UNIVERSITI TEKNOLOGI MARA

DOSE–RESPONSE AND MODALITY EFFECTS OF RECREATIONAL BADMINTON VERSUS CLOSED SKILL EXERCISE ON PHYSICAL, PHYSIOLOGICAL, AND COGNITIVE OUTCOMES IN OLDER ADULTS

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PhD

February 2026

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Thesis submitted in fulfilment
of the requirements for the degree of
Doctor of Philosophy
(Sports Science and Recreation)

Faculty of Sports Science & Recreation

February 2026

CONFIRMATION BY PANEL OF EXAMINERS

I certify that a Panel of Examiners has met on 22 September 2025 to conduct the final examination of Syed Muhammad Murshid Bin Syed Zubir on his Doctor of Philosophy thesis entitled "Dose–Response and Modality Effects of Recreational Badminton Versus Closed Skill Exercise on Physical, Physiological, and Cognitive Outcomes in Older Adults" in accordance with Universiti Teknologi MARA Act 1976 (Akta 173). The Panel of Examiners recommends that the student be awarded the relevant degree. The Panel of Examiners was as follows:

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ABSTRACT

Open skill exercise may offer cognitive advantages beyond closed skill (CSE) modes in older adults. This thesis evaluates recreational badminton, as an open skill activity, against closed skill exercise across five studies involving recreationally older adults' badminton players and spanning cardiovascular, metabolic, physical, and cognitive domains. Study 1 (age >55 years; HPT n = 18, LPT n = 18, CSE n = 18). Badminton participants were stratified by weekly playing time using a median cut off 7.05 hours per week, with High Playing Time (HPT) at least 7.05 and Low Playing Time (LPT) below 7.05. The closed skill comparator comprised cycling, swimming, and gym circuit activities performed in stable and predictable environments. HPT demonstrated more favorable cardiovascular and body composition profiles than CSE. Study 2 (age >55 years; HPT n = 18, LPT n = 18, CSE n = 18). Using the same groupings and activities, fasting glucose was lower in HPT than in CSE. Study 3 (age >55 years; RBP n = 18, CSE n = 18, CON n = 18). Recreational badminton participants (RBP) were compared with closed skill participants engaged in cycling, swimming, or gym circuit, and with controls who reported no structured exercise. Recreational badminton participants outperformed controls on flexibility, balance, agility, handgrip strength, and the six minute walk distance, with several advantages also observed over closed skill participants. Study 4 (age >55 years; RBP n = 18, CSE n = 18, CON n = 18). Recreational badminton participants showed faster reaction time, higher working memory accuracy, and higher global cognitive screening scores than controls, with trends that favored recreational badminton over closed skill participation. Study 5 (age >60 years; RBP n = 18, CSE n = 18, CON n = 18), acute bout. Following a single session aligned to habitual modality, badminton rally or play for recreational badminton participants and a closed skill session for closed skill participants, immediate improvements in reaction time and accuracy were observed in recreational badminton participants versus controls. Across studies, recreational badminton was consistently associated with favorable profiles across cardiovascular, metabolic, physical, and cognitive measures when compared with closed skill exercise or no structured exercise. The collective evidence highlights the distinctive value of an open skill activity that combines locomotion, interceptive actions, and rapid perceptual decision demands. These findings support the inclusion of recreational badminton within community and clinical exercise programming for healthy ageing in older adults.

ACKNOWLEDGEMENT

I would like to thank my supervisors Dr. Raja Nurul Jannat Binti Raja Hussain, Mr Adam Fiezrel Linoby Bin Ronny Linoby and Miss Siti Aida Binti Lamat for providing me with the opportunity to persuade my study under them. Thank you, Dr, Mr Adam and Miss Aida for all your dedication and all the time you guys on me (Especially during weekend) to make sure my study always on track. Without their guidance, support and advice, I would struggle to complete my studies. I really appreciate it!!

I would like to thank my friends, Iqbal Khan and Asyraff Haslam for guiding me during my early stage of study. Without them, I would totally get lost and have no direction with my studies. Thanks, mate! Not to forget my juniors, Aqil Zulkhairi, Rizal Puniran, Nureen, Adibah and Iffah for helping me with my data collection. You guys spent time to accompany me day and night for my data collection without any complaint (Except for Nureen because she always complains she is hungry 24/7). Thank you so much

I would like to thank my family without whom none of this would have even been possible. My dad, who support me financially (Yeap, especially during my tough times) and convince me to continue my study. My beloved mom, who support me mentally and always comfort me when I feel demotivated. My brother and sister, who always cheers me up when I need them the most. Thank you! Finally, I want to thank myself. Thank you for working hard. Thank you for sacrifice everything you had to continue study and thank you for not giving up.

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Abbreviations

BAD	Badminton
CSE	Close-skills exercise
CSP	Close-skills participants
HDL	High-density lipoprotein
HPT	High-playing time
LDL	Low-density lipoprotein
LPT	Low-playing time
OSP	Open-skills participants
T-Cho	Total cholesterol
TG	Triglycerides

CHAPTER 1
INTRODUCTION

1.1 Research Background

Badminton is one of the most popular sports in the world, having attracted a billion spectators since its debut in Olympic Games 1992. Initially developed in China and later formalized in England (Pardiwala et al., 2020), badminton is the national sport of several Asian countries and is widely practiced by individuals across various age categories (Phomsoupha & Laffaye, 2015). Notably, badminton is recognized as the fastest racquet sport globally, with shuttlecock speeds reaching up to 426 km/h, achieved by Danish doubles player Mads Pieler Kolding, surpassing the previous record of 421 km/h held by Malaysian player Tan Boon Heong (Alder et al., 2019). In the current competition format, badminton matches are contested over three sets of 21 points each, with victory awarded to the first player to win two sets. A third set, known as a deciding game, is played only if each player wins one of the initial sets. When both players reach a tie score of 20–20 (deuce), a two-point lead is required to secure victory (Percy et al., 2015). Should the score escalate to 29–29, the first player reaching 30 points wins the game. The increased physical demands of modern badminton necessitate a combination of advanced technical and tactical skills, alongside high levels of physiological and psychological preparedness (Phomsoupha & Laffaye, 2015).

The rapid and repetitive transitions from low to high metabolic demands classify badminton primarily as a high-intensity intermittent sport (Ooi et al., 2009). The progressive increase in shot frequency and match tempo over recent decades has further intensified the game's physical requirements (Phomsoupha & Laffaye, 2015). For the past decade, badminton has shown rapid development in many aspects such as scoring system and gameplay. For the scoring system, badminton has previously been played in the scoring of 5 sets of 7 points but was abandoned after the 2002 Commonwealth Games. The scoring system then continued to change as the scoring of 11 points best of 5 sets was proposed and experimental by the Badminton World Federation (BWF) in 2014 but were turned down due to the players criticism (Percy et al., 2015). Badminton’s intermittent actions predominantly rely on aerobic (30%) and anaerobic systems (60–70%), particularly the lactic anaerobic metabolism (Gomez et al., 2020). Consequently, regular participation in badminton potentially improves hand-eye coordination, speed, strength, and cardiovascular fitness (Shapie et al., 2023). Badminton previously was played in long rallies with a slow pace which was believed to be time consuming (Gomez et al., 2020). The studies indicated that numerous motor actions of the player occur during the rallies such as sudden change of direction, racquet strokers and shot choices. The longer rallies with the quicker number of strokes per rally result in more challenging physical demand (Abián et al., 2014).

Recently, participation in racquet sports as recreational physical activities has significantly increased (Tator et al., 2008). Studies exploring cardiovascular and metabolic health biomarkers through racquet sports, such as tennis (Chao et al., 2021), table tennis (Zagatto et al., 2018) and racquetball (Oja et al., 2017), indicate substantial health benefits. Badminton, similarly, popular as a recreational activity, has been associated with general health maintenance (Nassef et al., 2019). Alves et al. (2016) mentioned that regular physical activity improved cardiovascular function and insulin sensitivity. Exercise lowered insulin resistance while enhanced insulin responsiveness, glucose absorption and glycogen replenishment in muscle (Bird & Hawley, 2017). Regular physical activity also contributes to physiological advantages, habitual movement supports metabolic health, frequent physical activity aids in metabolic function by enhancing lipid metabolism (Suk & Shin, 2015). Triacylglycerols, a lipid reserves in fat cells are hydrolyzed into free fatty acids, which enter circulation to supply energy to active muscles (Mika et al., 2019). A study done by Couillard et al. (2001) indicates that physical activity also enhances the high-density lipoprotein cholesterol. Recent works by Jannah et al. (2020) also found out that regular exercise enhances haemoglobin and subsequently increased the oxygen of carrying capacity. During exercise, the oxygen demand of skeletal muscle increases as it matches the increase of blood flow due to the increasing cardiac output (Ross et al., 2002). Studies conducted by Jang et al. (2019) stated that physical activity improves glycemic control. This is because physical activity subjugates the abdominal fat and enhances the insulin sensitivity in skeletal muscles which results in the improvement of glycemic control (Ross et al., 2002).

Interestingly, regular physical activity also has been touted to minimize the risk of the aging process. Aging is a complex phenomenon which involves numerous biological pathways at cellular level (Chini et al., 2017). Age relates to change in cardiac structure in which cardiac myocyte enlargement and increases in quantitative and qualitative changes in collagen structures. Charansonney et al, (2011) paper indicates that aging also causes other disorders such as ischemia, myocardial infarction and myocardial hypertrophy which limit the heart function. Accordingly, previous literature unanimously agreed that exercise in general can minimize the aorta stiffness and enhance aorta compliance. The pulsation of continuous blood flow induced by regular exercise bouts activates endothelial nitric oxide synthase which is considered as a potent survival sign for endothelial cells (Gielen et al., 2010).

Mounting evidence supports that physical activity positively influences systemic blood pressure, both in animal (Roh et al., 2020) and human (Herrod et al., 2018) studies, both in an acute and long-term benefits. A study by Brill et al. (2012) indicated the effect of exercise on blood pressure is dependent on the volume of physical activity. Interestingly, majority of studies found that exercise may reduce systolic blood pressure while the diastolic pressure is unchanged or reduce marginally. Previous study by Eicher et al. (2010) mentioned that aerobic- or endurance-based activities may lead to the decline in the mean arterial pressure. The study indicated that, with long term regular exercise, the drop in blood pressure can be as much as 10–20 mm Hg, and it may usually last for several weeks prior to start of routine exercise regime.

There is growing evidence stated that physical activity influences cognitive function. Cognitive function is defined as the internal psychological process which underlie how human beings understand, remember, communicate, think, making decision and critical task such as problem solving (Hockley et al., 2010) One of the most important aspects of cognitive function especially among aging population is a working memory function. Working memory can be define generally as a brain process that provides temporary information capture and manipulation for the ongoing complex tasks (Kato et al., 2018). A good working memory capacity permits an individual to memorize critical information in stressful environment. A study by Donnelly et al. (2016) stated that a long-term physical activity intervention may provide substantial benefit towards the working memory and general cognitive function. A finding by Mandolesi et al. (2018) found that working memory performance was improved following moderate intensity exercise training. The authors speculated that the physical activity intervention may have enhanced the brain neuro cognitive function. This is evident by enhance activity of hippocampal, prefrontal cortex and basal ganglia connectivity which allows the brain to work more efficiently (Kirk & Klein, 2009).

A study by Oja et al. (2017) showed that participation in racquet sports may contribute to a decrease of all causes of mortality by 47% and risk of CVD mortality by 53%. This phenomenon may have been contributed by the intermittent nature of the racquet sports as the demands for both aerobic and anaerobic are increasing during play and recovery as it equates to 60% to 70% of energy expenditure (Phomsoupha & Laffaye, 2015). Although participation in racquet sport training may provide certain health benefits, no previous study has investigated the links between elderly participation in recreational badminton and cardiometabolic health. Most previous studies focus more on other racquet sports such as tennis (Chao et al., 2021) table (Zagatto et al., 2018) and racquetball (Oja et al., 2017). Interestingly, more recent attention in the literature is now turning towards the impact of total exercise time on the physiological responses and cardiometabolic health. Chao et al. (2021) demonstrated that a subset of population with a higher duration of tennis-playing exhibited relatively lower insulin resistance when compared to those with lower time tennis-playing counterpart. Despite these positive association between physiological and cardiometabolic indices and regular participation in racquet sports (majority in younger adults' population), very few studies have investigated whether the time of badminton participation elicits different cardiovascular and metabolic health biomarker benefits in elderly populations as the recent study by Chao et al. (2021) only focus on health benefit of tennis in elderly. It is hoped that this proposed study can lead to an advancement in knowledge regarding recreational badminton playing to positively alter physiological, cognitive and cardiometabolic health, especially in older adults' population.

