someone's help	4
No I cannot do it at all. I need complete help	4

Individuals will be considered as having intact daily functioning: no report of disability in activities of daily living on GARS-scale, except on the item 'taking care of feet and toe nails'

The higher the score the greater the disability

Interpretation:

Minimum score = 11

Maximum score = 44

References:

Suurmeijer TBPM Doeglas DM et al. The Groningen Activity Restriction Scale for measuring disability: Its utility in international comparisons. Am J Public Health. 1994; 84: 1270-1273 (Table 1 page 1271).

Appendix D4: The Telephone Interview for Cognitive Status

TELEPHONE INTERVIEW FOR COGNITIVE STATUS (TICS)

Name: _____ Date: _____

Directions: (1) Explain exam to subject (or patient's caregiver). (2) Get address. (3) Be sure distractions are minimal (e.g., no T.V. or radio on, remove pens and pencils from reach). (4) Be sure sources of orientation (e.g., newspapers, calendars) are not in subject's view. (5) Caregivers may offer reassurance, but not assistance. (6) Single repetitions permitted, except for items 5 and 8.

Instruction	Scoring criteria	Score
1. "Please tell me your full name?"	1 pt. for first name, 1 pt. for last name.	_____
2. "What is today's date?"	1 pt. each for month, date, year, day of week, and season. If incomplete, ask specifics (e.g., "What is the month?" "What season are we in?")	_____
3. "Where are you right now?"	1 pt. each for house number, street, city, state, zip. If incomplete, ask specifics (e.g., "What street are you on right now?")	_____
4. "Count backwards from 20 to 1."	2 pts. if completely correct on the first trial; 1 pt. if completely correct on second trial; 0 pts. for anything else.	_____

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Instruction	Scoring criteria	Score
5. "I'm going to read you a list of ten words. Please listen carefully and try to remember them. When I am done, tell me as many words as you can, in any order. Ready? The words are: cabin, pipe, elephant, chest, silk, theatre, watch, whip, pillow, giant. Now tell me all the words you can remember."	1 pt. for each correct response. No penalty for repetitions or intrusions.	_____
6. "One hundred minus 7 equals what?" "And 7 from that?", etc.	Stop at 5 serial subtractions. 1 pt. for each correct subtraction. Do not inform the subject of incorrect responses, but allow subtractions to be made from his/her last response (e.g., "93-85-78-71-65" would get 3 points).	_____
7. "What do people usually use to cut paper?" "How many things are in a dozen?" "What do you call the prickly green plant that lives in the desert?" "What animal does wool come from?"	1 pt. for "scissor" or "shears" only. 1 pt. for "12." 1 pt. for "cactus" only. 1 pt. for "sheep" or "lamb" only.	_____ _____ _____ _____
8. "Say this: 'No ifs, ands or buts'." "Say this: 'Methodist episcopal'."	1 pt. for each complete repetition on the first trial. Repeat only if poorly presented.	_____
9. "Who is the President of the United States right now?" "Who is the Vice-President?"	1 pt. for correct first and last name. 1 pt. for correct first and last name.	_____ _____
10. "With your finger, tap 5 times on the part of the phone you speak into."	2 pts. if 5 taps are heard; 1 pt. if subject taps more or less than 5 times.	_____
11. "I'm going to give you a word and I want you to give me its opposite. For example, the opposite of hot is cold. What is the opposite of 'west'?" "What is the opposite of 'generous'?"	1 pt. for "east." 1 pt. for "selfish," "greedy," "stingy," "tight," "cheap," "mean," "meager," "skinny," or other good antonym.	_____ _____
<i>Total</i>		_____

Appendix E1: Borg's Scale of Perceived Exertion

Borg's Scale of Perceived Exertion (RPE)

0	No exertion at all	
0.3		
0.5	Extremely weak	"Just noticeable"
0.7		
1	Very weak	
1.5		
2	Weak	"Light"
2.5		
3	Moderate	
4		
5	Strong	"Heavy"
6		
7	Very strong	
8		
9		
10	Extremely strong	"Maximal"