1.2 Problem Statement

Despite extensive work on general exercise and healthy ageing, specific evidence for badminton on physical, physiological, and cognitive functions remains limited in older adults. Badminton places combined locomotor, perceptual, and decision-making demands that may yield outcomes distinct from closed skill exercise and even from other racket sports that differ in court size, rally structure, and movement dynamics (Phomsoupha & Laffaye, 2015; Lees, 2003). Evidence in adults below sixty indicates that regular badminton participation is associated with favorable cardiovascular and functional profiles and advantages on selected cognitive tasks, suggesting that this multimodal demand can translate into broad health benefits before older age (Phomsoupha & Laffaye, 2015; Chao et al., 2021). Early laboratory work in young samples also shows that intermittent racket sport play elicits substantial cardiovascular strain, consistent with a meaningful training stimulus (Docherty et al., 1982). However, for adults aged sixty and above, sport specific evidence remains scarce, and it is unclear whether lower versus higher weekly amounts of badminton play confer different magnitudes of benefit in cardiometabolic, physical, or cognitive domains. Clarifying this requires studies that specify a closed skill comparator, define badminton participation dose with transparent thresholds, and evaluate multidomain outcomes in older adults. Addressing this gap would provide evidence-based guidance on whether the distinctive combination of movement, interception, and real time decision making in badminton affords advantages beyond closed skill exercise for healthy ageing.

1.3 Purpose of The Study

This thesis aims to investigate whether playing frequency in recreational badminton influence the physical, physiological, and cognitive function in the elderly individuals, compared to closed-skilled exercisers and/or irregular exercisers.

1.4 Research Objectives

To compare recreational badminton, an open skill activity, with closed skill exercise on cardiovascular, metabolic, physical, and cognitive outcomes in elderly population, this thesis addressed the following objectives through five individual studies:

a) To examine the influence of higher versus lower weekly participation in recreational badminton on blood pressure and body composition, compared with a closed skill exercise in recreationally active older adults. (Study 1)

b) To investigate the influence of higher versus lower weekly participation in recreational badminton on cardiometabolic indices, compared with a closed skill exercise in recreationally active older adults. (Study 2)

c) To evaluate the effects of long-term participation in recreational badminton on physical function, in comparison with closed skill participants and non exercising controls in recreationally active older adults. (Study 3)

d) To determine the effects of long-term participation in recreational badminton on cognitive function, in comparison with closed skill participants and non exercising controls in recreationally active older adults. (Study 4)

e) To examine the immediate effects of a single badminton session compared with a single closed skill session on multi domain cognitive function in recreationally active older adults.

1.5 Research Question

This thesis aimed to answer the following research questions:

a) Do elderly individuals who participate frequently in recreational badminton exhibit more favorable BP indices and body composition compared to those engaged in closed-skilled exercises or those playing badminton less frequently (Study 1).

b) Do elderly individuals who frequently participate in recreational badminton exhibit more favorable cardiometabolic health indices compared to elderly individuals who participate less frequently or primarily in closed-skilled exercises? (Study 2).

c) Do elderly individuals with extensive recreational badminton playing experience demonstrate superior physical function compared to those participating in closed-skilled exercises or leading sedentary lifestyle? (Study 3).

d) Do the elderlies with greater playing experience in recreational badminton have better cognitive function as compared to the closed skilled-exercise participants and sedentary individuals? (Study 4).

e) Do elderly individuals performing a single session of recreational badminton show improved multi-domain cognitive function compared to individuals performing a single session of closed-skilled exercise or sedentary individuals? (Study 5).

1.6 Research Hypotheses

a) Elderly individuals with higher recreational badminton-playing frequency will have significantly lower systolic blood pressure and improved body composition (particularly greater lean body mass) compared to those with lower badminton-playing frequency or those who engage in closed-skilled exercises (Study 1).

b) Elderly participants who engage more frequently in recreational badminton will have more favorable cardiometabolic profiles than their counterparts who play badminton less frequently or participate predominantly in closed-skilled exercises (Study 2).

c) Elderly recreational badminton participants will exhibit superior physical function including cardiovascular endurance, muscular endurance, strength, and flexibility compared to elderly individuals in closed-skilled exercise groups or sedentary control groups (Study 3).

d) Elderly participants with regular recreational badminton involvement will have enhanced cognitive functions especially executive functions, memory, and learning speed compared to elderly participants in closed-skilled exercises or sedentary individuals (Study 4).

e) A single acute bout of recreational badminton exercise will lead to greater improvements in multi-domain cognitive function compared to a single bout of closed-skilled exercise or no exercise among elderly individual (Study 5).

1.7 Operational Definition

a) Cardiometabolic markers – Profile concerning both heart and metabolic variables. Elevated cardiometabolic risk markers are biologically interrelated to heart and metabolic-related diseases. In the current proposed study, six cardiometabolic markers most relevant to heart and metabolic health risk in elderly will be evaluated including fasting blood glucose, triglycerides, creatinine, uric acid, high density lipoprotein, total cholesterol concentration.

b) Physiological indices – The physiological profile relating to the relevant body functioning system in recreational elderly badminton players including resting blood pressure and body composition. The tests will be conducted using dedicated measurements in accordance with the respective manufacturer guidelines.

c) Cognitive function – Cognitive function is the ability of the brain to response to stimuli. In this study, working memory will be conducted on recruited subjects.

d) Healthy elderly population – Ageing, an inevitable process, is commonly measured by chronological age. Elderly population can be defined quantitatively or qualitatively, and various cut-off chronological age has been proposed in the past. In this study, men over age of 55 or women after six-months of menopause with regular badminton-playing experience (at least once a week with no less than 30 minutes of weekly playing time) will be screened for eligibility.

e) Badminton-playing exercise time – The badminton-playing exercise time was evaluated using the modified Physical Activity Scale for Elderly (PASE). The validated questionnaire has been used to measure the badminton-playing duration (per week) among the elderly. HPT defined as playing more than once a week with more than 30 minutes per week while LPT defined as playing at least once with less than 30 minutes per week.

f) Blood pressure – The resting seated brachial artery's BP indices including systolic, diastolic, and mean arterial blood pressure was measured in this study.

g) Cholesterol level – Total cholesterol can be defined as the total amount of cholesterol contained in the blood. The total cholesterol contained both high-density lipoprotein and low-density lipoprotein. In this study, total cholesterol and high-density lipoprotein was measured using dedicated measurement in accordance with the respective manufacturer guidelines.

h) Blood lipid – Blood lipids (or blood fats) are lipids in the blood, either free or bound to other molecules. It is well known that blood lipid is an important factor leading to cardiovascular and metabolic diseases such as diabetes mellitus and atherosclerosis. In this study, blood triglycerides (a type of blood lipid) was measured using dedicated measurement in accordance with the respective manufacturer guidelines.

i) Physical fitness – Physical fitness defined as the capabilities of body systems to cooperate effectively, enabling the individuals to maintain good health and perform daily tasks.

j) Health related fitness – Health related fitness defines as exercises that individual perform to maintain or enhances physical health. This component consists of five categories, cardiovascular endurance, muscular strength, flexibility, muscular endurance, and body composition.

k) Healthy elderly – Individual who aged 55 years old and above who free from any health-related disease.

l) Skill related fitness – A person's abilities in areas likely to enhance effectiveness in sports or work-related activities. Skill related fitness can be divided into six categories which is agility, speed, power, balance, coordination, and reaction time.

m) Irregular exercisers – Individuals who participate in physical activity or exercise in inconsistent manner rather than following a consistent and regular training schedule.

n) Open-skills sport – A sport that been performed in unstable and unpredictable environment such as badminton and rugby.

o) Close-skills sport – Defined as sport that been played in a stable and predictable environment such as jogging, cycling and swimming.

p) Recreational play – Defined as casual or leisure participation, typically without formal rules enforcement, structured training, or systematic competition. Participants engage primarily for enjoyment, fitness, social interaction, or informal skill development.

q) Competitive play – Characterized by structured participation involving official rules, regulated competitions, systematic training, measurable performance metrics, and formalized ranking or achievement standards

1.8 Delimitation

a) Participants was delimited to healthy, non-smoker men over age of 55 or women after six-months of menopause with regular badminton-playing experience (at least once a week with no less than 30 minutes of weekly playing time) within the state of Negeri Sembilan, Malaysia, after providing informed consent in accordance with the Institutional Review Board for human subjects and the Helsinki Code (the subject selection process is outlined further in the Methodology section).

b) All testing was performed in the Physiology and Nutrition Laboratory at Faculty of Sport Science and Recreation, University Technology Mara, Negeri Sembilan Branch, Seremban Campus, Malaysia according to all policies and procedures of the laboratory.

c) Cardiometabolic marker tests was generalized to blood glucose, triglycerides, creatinine, uric acid, high density lipoprotein, total cholesterol concentration using dedicated measurement in accordance with the respective manufacturer guidelines.

d) Physiological tests were generalized to resting mean arterial pressure, body fat percentage and body lean mass level using dedicated measurement in accordance with the respective manufacturer guidelines.

e) Anthropometric measurement was generalized to weight (in kg) and height (in cm) using a validated stadiometer (SECA 220; Seca, Ltd, Hamburg, Germany).

f) All researchers and appointed assessors involved in this study are delimited and therefore not involved in the study.

g) Participants were instructed to be in the fasting condition (for 8 to 12 hours) prior to the first assessment during laboratory visit.

1.9 Limitation

a) A cross-sectional design was utilized with a purposive sampling method. Thus, this study will only recruit elderly population with regular badminton- playing experience within the state of Negeri Sembilan, Malaysia. It is expected that the sample size will be relatively small compared to the actual target population, nationally. While it is possible that the external validity may be decreased, it is unlikely to be a significant concern since minimum sample size will be determined by a priori sampling power calculation.

b) This study only recruited elderly participants. While it is possible that the generalizability of the study may be limited to this aging population, the information that could be provided by current proposed study would be critical to health care professionals in appropriately prescribing exercise training for this population. Hypothetically, this approach of recruiting specific subset of age group should result in a more homogenous data, ultimately reducing the likelihood of type I and type II error of the outcome of the study.

c) Each prospective participant of this study likely had different circadian rhythms that may interfere with the physiological and cardiometabolic response, and this could affect the outcome of this study. However, this effect is likely to be very minimal as participants will be tested during similar time following overnight fasting (7:00 - 9:00 am).

d) The training status and different gender is proposed in previous literature to cause different physiological and cardiometabolic responses. To decrease this variability, a subgroup training status and gender group analysis will be conducted to determine if such variables act as mediating factors affecting the outcome of the current proposed study.

e) Nutritional intake and physical activity level are known to modify the majority of biochemical; physiological and exercise performance responses measured in this study.

f) To minimize these external variable participants were asked to fill out a 24-hour dietary record a day prior to the lab visit.

g) This study recruit's participants exclusively from Malaysia, where badminton serves as a culturally integrated recreational activity with widespread popularity across age groups. As established in the research background, badminton is the national sport of several Asian countries and widely practiced by individuals across various age categories. This cultural context may enhance participant adherence, skill proficiency, social support networks, and facility accessibility compared to regions where badminton is less culturally embedded. Consequently, the external validity and transferability of findings to non-badminton cultures, particularly Western populations where badminton participation is less common among elderly individuals, may be limited. The observed health benefits in this study might be partially attributable to Malaysia's supportive badminton infrastructure and social environment, factors that may not exist in other cultural contexts.

h) Subjects may not perform overnight fasting has been requested. However, adequate effort will be made to remind participants to perform adequate fasting duration (for 8 to 12 hour) using short message service, social messaging platform and email prior to the first measurement in the lab.

1.10 Assumption

a) Participants were truthfully answer all questions regarding medical history, nutritional and exercise time status, and drug consumption, participation level in sport, dietary consumption and physical activity routine performed prior to the data collection of this proposed study.

b) Participants adequately completed their 24-hour food and physical activity log before the testing visit.

c) Participants adhered to overnight fasting instruction (for 8 to 12 hour), and to the guidelines provided at the beginning of the study.

d) Participants rest and sleep adequately (7 - 8 hours) before and after each laboratory visit session.

1.11 Significance of Study

Aging is linked to chronic inflammation and oxidative stress, which elevate the risk of cardiovascular disease. Older adults who engage in badminton more frequently may experience greater benefits for cardiometabolic health. With appropriate playing durations, recreational badminton can serve as a beneficial activity for enhancing their overall well-being.

Moreover, the information that also could be provided by current proposed study would be critical to health care professionals in appropriately prescribing exercise for the aging population. The outcome of the current findings could help the health care professional to provide concrete evidence to inform public health guidelines by clearly demonstrating the optimal frequency and duration of badminton activity required to reduce cardiovascular risks and chronic inflammation in older adult. Obviously, the outcomes from this proposed work will be immediately relevant to badminton practitioners specifically among elderly population and, in the longer term, may contribute to the physical well-being of the elderly population. Accordingly, the results obtained in this study could provide evidence on cardiovascular health of the elderly population through participating in recreational badminton play.

Furthermore, the proposed research will likely benefit a range of stakeholders from the academic, public and health sectors. As for the academic, this proposed study will have a positive impact on the personal development of researchers involved in the work and new research can be conducted to overcome the limitations from this proposed study. The information gained from this study will provide benefit toward the public. This due to the reason that the outcome from this proposed study may inform the public of the possible benefits of badminton playing on cardiometabolic, physiological and cognitive health, especially in aging population and hence will spread the awareness regarding the benefit on both physical activity and recreational badminton playing. As for the health sector, this study will help the government to organize the health event related with recreational badminton playing to spread the awareness about participation in physical activity especially in advancing aging population.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

This chapter reviews existing literature to critically evaluate the impact of recreational badminton on physiological, physical, and cognitive functions in elderly populations. It systematically discusses the biological mechanisms underlying age-related decline, the comparative effects of different types of physical activity, particularly open skilled versus closed skilled sports, and the potential role of badminton as an effective intervention for healthy aging.

2.2 Aging and Physical Activity

2.2.1 Physiological Changes Associated with Aging

The aging process leads to considerable cardiovascular decline, characterized by a reduction in maximal heart rate, diminished heart rate variability (HRV), and decreased cardiac output, which significantly affect elderly individuals. Previous research has established that a negative correlation between age and heart rate (Chime et al., 2020). The age-related decrease in HRV, reflecting a loss of autonomic control, contributes to increased morbidity and mortality among older populations (Voss et al., 2015). The effects of polypharmacy and chronic conditions further amplify these changes, influencing both HRV and overall cardiovascular function (Pearson-Stuttard et al., 2019). However, lifestyle interventions, including recreational activities such as badminton, may help counteract these age-related declines by improving aerobic capacity and maintaining HRV, thereby potentially enhancing long-term health outcomes (Viana et al., 2020).

Physical activity, particularly recreational badminton, provides a thorough approach to mitigating cardiovascular decline in aging populations. Evidence suggests that preserving HRV, improving aerobic capacity, and enhancing cardiovascular resilience are critical outcomes of regular physical activity (Viana et al., 2020). As a fast-paced sport requiring bursts of high-intensity effort, badminton mirrors interval training, which has been shown to counteract age-related declines in maximal heart rate and cardiac output (Huang et al., 2019). This alignment with exercise recommendations for older adults is further supported by the characteristic of the sport to enhances autonomic function, which is critical factor in managing cardiovascular health and reducing mortality risks (Oja et al., 2017; Zhao et al., 2014).

In addition to its cardiovascular benefits, recreational badminton positively affects metabolic health, particularly in combating insulin resistance and lipid profile changes commonly seen in aging populations. Age-related factors such as reduced skeletal muscle mass and increased visceral fat contribute to decreased insulin sensitivity (Chao et al., 2021) and elevated low-density lipoprotein (LDL) cholesterol levels (Chao et al., 2021). Engaging in physical activity such as badminton mitigates these issues by promoting muscle engagement and reducing visceral adiposity, thereby improving insulin sensitivity and regulating lipid metabolism (Mancusi et al., 2020; Park & Seo, 2020; Ross et al., 2002)

Recent evidence indicates that aging is associated with elevated levels of pro-inflammatory cytokines and oxidative damage, which impair cardiovascular function, exacerbate lipid peroxidation, and contribute to insulin resistance (Li et al., 2022; Suk & Shin, 2015). Garcia-Hermoso et al. (2016) demonstrated that physical activity decreases systemic inflammation by lowering C-reactive protein (CRP) and interleukin-6 (IL-6). Moreover, the high-intensity intervals inherent to badminton stimulate the production of endogenous antioxidants, such as superoxide dismutase (SOD), which counteract oxidative damage and improve endothelial function (Ruffino et al., 2016). Grevendonk et al. (2021) and Zoll et al. (2002) confirmed that regular participation in such activities enhances mitochondrial efficiency, supporting both metabolic and cardiovascular resilience in older adults.

2.2.2 Cognitive Decline in Elderly

Badminton, as a dynamic sport requiring coordination, agility, and strategic thinking has been recognized for its significant impact on cognitive function among older adults (Phomsoupha & Laffaye, 2015). Evidence from multiple studies highlights the role of physical activity in increasing neurotransmitter levels, including dopamine and serotonin, which are critical for memory processes and mood regulation (Davenport et al., 2012) Goenarjo et al. (2020) reported that improved cardiovascular health resulting from such activities supports better cerebral oxygenation, which positively influences cognitive performance. The interplay between motor skills and cognitive performance is also notable, as the sport requires rapid decision making, thereby enhancing reaction times and information processing speeds (Faude et al., 2007). Furthermore, participation in structured recreational sports like badminton promotes social engagement, which reduces stress and depressive symptoms that are known contributors to cognitive decline (Marshall et al., 2018). These findings underscore the multifaceted benefits of integrating recreational badminton into interventions aimed at preserving cognitive health in older adults, highlighting its potential as a preventive strategy against memory and executive function deterioration.

The role of badminton in reducing the risk and progression of neurocognitive diseases like Alzheimer's (AD) and Parkinson's (PD) is particularly noteworthy. Regular participation in physically and mentally stimulating activities enhances neuroplasticity, which is critical for mitigating age-related cognitive decline and neurodegeneration (Phillips et al., 2017). Physical activity has been shown to counteract metabolic dysfunctions linked to AD, including diabetes and obesity, by reducing inflammation and improving vascular health, which are essential for maintaining cognitive function (Wang et al., 2024). Furthermore, badminton's requirement for strategic planning and rapid decision making directly supports executive functions, potentially delaying the onset of neurocognitive impairments associated with Alzheimer's and Parkinson's diseases (Ribarič et al., 2022)

The neurobiological underpinnings of cognitive decline in aging further emphasize the significance of interventions like recreational badminton. Neuronal loss, particularly in the hippocampus, is a key factor driving the deterioration of memory and executive functions central to cognitive health (Oliveira et al., 2019) Activities requiring complex motor coordination, such as badminton, may counteract this neuronal loss by stimulating synaptic plasticity, supported by mechanisms like brain derived neurotrophic factor (BDNF) signalling, which facilitates long-term potentiation critical for memory processes (Loprinzi, Loenneke, et al., 2021). However, aging is also marked by reductions in neurotransmitters like acetylcholine and dopamine, impairing attention, learning, and motor functions (Basak et al., 2020). The aerobic intensity of badminton can mitigate these declines by promoting neurotransmitter balance and reducing oxidative stress, which is a major contributor to neurodegeneration (Höhn et al., 2017).

Based on neurobiological perspective, the role of recreational badminton extends to mitigating age-related pathological changes, including the accumulation of neurofibrillary tangles (NFTs) and amyloid plaques hallmarks of Alzheimer's disease. These pathological changes disrupt synaptic function and neuronal integrity, driving cognitive decline (Shukla & Heath, 2022). Regular physical activities like badminton may attenuate these effects by enhancing cerebral circulation and reducing neuroinflammation, mechanisms implicated in amyloid (Bonanni et al., 2022) Moreover, badminton's demand for strategic thinking and physical endurance stimulates regions like the hippocampus, which are particularly vulnerable to neuronal loss in Alzheimer's progression (Bernardo et al., 2016). The interplay of physical exertion and cognitive engagement can also enhance neurotrophic support, exemplified by increased BDNF expression, further counteracting synaptic deficits linked to NFTs (Chmielarz & Saarma, 2020). Additionally, the social and psychological benefits of group sports foster resilience against risk factors like social isolation and stress, which exacerbate neurodegeneration (Bernardo et al., 2016)

Complementing its neuroprotective effects, badminton also addresses the biochemical and cellular factors underpinning cognitive decline in the elderly. Aging is associated with oxidative stress and mitochondrial dysfunction, both of which exacerbate synaptic and neuronal damage (Tönnies & Trushina, 2017). Engaging in moderate-intensity aerobic activities like badminton promotes antioxidant defense mechanisms, reducing oxidative damage and preserving synaptic plasticity critical for learning and memory (Di Liegro et al., 2019). Additionally, badminton's impact on enhancing neurotransmitter synthesis and receptor sensitivity such as those involving acetylcholine and dopamine can counteract age-related deficits in attention, decision-making, and motor coordination (Sanaeifar et al., 2024).

2.2.3 Benefit of Physical Activity in Elderly

Engaging in recreational physical activities such as badminton offers multifaceted benefits to elderly individuals, encompassing physical, physiological, and cognitive enhancements. Badminton, as a dynamic aerobic activity, has been linked to improved cardiovascular health and muscular endurance, essential for maintaining independence and reducing mortality among seniors (Zubir et al., 2022a). Regular participation also fosters neuromuscular coordination, which is critical for balance and agility, reducing the risk of falls, which is a major health concern in this demographic (Zhong et al., 2024). Physiologically, the high-intensity intervals characteristic of badminton stimulates bone density maintenance through mechanical loading, counteracting osteoporosis and sarcopenia prevalent in aging populations (Morcillo-Losa et al., 2024). Furthermore, the sport enhances cognitive functions by promoting decision-making, spatial awareness, and reflexes, contributing to overall mental acuity (Culpin et al., 2018).

In addition to the cognitive and social benefits of badminton, engaging in such recreational physical activities positively influences metabolic and physiological functions, which are vital for elderly health. Regular badminton sessions can help regulate glucose metabolism, a crucial factor as aging often diminishes insulin sensitivity and beta-cell functionality (Zhang et al., 2022). Bhaskarabhatla & Birrer, (2005) stated that by promoting muscle activity and enhancing glycogen storage capabilities, badminton supports stable blood sugar levels and reduces risks associated with diabetes and obesity. Furthermore, the aerobic nature of the sport contributes to cardiovascular health by improving cholesterol profiles and aiding in hypertension management through better arterial compliance and reduced vascular stiffness (Boutouyrie et al., 2021). This dual action of glucose regulation and cardiovascular enhancement highlights badminton's potential as an accessible intervention for metabolic disorders and heart health. Additionally, the anti-inflammatory benefits associated with physical activity mitigate chronic conditions like arthritis and inflammaging, improving the overall quality of life (Ciolac et al., 2020)

Recreational activities like badminton also play a significant role in enhancing cognitive and psychological well-being among the elderly, addressing critical aspects of aging such as memory retention, mental agility, and emotional health. Regular engagement in physical activities has been linked to improved neurogenesis, particularly in the hippocampus, a region vital for learning and memory, which can counteract age-related cognitive decline (Ma et al., 2017). The combination of physical exertion and mental strategy inherent in badminton stimulates brain plasticity, fostering improved executive functions and attentional capacities (Huang et al., 2017) Psychological benefits are equally profound; participation in structured physical activities significantly alleviates symptoms of anxiety and depression, promoting emotional resilience and reducing stress levels (Herbert et al., 2022). This holistic approach underscores the dual cognitive and psychological benefits of badminton, positioning it as a key intervention in elderly care programs aimed at promoting mental health and enhancing quality of life.

Building on its cognitive, emotional, and social benefits, badminton also serves as an effective tool for enhancing adaptive brain plasticity and mitigating age-related neural degeneration. Regular participation in such activities has been shown to stimulate hippocampal neurogenesis and synaptic remodelling, essential for sustaining learning capabilities and memory functions in aging populations (Loprinzi et al., 2021; Wilke, 2020). Furthermore, the integrative demands of badminton, which requiring quick decision-making, spatial navigation, and coordination enhances functional connectivity across neural networks, thereby supporting executive functions and delaying cognitive impairments associated with conditions like mild cognitive impairment (Loprinzi et al., 2021; Moreau & Chou, 2019; Wang et al., 2013). Moreover, badminton’s ability to reduce chronic stress and inflammation through physical activity mechanisms provides neuroprotective effects that further safeguard against neurodegenerative diseases such as Alzheimer’s and Parkinson’s (Abdou et al., 2018; Ribarič et al., 2022).

2.3 Badminton as Physical Activity for Elderly

2.3.1 Overview of Badminton

Badminton, as a dynamic racquet sport, offers unique physical, physiological, and cognitive benefits for elderly individuals, particularly when played recreationally. The sport, which involves hitting a shuttlecock over a net in singles or doubles formats, emphasizes agility, speed, and strategic thinking, traits that contribute to both physical fitness and mental acuity (Phomsoupha & Laffaye, 2015). Unlike many other sports, badminton utilizes a shuttlecock with distinct aerodynamic properties, fostering precise coordination and movement patterns critical for maintaining balance and motor control in older players (González-Badillo, 2003). Furthermore, the sport's combination of aerobic and anaerobic exertion aids in cardiovascular health while supporting muscular endurance and flexibility, which are essential for aging populations (Alder et al., 2019). Cognitive demands, such as decision-making and strategic gameplay, also promote mental sharpness, potentially mitigating age-related cognitive decline (Edmizal et al., 2025).

Several lines of evidence suggest that badminton's unique demands on agility, speed, and endurance make it an ideal activity for maintaining holistic fitness in elderly individuals. The sport requires quick lateral movements, rapid directional changes, and sustained energy expenditure, all of which help to preserve muscular strength and cardiovascular health in aging players (Faude et al., 2007; González-Badillo, 2003; Phomsoupha & Laffaye, 2015). Specific training regimens such as plyometric exercises and balance training have proven effective in enhancing dynamic stability and footwork, addressing age-related declines in proprioception and coordination (Guo et al., 2021) Furthermore, the intermittent nature of badminton rallies with bursts of explosive movements aligns well with promoting anaerobic power and endurance, both critical for countering age-related physical decline (Abián et al., 2014). The biomechanics of badminton also highlight the need for proper joint strength and proprioceptive training, particularly to safeguard against common injuries like knee and ankle strains, which are risks amplified by rapid movements and high-impact landings (Guo et al., 2021) This combination of benefits makes badminton a versatile and effective recreational activity for elderly individuals seeking to sustain functional fitness and overall well-being.

The cognitive demands of badminton further underscore its suitability as a physical activity for elderly individuals, promoting not only physical fitness but also mental agility and resilience. This fast-paced sport requires players to make split-second decisions, anticipate opponents' moves, and adapt their strategies in real-time, which enhances decision-making skills and cognitive flexibility (Prak et al., 2022). The continuous need to assess spatial positioning and respond to the shuttlecock’s rapid movements sharpens hand-eye coordination and spatial awareness, skills that are vital in maintaining independence and functionality in older adults (Jafarzadehpur et al., 2012). Moreover, integrating cognitive training into badminton practice, such as teaching tactical strategies alongside technical skills, can enhance the mental acuity of elderly players, helping to mitigate age-related cognitive decline and fostering overall neurological health (Chiminazzo et al., 2018). This synergistic blend of cognitive and physical challenges makes badminton a comprehensive and beneficial activity for the aging population.

The unique blend of physical and cognitive challenges in badminton not only supports fitness and brain health but also fosters social engagement, which is particularly advantageous for elderly individuals. As a social activity, badminton encourages interaction and teamwork, especially in doubles formats, where effective communication and coordination are essential (Phomsoupha & Laffaye, 2015). This social dimension of badminton has been shown to improve mood, reduce feelings of isolation, and enhance overall mental well-being among participants (Basso & Suzuki, 2017). Moreover, the competitive yet inclusive nature of the sport provides opportunities for players of all skill levels to engage in meaningful and enjoyable physical activity, which is critical for sustained participation and adherence to exercise routines (Brahms et al., 2014).

2.3.2 Physiological Demand of Badminton

Badminton is a highly effective physical activity for elderly individuals due to its unique physiological demands, which include significant cardiovascular and metabolic engagement. As an intermittent high-intensity sport, badminton alternates bursts of vigorous activity with short recovery periods, mirroring the benefits of high-intensity interval training (HIIT). This pattern has been shown to enhance aerobic capacity, with studies demonstrating improvements in VO2max and reduced heart rate during submaximal exertion after consistent participation (Patterson et al., 2017). Additionally, players often reach up to 90% of their maximal heart rate during matches, highlighting the sport's potential for substantial cardiovascular stimulation (Docherty et al., 1982). Badminton also incorporates anaerobic activity during intense rallies, where approximately 30% of energy expenditure is derived from anaerobic pathways, making it particularly beneficial for developing strength and quick response times (Ando et al., 2024). These dual benefits of aerobic and anaerobic fitness, coupled with evidence of improvements in blood pressure, heart rate recovery, and lipid profiles, position badminton as a highly suitable and enjoyable activity to support cardiovascular health and overall fitness in elderly populations (Nassef et al., 2019; Patterson et al., 2017).

In addition to cardiovascular benefits, badminton imposes significant musculoskeletal demands that enhance overall physical fitness and functional capacity, particularly among elderly participants. The sport engages major muscle groups, including the legs, arms, and core, fostering improvements in muscle strength, endurance, and flexibility (Senadheera et al., 2021). Quick directional changes and rapid accelerations necessitate strong leg muscles, which can be developed through sport-specific training such as plyometrics (Huang et al., 2023) The repetitive striking of the shuttlecock utilizes arm muscles, emphasizing the importance of upper body strength for executing powerful smashes and precise serves (Sun & Shao, 2023). The integration of arm and leg coordination further underscores the importance of whole-body strength and agility in maintaining optimal performance and reducing fall risk in older adults (Mokhtari et al., 2013). Additionally, core strength is critical in badminton, as it supports dynamic balance, energy transfer, and stroke execution, minimizing the risk of musculoskeletal injuries (Hassan et al., 2017; Sun & Shao, 2023). These physical demands not only improve musculoskeletal health but also contribute to sustained mobility and independence in elderly individuals, positioning badminton as an ideal activity for aging populations (Reddy & Rajeswari, 2020).

The intricate balance and coordination requirements of badminton make it a particularly beneficial activity for elderly individuals, as it promotes proprioception, stability, and injury prevention. The rapid directional changes, lunges, and jumps involved in badminton challenge dynamic balance and neuromuscular control, essential factors for maintaining mobility and reducing fall risks in aging populations (Zhong et al., 2024). Previous study by Malwanage et al. (2022); Sonoda et al. (2018) indicates that specific training regimens, such as combined balance and plyometric exercises, significantly enhance posture control and lower limb strength, which are vital for quick, stable movements on the court. Moreover, the biomechanics of badminton, including forward lunges and footwork mechanics, contribute to enhanced plantar pressure distribution and joint stability, further supporting balance during high-impact activities (Wang et al., 2024). By engaging both physical and neural systems, badminton fosters a comprehensive approach to improving balance, coordination, and overall functional capacity in elderly participants (Malwanage et al., 2022; Sonoda et al., 2018; Wang et al., 2024). Having established badminton's multifaceted physiological demands, it becomes essential to examine how these demands differ from more predictable, repetitive exercises. This distinction between open-skilled sports like badminton, which require constant environmental adaptation, and closed-skilled activities performed in stable conditions, has important implications for understanding their differential effects on elderly cognitive and physical function

2.4 Open-skilled vs Close-skilled Sports

2.4.1 Definition and Characteristics

Open-skilled sports are characterized by their execution in dynamic and unpredictable environments, demanding continuous adaptation to external stimuli (Culpin et al., 2018). Open-skilled activities such as badminton, soccer, and tennis require athletes to respond effectively to variable conditions (Culpin et al., 2018). Furthermore, research highlights that open-skilled athletes demonstrate superior motor cognition, reaction times, and hand-eye coordination compared to their closed-skilled counterparts (Becker et al., 2018). The unpredictable nature of open-skilled sports fosters not only physical dexterity but also cognitive development, including working memory and decision-making capabilities, which are essential for managing complexity in real-world situations (Becker et al., 2018; Zhu et al., 2020) These attributes underscore the unique characteristics of open-skilled sports, linking physical performance with cognitive adaptability in ways that contribute profoundly to holistic athletic and cognitive excellence (Koch & Krenn, 2021).

Closed-skilled sports, in contrast to their open-skilled counterparts, are performed in stable and predictable environments where athletes execute pre-learned, repetitive movements (Pancar et al., 2020). Activities such as swimming, running, and yoga are archetypes of closed-skilled sports, fostering motor proficiency through the absence of external variability (Tsai et al., 2017). These settings reduce cognitive demands by enabling athletes to focus on technique refinement and consistency, which in turn supports physical development and enhances cardiorespiratory fitness (Tsai et al., 2017). Additionally, the repetitive nature of closed-skilled activities fosters the encoding of motor patterns, relying heavily on use-dependent and error-based learning mechanisms, which systematically enhance neural pathways and motor skills (Gökçe et al., 2021). The controlled nature of these sports also aligns with improved executive functions, such as sustained attention and task-switching abilities, particularly in younger populations, who demonstrate significant cognitive and motor benefits from such training (Formenti et al., 2021). This distinction complements the dynamic adaptability required in open-skilled sports, underscoring the diverse cognitive and physical benefits of closed-skilled activities.

2.4.2 Differences in Physical and Cognitive Demand

The distinction between open-skills and closed-skills activities is critical when examining the physical and cognitive demands placed on individuals, especially in elderly populations. Open-skill sports, like badminton, require players to constantly adjust to a dynamic environment, making them more physically and cognitively demanding than closed-skill sports, where movements are more predictable and less influenced by external factors (Culpin et al., 2018). In the context of recreational badminton, elderly individuals engage in a variety of physical movements, such as quick lateral shifts and overhead strokes, which are influenced by unpredictable opponent actions and environmental conditions (Chao et al., 2021). These demands place additional strain on both cognitive processing and physical stamina, requiring real-time decision-making and adaptive motor control (Tsai et al., 2017). The unpredictability of open-skill sports, such as badminton, significantly challenges the elderly's cognitive functions, such as attention, reaction time, and decision-making under pressure, compared to the more repetitive nature of closed-skill activities (Culpin et al., 2018).

The physical and cognitive challenges associated with open-skill sports like badminton extend beyond simple reaction times, involving complex processes such as anticipatory movements and strategic decision-making. For elderly players, the adaptation to sudden changes in direction and the need to process rapidly occurring stimuli significantly increase the mental load, requiring enhanced coordination between the sensory, cognitive, and motor systems (Oishi & Yamasaki, 2024) Studies on the cognitive demands of open-skill activities have found that older adults show greater improvements in executive functions, including cognitive flexibility and working memory, when participating in such sports (Möhring et al., 2022). Furthermore, the cardiovascular and muscular demands of badminton such as explosive sprints and dynamic posture adjustments can improve physical endurance and agility, which is particularly beneficial in countering age-related physical decline (Khaothin et al., 2023). These multifaceted demands of open-skill activities provide substantial cognitive and physiological benefits that are less prevalent in closed-skill sports, where the controlled environment and repetitive nature do not stimulate similar levels of mental engagement (Liu et al., 2021).

2.5 Impact of Badminton on Physical Health in Elderly

2.5.1 Effect on Blood Pressure and Cardiovascular Health

Recreational badminton has been recognized for its potential benefits on cardiovascular health, particularly in elderly. Several studies have highlighted that regular participation in badminton can significantly reduce blood pressure and improve overall cardiovascular function in the elderly. Engaging in moderate-intensity physical activities, such as badminton, promotes enhanced circulation and efficient heart function, which can help manage hypertension and prevent related complications (Cornelissen et al., 2011; Kim et al., 2019). The dynamic nature of the sport, combining aerobic exercise with intermittent bursts of high-intensity activity that supports cardiovascular conditioning, increasing heart rate variability and improving arterial elasticity (Caminiti et al., 2019). Collectively, these findings underscore the importance of recreational badminton as a promising intervention for enhancing cardiovascular health in older populations.

Further research emphasizes that the benefits of recreational badminton on cardiovascular health extend beyond blood pressure regulation. Regular participation in badminton has been shown to improve endothelial function, which plays a critical role in vascular health by maintaining proper blood flow and reducing the risk of atherosclerosis (Tinken et al., 2010). Studies also indicate that the aerobic nature of the sport enhances heart efficiency by promoting increased stroke volume and cardiac output, essential for maintaining cardiovascular health as individuals age (Zeng et al., 2017). Additionally, badminton's combination of aerobic and anaerobic elements contributes to improved systemic circulation and reduced arterial stiffness, factors directly linked to a lower risk of heart disease and stroke in older adults (Jaworski et al., 2018). Notably, these cardiovascular improvements are observed even in individuals with pre-existing health conditions, reinforcing the accessibility and adaptability of badminton as a health-promoting activity (Pan et al., 2022). In addition to the physiological benefits, recreational badminton can also contribute to improved mental well-being, which in turn supports cardiovascular health in elderly individuals. Kato et al. (2018) indicated that badminton not promoting positive psychological benefit but also supports better sleep patterns, which are essential for cardiovascular recovery and overall heart function. Moreover, the social aspects of playing badminton often performed in a group or as part of a recreational community have been linked to reduced feelings of isolation, contributing to lower blood pressure and improved cardiac outcomes in older adults (Cabello-Manrique et al., 2022).

The mechanisms underlying the reduction of blood pressure through badminton are multifaceted, involving both physiological and behavioural factors. Studies suggest that badminton promotes improved cardiovascular and neuromuscular functions by enhancing vascular compliance and stimulating the parasympathetic nervous system, which collectively contribute to lower resting blood pressure levels (Hazari et al., 2023). Additionally, the repetitive, dynamic movements inherent in badminton engage large muscle groups, facilitating better glucose metabolism and lipid utilization key processes in reducing arterial stiffness and hypertension risk (Cabello-Manrique et al., 2022). The sport also addresses modifiable lifestyle factors such as physical inactivity and obesity, common among elderly populations, thereby reducing the systemic load on the cardiovascular system (Oishi & Yamasaki, 2024). The frequency and intensity of badminton sessions have been positively correlated with blood pressure management, as evidenced by Zubir et al. (2022) which highlight the sport's ability to mitigate hypertension-related complications effectively. These mechanisms illustrate badminton's efficacy as a non-pharmacological intervention, reinforcing its role in promoting cardiovascular health and longevity among older adults.

2.5.2 Influences on Body Composition

The influence of recreational badminton on body composition in elderly individuals has been extensively studied, with results indicating significant improvements in both muscle mass and reductions in body fat percentage. Regular participation in badminton enhances muscular strength and endurance, leading to an increase in lean body mass and a decrease in adiposity, particularly visceral fat that is strongly associated with metabolic disorders (Nugroho et al., 2022). This combination of aerobic and anaerobic activity also contributes to the maintenance of an optimal body mass index and improved metabolic health, outcomes that are critical for reducing the risks of obesity and sarcopenia in older adults (Zhao et al., 2014). Moreover, the dynamic nature of badminton, involving lateral movements, jumping, and sprinting, has been linked to improved fat distribution and lower visceral fat levels (Nassef et al., 2019).

Several studies emphasize on badminton in enhancing bone density and reducing the risk of osteoporosis among older adults. Badminton, as a weight-bearing activity, exerts mechanical loading on bones, stimulating osteogenic activity and promoting calcium retention (Adirahma et al., 2024) This is particularly crucial for elderly individuals, whose bone mass typically decreases with age, leading to increased fragility and higher susceptibility to fractures (Losa-Reyna et al., 2019). Additionally, the sport's emphasis on agility and quick directional changes not only improves balance and coordination but also contributes to better posture and alignment, which can further mitigate musculoskeletal degeneration (Lennemann et al., 2013). In combination with its cardiovascular benefits, badminton provides a multifaceted approach to improving overall physical health in the elderly by promoting lean body mass preservation, reducing fat accumulation, and strengthening the musculoskeletal system (Silva et al., 2019).

Table 2.1
Body Composition and Metabolic Effects

Author	Participants	Intervention	Measurement	Outcome
Nugroho et al., (2022)	66.9 ± 4.7	Regular badminton	Lean body mass, visceral fat	Increased muscle, decreased adiposity
Zhao et al., (2014)	66.0 ± 3.6	Recreational play	BMI, body fat percentage	Optimal BMI
Nassef et al., (2019)	66.0 ± 3.6	Badminton sessions	Fat distribution, visceral fat	Improved fat distribution
Adirahma et al.,, (2024)	69.4 ± 3.0	Recreational badminton	Bone density, calcium retention	Enhanced bone health

Note: -Lean Body Mass (LBM)

2.5.3 Cardiometabolic Health Outcomes

Engaging in recreational badminton provide substantial benefits for cardiometabolic health in elderly individuals. Several studies suggest that regular participation in this sport leads to improvements in key cardiovascular metrics such as blood pressure, heart rate variability, and lipid profiles (Nassef et al., 2019; Zubir et al., 2022). Badminton, as a moderate to high intensity aerobic activity, enhances both aerobic capacity and muscular endurance, which are critical factors in the prevention and management of cardiometabolic diseases like hypertension, type 2 diabetes, and dyslipidemia (Wee et al., 2017). Furthermore, research highlights that elderly individuals who engage in badminton experience improved glucose metabolism and reduced waist circumference, which are linked to lower risks of cardiovascular events (Zubir et al., 2022).

In addition to the direct improvements in cardiovascular parameters, racquet sports have also been linked to enhanced insulin sensitivity and reduced markers of systemic inflammation, both of which are critical factors in the management of metabolic syndrome in older adults (Chao et al., 2021). Studies have shown that regular participation in badminton results in significant reductions in fasting blood glucose levels and improved HbA1c, indicating better long-term blood sugar control (Nassef et al., 2019; Oishi & Yamasaki, 2024). Furthermore, the weight-bearing nature of the sport promotes bone density and muscle strength, contributing to overall metabolic health by reducing fat mass and increasing lean muscle tissue (Liu et al., 2021; Wee et al., 2017). These effects are particularly beneficial for aging individuals, as they help mitigate the risks associated with sarcopenia and obesity, two major contributors to cardiometabolic disease in the elderly (Cruz-Jentoft et al., 2019; Hall et al., 2019). These findings suggest that badminton not only improves cardiovascular health but also plays a crucial role in managing and preventing metabolic disorders, reinforcing its value as a therapeutic exercise for elderly populations (Docherty et al., 1982). Furthermore, the preventive impact of badminton on metabolic syndrome in the elderly is further supported by its role in enhancing physical activity levels and reducing sedentary behaviors, both of which are pivotal in mitigating the risks associated with this syndrome. Research indicates that regular badminton sessions promote significant decreases in visceral fat and improvements in the lipid profile, including reductions in

LDL cholesterol and triglycerides, while simultaneously increasing HDL cholesterol levels (Pan et al., 2022; Patterson et al., 2017). These biochemical changes are instrumental in curbing the development of insulin resistance, a primary driver of metabolic syndrome.

The long-term adherence to badminton as a recreational activity underscores its potential in sustaining cardiometabolic health benefits among elderly populations. Regular engagement fosters a consistent caloric expenditure, which contributes to maintaining a healthy body weight and reduces adiposity, a critical factor in the prevention of atherogenic dyslipidemia and systemic inflammation (Hedayatnia et al., 2020). Additionally, studies highlight that badminton's dynamic nature improves mitochondrial efficiency and promotes oxidative capacity, further aiding metabolic health at the cellular level (Kavanashri et al., 2023). These physiological benefits are complemented by the sport's role in enhancing vascular function, as evidenced by improved endothelial reactivity and reduced arterial stiffness, both of which are pivotal in reducing the risk of cardiovascular events (Ashor et al., 2014). Furthermore, the non-linear movement patterns and bursts of activity required in badminton promote neuromuscular coordination and proprioception, minimizing fall risks and promoting overall physical resilience in aging individuals (Zagatto et al., 2018). This holistic approach to health makes badminton not only a feasible intervention but also a sustainable lifestyle choice for mitigating the complex risks of cardiometabolic disorders in the elderly.

Table 2.2
Effect of Badminton on Cardiovascular Health in Elderly

Author	Participants	Intervention	Measurement	Outcome
Cornelissen et al., (2011)	66.9 ± 4.7	Moderate-intensity badminton	Blood pressure, circulation	Significant BP reduction improved heart function
Zeng et al., (2017)	66.0 ± 3.6	Regular badminton session	Stroke volume, cardiac output	Enhanced heart efficiency and cardiovascular health
Caminiti et al., (2019)	66.0 ± 3.6	Dynamic badminton activity	Heart rate variability, arterial elasticity	Increased HRV, improved arterial elasticity
Tinken et al., (2010)	69.4 ± 3.0	Recreational badminton	Endothelial function. blood flow	Improved vascular health, reduced atherosclerosis risk

Note: BP = Blood pressure; HRV = Heart rate variability

2.6 Effect of Badminton on Physical Function in Elderly

2.6.1 Improvements in Muscular Strength and Endurance

Regular participation in recreational badminton has shown significant benefits for improving muscular strength and endurance among elderly individuals. The dynamic nature of badminton, involving repetitive movements such as jumping, lunging, and quick directional changes, activates various muscle groups, contributing to both muscular endurance and strength development (Ma et al., 2024; Wang et al., 2024). Elderly participants who engaged in consistent badminton play demonstrated improvements in muscle power, coordination, and balance, all of which are vital in promoting overall mobility (Sighamoney et al., 2018). Furthermore, the cardiovascular demands of the sport also complement muscular training, fostering a holistic improvement in physical function. Overall, recreational badminton provides an enjoyable and accessible form of exercise that can significantly enhance muscular strength and endurance in elderly individuals, thereby contributing to healthier aging (Malwanage et al., 2022; Preeti et al., 2019).

In addition to its impact on strength and endurance, recreational badminton has been shown to foster improvements in muscular endurance through its unique combination of aerobic and anaerobic demands. The sport's intermittent nature, characterized by short bursts of high-intensity activity followed by brief recovery periods, mimics interval training, which has been associated with enhanced muscular endurance (Culpin et al., 2018). Elderly participants who engaged in badminton exhibited increased stamina during prolonged physical activity, likely due to both the muscle-conditioning effect of the sport and its positive influence on metabolic function (Marcos-Pardo et al., 2019). This increased endurance capacity can improve day-to-day functional tasks, such as climbing stairs or walking for extended periods, thus contributing to better quality of life (Varahra et al., 2018) . Furthermore, consistent badminton play has been linked to increased muscle hypertrophy in older adults, supporting the notion that even in aging populations (Hazari et al., 2023) , regular engagement in resistance-type activities, such as those involved in badminton, can promote muscle growth and maintenance (Consitt et al., 2019).

2.6.2 Improvements in Balance and Flexibility

Badminton has been shown to significantly enhance flexibility and balance in elderly individuals. (Culpin et al., 2018; Varahra et al., 2018). The dynamic nature of the sport, which involves quick directional changes, arm swings, and coordinated movements, engages multiple muscle groups, contributing to improved joint flexibility and muscle elasticity (Gökçe et al., 2021) Furthermore, the balance required to maintain stability during play has been linked to better postural control in elderly (Malwanage et al., 2022). Studies indicate that regular participation in badminton enhances lower body strength, particularly in the legs, and improves proprioception, which are essential components of balance (Preeti et al., 2019). Previous study also stated that elderly individuals who engage in recreational badminton exhibit superior flexibility compared to their sedentary counterparts, as measured through flexibility tests and gait analysis (Kawanabe et al., 2007).

In addition to improvements in flexibility and balance, badminton has been demonstrated to enhance functional mobility in the elderly, with studies highlighting its impact on both static and dynamic balance control. For instance, a study by Yılmaz et al. (2022) found that older adults who participated in badminton experienced significant improvements in balance to a sedentary control group. This improvement in balance was attributed to the sport's requirement for constant coordination between the upper and lower body, which strengthens the neural pathways involved in postural control (Nugroho et al., 2022; Wee et al., 2017). Moreover, research by Wong et al. (2019) revealed that recreational badminton also aids in the reduction of age-related muscle stiffness, which in turn enhances balance stability. The sport’s aerobic nature further supports cardiovascular health, which indirectly benefits overall balance by improving circulatory efficiency and oxygenation of tissues involved in motor function (Losa-Reyna et al., 2019)

Furthermore, previous study stated that ehanced proprioception, a key outcome of regular badminton play, allows older adults to adjust their posture effectively, reducing the likelihood of falls during daily activities (Jaworski et al., 2018). Studies further emphasize that badminton fosters cognitive function due to its open-skill nature, which requires constant environmental awareness and quick decision-making, attributes linked to better motor coordination and fall prevention (Oishi & Yamasaki, 2024).

Additionally, incorporating core stability exercises into badminton training regimens has been shown to significantly augment its benefits, further reducing fall risks among participants by addressing age-related declines in muscle strength and neuromuscular efficiency (Sighamoney et al., 2018; Sun & Shao, 2023). Such evidence underscores badminton as a holistic intervention, targeting both physical and cognitive dimensions of balance and stability essential for elderly individuals to maintain functional independence.

Table 2.3
Physical Function Improvement

Author	Participants	Intervention	Measurement	Outcome
Malwanage et al., (2022)	66.9 ± 4.7	Regular badminton	Posture control, lower limb strength	Enhanced balance and stability
Sighamoney et al., (2018)	66.0 ± 3.6	Recreational badminton play	Muscle power, coordination, balance	Improved mobility and overall function
Wang et al., (2024)	66.0 ± 3.6	Badminton sessions	Plantar pressure, joint stability	Better balance during high impact activities
Preeti et al.,, (2019)	69.4 ± 3.0	Recreational badminton	Lower body strength, proprioception	Enhanced balance components

Note:-Proprioception, Plantar Pressure

2.7 Effects of Badminton on Cognitive Function in Elderly

2.7.1 Cognitive Domains Influenced by Badminton

Participation in racquet sports has been shown to positively influence several cognitive domains in the elderly, contributing to improvements in attention (Culpin et al., 2018), executive function (Zhu et al., 2020), memory, and processing speed (Han et al., 2023) . Previous study indicated that badminton, through its combination of aerobic activity and complex motor tasks, fosters neuroplasticity, which is particularly beneficial for older adults experiencing age-related cognitive decline (Northey et al., 2018). Specifically, the fast-paced nature of the sport requires sustained attention, rapid decision-making, and spatial awareness, which are known to enhance cognitive flexibility and working memory (Grosprêtre & Gabriel, 2021). Moreover, badminton's aerobic demands have been linked to increased blood flow to the brain, thereby promoting cognitive health and mitigating the effects of age-related cognitive impairments such as dementia (Oishi & Yamasaki, 2024). Hence, badminton can serve as a valuable intervention for preserving and enhancing cognitive function in older adults.

Regular participation in badminton can also improve specific aspects of sensory-motor integration, which are critical for cognitive function in the elderly. Research has demonstrated that the dynamic movement required by badminton such as rapid lateral shifts, eye-hand coordination, and reaction time stimulates both visual and motor processing areas of the brain (Water et al., 2017). Noviati et al. (2020) stated that when physical activities combined with the cognitive demands of the sport, enhance motor control and sensory integration, which are essential for maintaining cognitive agility and preventing motor-related cognitive decline. Moreover, the social component of badminton, through its often collaborative or competitive nature, further amplifies cognitive benefits by fostering communication skills and social interaction, both of which are linked to better cognitive outcomes in aging populations (Cabello-Manrique et al., 2022).

The enhancement of procedural memory and working memory in badminton is intrinsically linked to the sport's demands for real-time decision-making and anticipatory skills. Research underscores that badminton players, especially at advanced levels, exhibit superior procedural memory, allowing them to execute complex motor patterns automatically through practice (Jaworski et al., 2018). This is supported by studies indicating that the integration of perceptual-cognitive training, such as app-based systems, helps players internalize tactical knowledge and enhances their procedural memory over time (Wu et al., 2024). Additionally, working memory is consistently challenged in badminton through the continuous processing of game dynamics, such as adjusting strategies mid-game based on opponents' behaviors (Dube et al., 2015).

2.7.2 Neurobiological Mechanism

Engaging in recreational badminton has been shown to induce neurobiological changes that may enhance cognitive function in elderly individuals, primarily through its effects on brain plasticity and neurochemical pathways. Physical activities, including badminton, stimulate the release of brain-derived neurotrophic factor (BDNF), a protein associated with neurogenesis, synaptic plasticity, and cognitive function (Hung et al., 2018). The aerobic demands of badminton, which involve sustained cardiovascular activity, have been linked to improved blood flow to the brain, promoting neuronal health and stimulating the hippocampus, an area crucial for memory and learning (Abián-Vicén et al., 2021; Chen, et al., 2021). Furthermore, the coordination and reflexes required in badminton activate both motor and cognitive networks, fostering cognitive flexibility and executive function (Jaworski et al., 2020).

The neurobiological benefits of badminton extend beyond immediate physical exercise, influencing long-term brain health by mitigating age-related cognitive decline. Studies indicate that regular participation in activities like badminton not only increases BDNF levels but also supports the regulation of neurotransmitters such as dopamine and serotonin, which play key roles in mood regulation and cognitive function (Hung et al., 2018).Moreover, badminton's impact on reducing chronic inflammation, a factor often associated with neurodegenerative diseases, further underscores its potential as a neuroprotective activity. Recent research has shown that elderly individuals engaging in aerobic and coordination-based sports like badminton exhibit reduced markers of systemic inflammation, contributing to better cognitive performance over time (Behrendt et al., 2021). The cognitive benefits may also be linked to improvements in neurovascular health, with enhanced endothelial function and blood-brain barrier integrity observed in physically active elderly individuals (Guimaraes et al., 2024). These neurobiological effects suggest that badminton provides a multifaceted approach to maintaining and even improving cognitive health in aging populations.

In addition to its physiological and neurochemical effects, the cognitive benefits of badminton are also influenced by the social and psychological aspects of the activity. Engaging in a team sport such as badminton fosters social interaction, which has been shown to contribute to enhanced cognitive health in older adults (Huang et al., 2014). Furthermore, the mental stimulation required by the strategic and dynamic nature of badminton such as decision-making, memory recall, and multitasking engages various cognitive domains that are vital for maintaining brain health (Oishi & Yamasaki, 2024). This combination of physical exertion, mental challenge, and social interaction creates a holistic approach to cognitive enhancement, with several studies indicating that elderly participants in badminton experience improvements in not only motor skills but also memory retention and attention span (Roig et al., 2012; Segal et al., 2012).

Table 2.4
Neurobiological Mechanism Supporting Cognitive Function

Author	Focus Area	Biological Mechanism	Measurement	Outcome
Huang et al., (2018)	Neuroplasticity	BDNF production	Protein levels, neurogenesis	Enhanced synaptic plasticity,improved memory
Loprinzi et al. (2021)	Hippocampal function	Neurogenesis stimulation	Brain region activity	Better learning and memory processes
Behrendt et al., (2021)	Inflammation	Reduce systemic inflammation	Inflammatory markers	Improved cognitive performance over time
Guimaraes et al.,, (2014)	Vascular health	Enhanced blood-brain barrier	Cerebral blood flow	Better neurovascular health, cognitive maintenance

Note:- BDNF Production

2.7.3 Comparative Studies with Close-skilled Sports

The impact of recreational badminton on cognitive function in the elderly has been compared to other closed-skilled sports, shedding light on the relative effectiveness of badminton in enhancing cognitive performance. Closed-skilled sports, such as bowling and archery, are characterized by their repetitive, structured nature and minimal environmental variability, which contrasts with the dynamic and multifaceted demands of badminton (Culpin et al., 2018). Previous study has shown that while both types of sports contribute to physical health and cognitive benefits, badminton, with its combination of aerobic activity, quick reflexes, and strategic decision-making, tends to provide a more robust cognitive stimulation for elderly participants (Tsai & Wang, 2015; Wong et al., 2019; Wu et al., 2024). Notably, research indicates that badminton promotes better executive function, memory, and attention in older adults compared to less physically demanding closed-skilled sports (Wang et al., 2023; Wong et al., 2019).

Comparative studies also highlight the different cognitive benefits observed in elderly participants engaging in badminton versus other closed-skilled sports, particularly in terms of neuroplasticity and brain health. Unlike the more static nature of closed-skilled sports, badminton's fast-paced, unpredictable movements require a high degree of mental agility, stimulating brain regions involved in coordination, memory, and executive function (Culpin et al., 2018). This dynamic activity has been linked to enhanced neurogenesis in areas like the hippocampus, which is crucial for learning and memory processes (Loprinzi et al., 2021) Moreover, studies suggest that badminton's combination of aerobic exercise and mental focus promotes better attention control and faster cognitive processing speeds in older adults compared to those who engage in sports with lower cognitive demands, such as golf or billiards (Gu et al., 2019; Wang et al., 2023). Additionally, the social and strategic aspects of badminton, such as doubles play and the need for real-time decision-making, further contribute to cognitive stimulation, positioning it as a more effective intervention for cognitive aging than more solitary or less mentally demanding closed-skilled sports (Gu et al., 2019). In addition to its cognitive benefits, the psychological and emotional advantages of badminton over other closed-skilled sports are also significant in the context of elderly cognitive health. Previous study indicates that the engaging and competitive nature of badminton fosters positive emotions, motivation, and a sense of accomplishment, which can improve overall cognitive function (Wu et al., 2024). Furthermore, studies suggest that the mental resilience developed through badminton, especially in terms of strategic thinking and adapting to the unpredictability of gameplay, may serve as a protective factor against cognitive deterioration, helping elderly individuals to maintain mental sharpness and delay the onset of neurodegenerative conditions such as dementia (Noviati et al., 2020; Oishi & Yamasaki, 2024).

2.8 Conclusion

In conclusion, the literature reviewed in this chapter supports the potential of recreational badminton as an effective approach for enhancing physiological, physical, and cognitive health in elderly individuals. Regular participation is associated with improvements in cardiovascular function, musculoskeletal strength, metabolic regulation, and cognitive abilities that support healthy aging. Physiologically, badminton contributes to cardiovascular health by improving heart rate variability, promoting healthier lipid profiles, enhancing insulin sensitivity, and reducing systemic inflammation. Physically, it improves muscular strength, endurance, flexibility, and balance, which are critical for maintaining mobility and independence. Cognitively, the strategic and fast paced nature of badminton supports executive functions, working memory, decision making, and spatial awareness, all of which are important for preserving cognitive health in older adults. As an open-skilled and socially engaging activity, badminton encourages continued cognitive stimulation and emotional well-being, contributing to a higher quality of life. While this study provides valuable insights into the associations between recreational badminton participation and health outcomes in elderly individuals, further research using longitudinal designs and experimental controls is recommended to better understand the long-term effects and causal mechanisms involved.

Table 2.5
Open versus closed-skills studies on elderly population

Author	Participants OSP	Participants CSP	Cognitive assessment	Cognitive domains	Outcome
Tsai et al. (2017)	1) 66.9 ± 4.7 2) Table tennis	1) 66.2 ± 4.9 2) Cycling or brisk walking/jogging	Task-switching paradigm; N-back task	Cognitive flexibility; Working memory	OSP and CSP had distinct effects on executive function. OSP enhanced cognitive function, while CSP improved working memory.
Dai et al. (2013)	1) 66.0 ± 3.6 2) Table tennis or tennis	1) 69.9 ± 3.6 2) Jogging or swimming	Task-switching paradigm	Cognitive flexibility	The OSP and CSP groups exhibited greater cognitive flexibility than the control group. Additionally, the OSP group demonstrated higher cognitive flexibility than the CSP group.
Gu et al. (2019)	1) 66.0 ± 3.6 2) Table tennis	1) 69.9 ± 3.6 2) Jogging or swimming	VWMT; VSMT; VMTT	Visuospatial working memory	The OSP group outperformed the control group on the visuospatial short-term memory task
Huang et al. (2014)	1) 69.4 ± 3.0 2) Table tennis, tennis, badminton	1) 70.6 ± 2.6 2) Jogging, swimming	Eriksen flanker task	Inhibitory control	The OSP and CSP groups exhibited better inhibitory control than the sedentary control group.
Li et al. (2019)	1) 69.0 ± 3.0 2) Table tennis, tennis	1) 68.9 ± 3.1 2) Jogging or brisk walk	SCWT; Task-switching paradigm	Inhibitory control; Cognitive flexibility	The OSP and CSP groups demonstrated superior performance in inhibitory control and cognitive flexibility compared to the control group.

Tsai & Wang, (2015)	1) 65.4 ± 4.2 2) Badminton or table tennis	1) 68.9 ± 3.1 2) Jogging or swimming	Task-switching paradigm	Cognitive flexibility	The OSP group demonstrated greater cognitive flexibility than both the CSP and control groups.
Tsai et al. (2016)	1) 65.3 ± 4.1 2) Badminton or table tennis	1) 67.0 ± 4.7 2) Jogging or swimming	Central cue Posner paradigm	Visuospatial attention	The OSP and CSP groups demonstrated better visuospatial attention than the control group.
Heilmann et al. (2022)	1) 65.4 ± 4.2 2) Badminton, table tennis, martial arts	1) 68.0 ± 4.7 2) Swimming, running, cycling	Task-switching paradigm	Cognitive flexibility	The OSP group demonstrated greater cognitive flexibility than the CSP group.

Note: OSP = Open Skilled Sports; CSP = Closed Skilled Sports.

CHAPTER 3

STUDY 1: INFLUENCE OF RECREATIONAL BADMINTON PLAYING ON BLOOD PRESSURE AND BODY COMPOSITION IN ELDERLY: A CROSS-SECTIONAL ANALYSIS WITH PLAYING TIME-STRATIFIED SAMPLINGS

3.1 Introduction

Since its inclusion in the 1992 Olympic Games, badminton has become one of frequently watched sports. It is classified as a physically demanding sport due to its frequent and rapid shifts between low and high metabolic demands (Pardiwala et al., 2020). The sport's mix of short, fast-paced, rallies and extended rallies requires energy from both the aerobic system (approximately 30%) and the anaerobic system (60–70%), particularly the anaerobic glycolysis (Gomez et al., 2020; Phomsoupha & Laffaye, 2015). The physiological requirements of badminton have increased as the game has evolved to feature longer rallies and an increased shot frequency (Patterson et al., 2017).

Participation in physical activity particularly through recreational badminton offers a comprehensive strategy for attenuating cardiovascular decline in aging populations. Empirical evidence underscores that the maintenance of heart rate variability (HRV), the enhancement of aerobic capacity, and the strengthening of cardiovascular resilience represent pivotal outcomes associated with sustained physical activity (Viana et al., 2020). As a fast-paced sport requiring bursts of high-intensity effort, badminton mirrors interval training, which has been shown to counteract age-related declines in maximal heart rate and cardiac output (Huang et al., 2019). This alignment with exercise recommendations for older adults is further supported by the characteristic of the sport to enhances autonomic function, which is critical factor in managing cardiovascular health and reducing mortality risks (Oja et al., 2017; Zhao et al., 2014). Moreover, Füzéki et al. (2020) reported that the effect of exercise on blood pressure (BP) influenced by the volume of physical activity. Regular prolonged exercise can lower BP within a 10–20 mmHg range (Pedralli et al., 2020).

Other than the benefit of physical activity in reducing the risk of cardiovascular disease, growing evidence indicates that physical activity also positively influences body composition in the elderly population. There is some evidence to show a decrease in fat mass after a period of high-intensity aerobic exercise (Shehata & Mahmoud, 2018). The outcome of this study is also in line with Wu et al. (2021), who stated that physical fitness and regular physical activity enhanced body composition by reducing fat mass, which is linked to a better lipid profile (Itani et al., 2002). Regular participation in physical exercise also enhances muscular strength and endurance, leading to an increase in lean body mass and a decrease in adiposity, particularly visceral fat that is strongly associated with metabolic disorders (Nugroho et al., 2022). This combination of aerobic and anaerobic activity also contributes to the maintenance of an optimal body mass index and improved metabolic health, outcomes that are critical for reducing the risks of obesity and sarcopenia in older adults (Zhao et al., 2014). Moreover, the dynamic nature of badminton, involving lateral movements, jumping, and sprinting, has been linked to improved fat distribution and lower visceral fat levels (Nassef et al., 2019).

Although regular exercise is known to have positive health effects, few studies have examined whether participation and overall playing time in racquet sports influence blood pressure and body composition in older adults. Therefore, this study aims to assess whether varying durations of badminton play lead to differences in these health indicators.

3.2 Methodology of Study

3.2.1 Study Design

A cross-sectional design was selected for this study. This design was selected to examine associations between different badminton playing volumes and health outcomes at one point in time. Participants were selected using a purposive sampling approach to ensure that only individuals meeting the specific criteria for recreational badminton participation were included. This method was selected due to primary aim was to evaluate the health effects among older adults who are active badminton players. Purposive sampling ensured participants met specific activity criteria five years minimum experience and regular participation. To reduce the risk of selection bias, the following objective inclusion criteria were applied which is at least five years of regular badminton play, participant must be 55 years old and above and participation in badminton for a minimum of 30 minutes per session, at least once per week over the past two years. The rationale behind this purposive approach was to focus on a well-defined subpopulation whose physical activity patterns are consistent with the study's objectives. Although purposive sampling inherently carries the risk of bias, using strict inclusion criteria and recruiting from diverse sources (e.g., email, social media, and printed posters) helped mitigate this risk. All study procedures were approved by the Research Ethics Committee (REC/06/2022-PG/MR/127) and completed in accordance with the requirements of the Helsinki Declaration (2013).

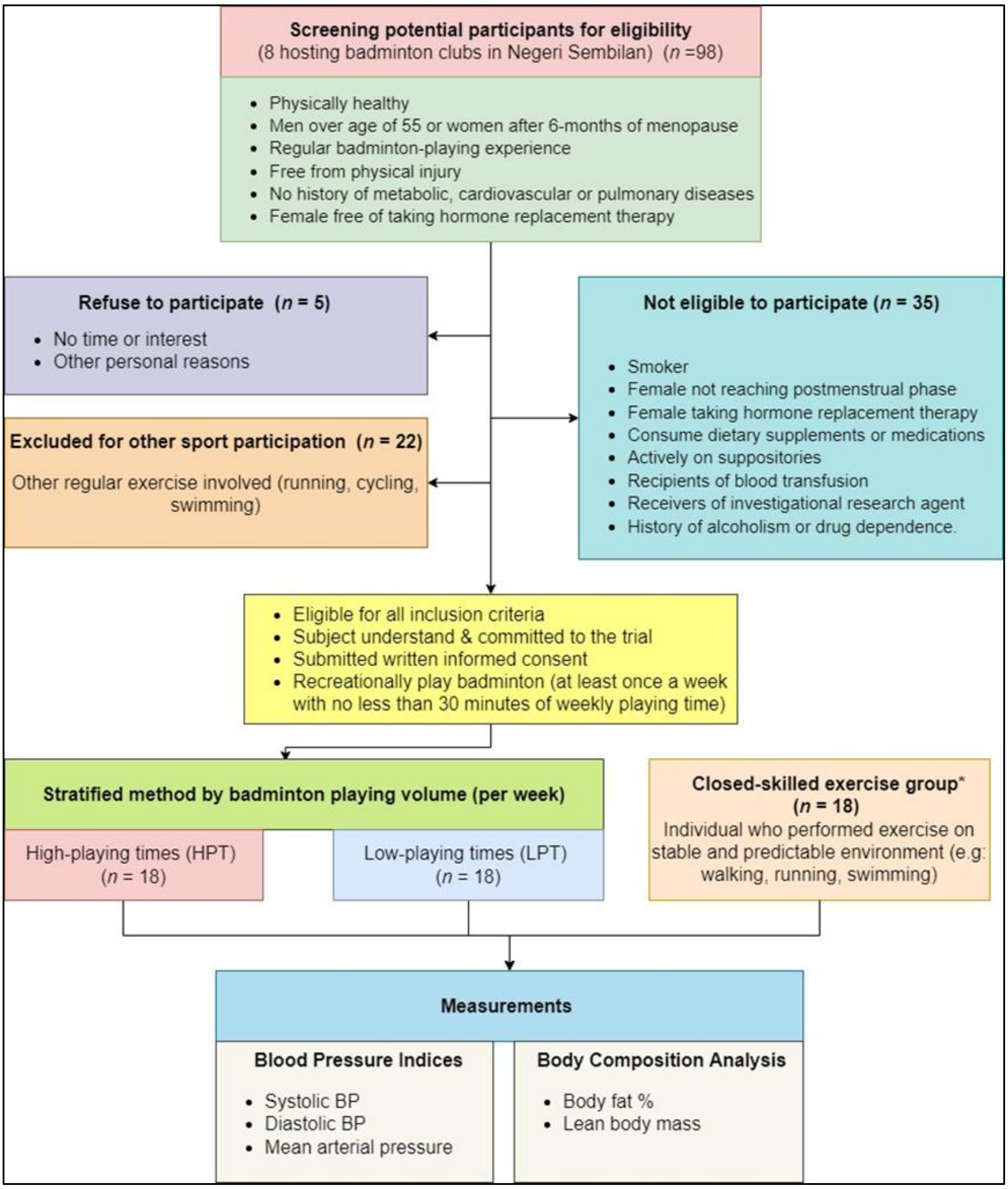

Figure 3.1 Flow Diagram of Participant Screening, Enrolment, and Measurement Performed in Study 1.

3.2.2 Participants and Sampling Technique

The initial sample size was estimated using the formula described by Charan and Biswas (2013) for population proportions, considering a 95% confidence interval and a 5% margin of error. Given an estimated prevalence of 1% for elderly badminton players in the general population (based on preliminary club interviews and census data), the calculation suggested a minimum of 16 participants per group for adequate power. However, to address potential issues with underestimation and to account for non-response or dropouts, the following adjustments were implemented which is the moderate effect size was assumed based on previous studies evaluating the impact of exercise on physiological outcomes. A 20% increment was applied to the estimated minimum sample size, resulting in approximately 18 participants per group and participants were subsequently stratified into high-playing time (HPT), low-playing time (LPT), and a closed skilled-exercise (CSE) group based on predefined activity levels. The CSE group selected individuals who participated in close-skills exercise, which exercise that performed in stable and predictable environments (e.g; walking, swimming, running).

3.2.3 Study Protocol

The subject who passed the screening process be requested to make themselves present at the Physiology and Nutrition Laboratory at Faculty of Sport Science and Recreation, University Technology Mara, Negeri Sembilan Branch, Seremban Campus, Malaysia. Following the arrival of the participants at the laboratory, the subjects were given written, informed consent, followed with detailed explanation regarding the testing procedures, the potential benefits, and associated risks of participation. Subjects then proceed with the anthropometric measurement (i.e., weight, height, and waist-to-hip ratio). After that, the blood pressure reading was taken. The subjects been placed in a quiet room with a thermoneutral temperature of ~22°C for a 10-minute rest for blood pressure (systolic and diastolic blood pressure) reading. All subjects then were asked to lie down for 10 minutes without wearing any electrical device for the body composition analysis. Finally, subjects were asked to fill in the questionnaires in a structured manner before leaving the testing centre. The rank stratification analysis was used to assign the badminton playing group to high-playing time (HPT) and low-playing time (LPT).

3.3 Measurement

3.3.1 Anthropometric measurements

Anthropometric measurements of weight (kg) and height (cm) were obtained using a validated stadiometer (Seca 220; Seca, Ltd, Hamburg, Germany). Participants stood upright on the wall-mounted stadiometer without shoes and in light clothing, following the procedure described by Meigh et al. (2022). These measurements were used to calculate body mass index (BMI). Waist circumference was measured using a Seca 201 measuring tape (Seca, Ltd, Hamburg, Germany) with consistent tension. The measurement was taken at the midpoint between the lowest palpable rib and the top of the iliac crest to determine the waist-to-hip ratio

3.3.2 Blood pressure

Participants' brachial artery resting BP was taken using an automated sphygmomanometer (AccutorrPlus, Paramus, NJ, US), with the participants in a seated position. Following 10-min sitting on a comfortable chair in a quiet room, with a thermos-neutral temperature of ~22°C, 5 resting BP measurements with the arm at heart level were recorded with 15 seconds of interval time between each measurement). The average of the final four measurements was used for data analysis. Recorded systolic BP and diastolic BP data were used to calculate mean arterial pressure (MAP) using the standard formula: (⅓·systolic BP) + (⅔·diastolic BP).

3.3.3 Body composition

Body composition analysis was conducted using multi-frequency bioelectrical impedance analysis. Specifically, body fat percentage and lean mass were measured with a tetrapolar, multi-frequency device (BodyStat QuadScan 4000, Bodystat Ltd., Isle of Man, UK). A trained investigator performed all measurements following the tetrapolar method. The assessment area was inspected to ensure it was free of drafts and portable electric heaters, as these factors could affect the accuracy of the equipment. Throughout the test, participants maintained an abducted position of the arms and legs. Impedance values were recorded at frequencies of 5, 50, 100, and 200 kHz, with resistance measured at 50 kHz. The coefficient of variation (CV) for the body composition analysis device was determined through repeated assessments (three times) in a pilot study, with an inter-study variation CV of 1.3% for body fat percentage.

3.3.4 Physical activity, Badminton-playing time and Group Stratification Analysis

Physical activity levels were assessed using the Global Physical Activity Questionnaire (GPAQ), as described by Goenarjo et al. (2020). Badminton playing time was evaluated through weekly playing records and a modified Physical Activity Scale for the Elderly (PASE) questionnaire. The badminton group was stratified based on total weekly playing time (hr·week^{-1}). Among the 36 eligible participants, ranks #18 and #19 reported weekly playing times of 6.6 hr and 7.5 hr, respectively. The median value of 7.05 hr·week^{-1} was used as the cut-off to classify the group into high playing time (HPT, 9.72 hr·week^{-1}) and low playing time (LPT, 3.34 hr·week^{-1}) categories.

3.3.5 Statistical Analysis

Statistical analyses were conducted to examine differences in badminton playing history characteristics using an independent samples t-test. A one-way repeated measures analysis, employing the Brown-Forsythe and Welch ANOVA, was utilized to assess variations in physical attributes (height, weight, BMI, and age), resting blood pressure indices (systolic blood pressure, diastolic blood pressure, and mean arterial pressure), and body composition parameters (body fat percentage and lean body mass) across the study groups. Dunnett's T3 multiple comparison test was applied to determine the specific sources of variation. All statistical analyses were performed using GraphPad Prism software (version 9.0, GraphPad Software Inc., La Jolla, California, USA), with statistical significance set at $p < 0.05$.

3.4 Result of Study

3.4.1 Anthropometric Measurement, Badminton-Playing History, and Physical Characteristics

Anthropometric measurement, badminton playing history, and physical activity characteristics between groups are outlined in Table 3.1. A total of 32 participants (58.2%) were men, and 23 participants (41.8%) were women. The mean age of the participants in HPT group was 64.2 ± 2.81 years, LPT group was 63.3 ± 2.59 years and CSE group was 64.9 ± 2.89 years. Mean participant's weight in HPT group was 64.8 ± 4.52 kg, LPT group was 67.2 ± 4.58 kg and CSE group was 66.3 ± 6.39 kg. The participants mean height in HPT group was 165 ± 3.95 cm, LPT group was 165 ± 3.58 cm and CSE group was 164 ± 3.48 cm. There were no differences in basic anthropometric characteristics (height, weight, BMI, age, and waist-to-hip ratio) between HPT, LPT, and CSE group (all p>0.05).

The table shows that the years of experience in playing badminton were not differed between HPT and LPT groups (p>0.05), with the frequency of badminton play per week, hours of play per day, a total time of play per week being higher in HPT compared to the LPT condition (p<0.05). The vigorous physical activity derived from GPAQ was higher in HPT compared to LPT and CSE group (p<0.05), with no difference between the LPT and CSE group (p>0.05). No significant differences were found in the GPAQ total physical activity level between HPT (3397 ± 913 MET-min·wk-1), LPT (3308 ± 1037 MET-min·wk-1), and CSE group (3180 ± 1186 MET-min·wk-1) (p>0.05).

Table 3.1
Physical Characteristics and Badminton-Playing History between Groups.

Parameter	HPT	LPT	CSE
Age	64.2 ± 2.81	63.3 ± 2.59	64.9 ± 2.89
Weight (kg)	64.8 ± 4.52	6.72 ± 4.58	66.3 ± 6.39
Height (cm)	165 ± 3.95	165 ± 3.58	164 ± 3.48
BMI ($kg{\cdot}m^{-2}$)	23.9 ± 1.46	24.8 ± 2.34	24.6 ± 2.31
Waist-to-hip ratio	0.90 ± 0.19	0.91 ± 0.12	0.92 ± 0.11
Playing experience (yrs)	28.6 ± 1.33	24.3 ± 3.03	-
Badminton playing frequency ($day{\cdot}week^{-1}$)	4.72 ± 1.13[a]	2.28 ± 1.02	-
Badminton playing hours ($hrs{\cdot}day^{-1}$)	2.14 ± 0.56 [a]	1.51 ± 0.50	-
Total badminton playing time ($hrs{\cdot}week^{-1}$)	9.72 ± 2.16 [a]	3.34 ± 1.53	-
Total physical activity level (METs)	3397 ± 913	3308 ± 1037	3180 ± 1186
Light intensity physical activity	1224 ± 160	1218 ± 513	1360 ± 452
Moderate intensity physical activity	1167 ± 252	1290 ± 409	1181 ± 477

Vigorous intensity physical activity	1114 ± 198	823 ± 248	716 ± 370

[a]Significantly different from LPT (*p*<0.05)

3.4.2 Systolic Blood Pressure

Group mean differences in resting systolic BP were assessed following different groups (HPT, LPT, and CSE group (Figure 3.2). There was no trial order effect across all different conditions (*p*>0.05). However, a one-way ANOVA test revealed that there was trended effect between HPT and CSE group, F (2,50) = 2.4, *p* = 0.099, ηp2 = 0.70, for systolic BP.

Unpaired t-test with Welch's correction reported significant differences in HPT relative to CSE group, 121.7 ± 9.68 vs. 128.7 ± 9.54 mmHg; p = 0.099, d = 2.20; mean differences = -7.000, 95% CI = [-13.47, -0.5322]. Meanwhile, there is no significant different in HPT relative to LPT group, 121.7 ± 9.68 vs. 125.1 ± 9.54 mmHg; *p* = 0.30, d = 1.06; mean differences = -3.39, 95% CI = [-9.896, 3.118] and LPT in relative to CSE group, 125.1 ± 9.54 vs. 128.7 ± 9.54 mmHg; *p* = 0.26, d = 1.14; mean differences = -3.611, 95% CI = [-10.03, 2.809].

Overall, the systolic BP level was not significantly changes after administration between HPT in relative to LPT group and LPT in relative to CSE group, respectively (all, *p* > 0.05). Therefore, a null hypothesis in which there is no significant differences in systolic blood pressure levels between HPT, LPT and CSE group in elderly recreational badminton players is rejected.

In comparing resting systolic blood pressure between the high-playing time (HPT) and closed skilled-exercise (CSE) groups, the analysis indicated a mean difference of 7.0 mmHg; however, this difference did not reach statistical significance (*p*=0.099). Although the result shows a trend toward lower systolic blood pressure in the HPT group, it does not satisfy the conventional criterion of *p*<0.05 for statistical significance. Consequently, it was failed to reject the null hypothesis of no significant difference in systolic blood pressure between these groups

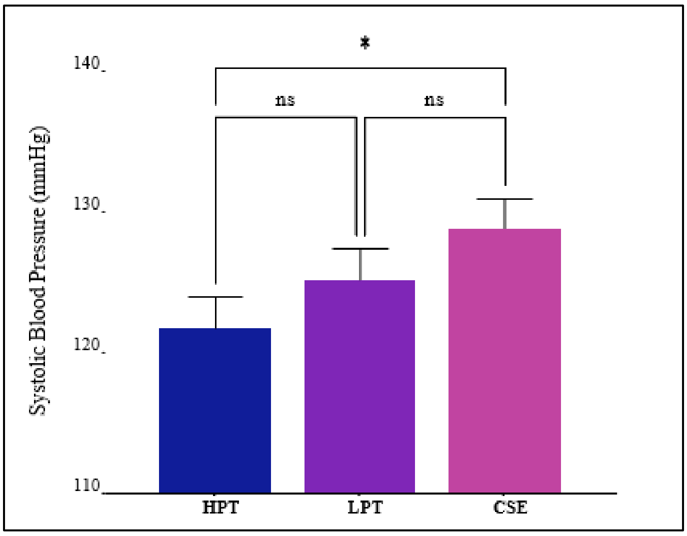

Figure 3.2 Systolic Blood Pressure Indices were measured in the HPT, LPT and CSE groups.

3.4.3 Diastolic Blood Pressure

Furthermore, group mean differences in diastolic BP were assessed following different groups (HPT, LPT and CSE group) (Figure 3.3). There was no trial order effect across all different conditions (*p*>0.05). A one-way ANOVA revealed neither significant differences for diastolic BP between HPT, LPT and CSE group. Therefore, a null hypothesis in which no significant differences in diastolic blood pressure levels between HPT, LPT and CSE group in elderly recreational badminton players is accepted.

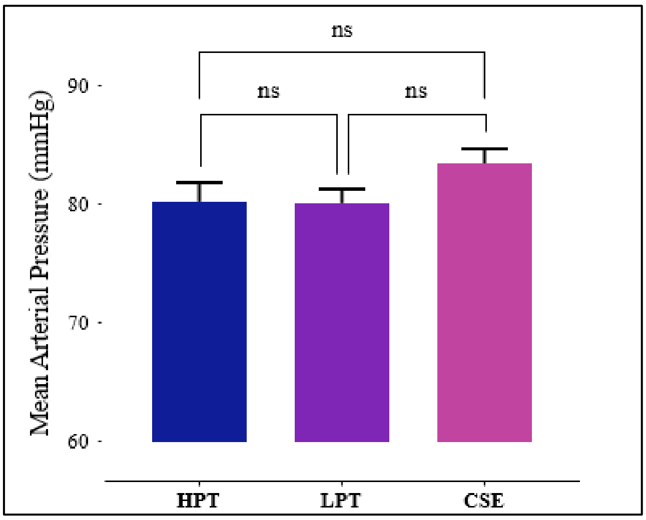

Figure 3.3 Diastolic Blood Pressure Indices was measured in the HPT, LPT and CSE groups

3.4.4 Mean Arterial Pressure

Group mean differences in MAP were assessed following different groups (HPT, LPT, and CSE group) is shown in Figure 3.4. No trial order effect across all different conditions (p>0.05). However, a one-way ANOVA test revealed that there was trended effect between HPT and CSE group, F (2,51) = 2.7, p=0.079, ηp2 = 0.70, for MAP.

Unpaired t-test with Welch's correction reported significant differences in HPT relative to CSE group, 94.1 ± 6.4 vs. 98.6 ± 5.9 mmHg; p = 0.037, d = 2.17; mean differences = -4.472, 95% CI = [-8.654, -0.2905]. Meanwhile, there is no significant different in HPT relative to LPT group, 94.1 ± 6.4 vs. 95.1 ± 5.6 mmHg; p = 0.64, d = 0.47; mean differences = -0.97, 95% CI = [-5.184, 3.239] and LPT in relative to CSE group, 95.1 ± 5.6 vs. 98.6 ± 5.9 mmHg; p=0.09, d = 1.18; mean differences = -3.500, 95% CI = -7.527, 0.5267].

Overall, the MAP was not significantly changes after administration between HPT in relative to LPT group and LPT in relative to, respectively (all, p>0.05). Therefore, a null hypothesis in which there is no significant differences in mean arterial pressure levels between HPT, LPT and CSE group in elderly recreational badminton players is accepted.

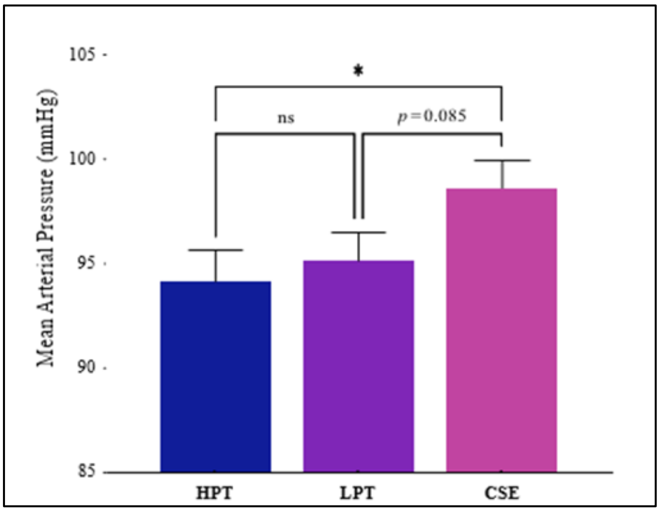

Figure 3.4 Mean Arterial Pressure Indices were measured in the HPT, LPT and CSE groups.

3.4.5 Body Fat Percentage

Group mean differences in % body fat were assessed following different groups (HPT, LPT, and CSE group) (Figure 3.5). There was no trial order effect across all different conditions (*p*>0.05). However, a one-way ANOVA test revealed that there was a significant difference between HPT and CSE group, F (2,42) = 3.84, *p* = 0.029, ηp2= 0.73, for % body fat.

The unpaired t-test with Welch's correction reported significant differences in HPT relative to closed skilled-exercise group, 20.7 ± 4.85 vs. 26.6 ± 8.52; p = 0.049, d = 2.55; mean differences = -5.89, 95% CI = [-12.5, 0.664]. Meanwhile, there is no significant different in HPT relative to LPT group, 20.7 ± 4.85 vs. 25.3 ± 6.22; p = 0.156, d = 2.46; mean differences = -4.58, 95% CI = [-9.79, 0.633] and LPT in relative to closed skilled-exercise group, 25.3 ± 6.22 vs. 26.6 ± 8.52; *p* = 0.93, d = 1.44; mean differences = -1.32, 95% CI = [-8.30, 5.67].

Overall, the body fat % was not significantly changes after administration between HPT in relative to LPT group and LPT in relative to closed skilled-exercise group, respectively (all, *p*>0.05). Therefore, a null hypothesis in which there is no significant differences in body fat percentage level between HPT, LPT and CSE group in elderly recreational badminton players were rejected.

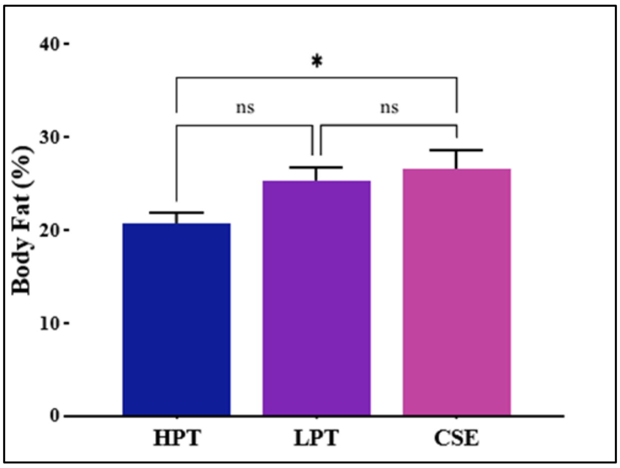

Figure 3.5 Body Fat Percentage in the HPT, LPT and CSE groups.

3.4.6 Lean Body Mass

Group mean differences in body lean mass were assessed following different groups (HPT, LPT, and CSE group) (Figure 3.6). There was no trial order effect across all different conditions (p>0.05). However, a one-way ANOVA test revealed that there was a significant difference between HPT and CSE groups, F (2,48) = 4.0, p = 0.025, ηp2 = 0.73, for lean body mass.

Unpaired t-test with Welch's correction reported significant differences in HPT relative to CSE group, 50.3 ± 4.89 vs. 45.6 ± 5.69 kg; p = 0.013, d = 2.62; mean differences = 4.63, 95% CI = [1.04 to 8.23]. Meanwhile, there is no significant different in HPT relative to LPT group, 50.3 ± 4.89 vs. 48.0 ± 4.04 kg; p = 0.14, d = 1.51; mean differences = 2.26, 95% CI = [-0.780, 5.30] and LPT in relative to CSE group, 48.0 ± 4.04 vs. 45.6 ± 5.69 kg; p = 0.16, d = 1.44; mean differences = 2.37, 95% CI = [-0.984, 5.73]. Overall, the body lean mass was not significantly changes after administration between HPT in relative to LPT group and LPT in relative to closed skilled-exercise group, respectively (all, p>0.05). Therefore, a null hypothesis in which there is no significant differences in body lean mass level between HPT, LPT and CSE group in elderly recreational.

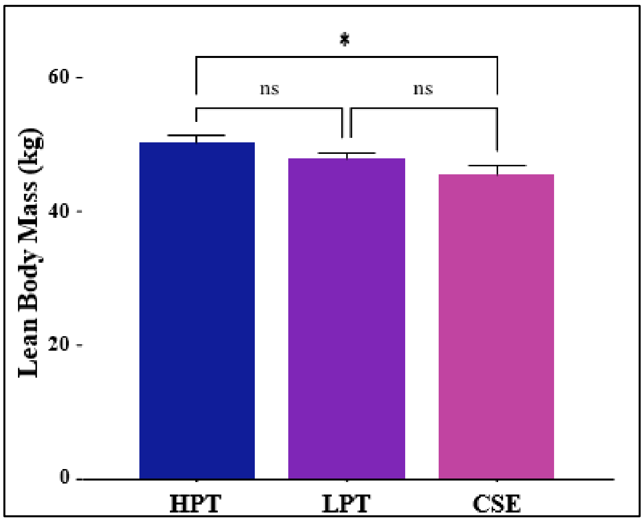

Figure 3.6 Lean Body Mass (kg) in the HPT, LPT and CSE groups.

3.5 Discussion of Study

A key finding of the current research is that, despite similar daily physical activity levels, participants in the higher badminton playing time group had lower resting blood pressure compared to those in the closed-skill exercise group, with no significant differences in working memory among the three groups. Regular participation in physical activity may be a crucial factor in the primary prevention of chronic diseases among the elderly. Previous research has demonstrated that badminton has a higher work density, defined as the ratio of performance time to rest time compared to other high-intensity team sports such as soccer (Lam et al., 2018).

The present study found that resting systolic BP and MAP in HPT that participated more in moderately vigorous intermittent activity (i.e., badminton) weekly were lower by 5.4% and 4.8% when compared to CSE group ($p < 0.05$), respectively. Previous research has demonstrated that regular exercise reduces blood pressure through multiple mechanisms, including enhanced vascular compliance, improved endothelial function, reduced sympathetic nervous system activity, and favorable alterations in arterial stiffness exercise (Caminiti et al., (2019). The intermittent nature of badminton, characterized by alternating periods of high-intensity effort and active recovery, may elicit unique hemodynamic responses compared to continuous moderate-intensity. As for body composition, while overall physical activity levels were comparable between groups, the GPAQ study revealed that HPT participants engaged in substantially more vigorous activities than other groups. This may partially explain the finding that the percentage of body fat was reduced in HPT by 22.2% and 18.2% in contrast to CSE and LPT group ($p<0.05$), respectively. Indeed, regular participation in high-intensity intermittent exercise has been demonstrated to improve hemodynamic response in both clinical (Herrod et al., 2018) and non-clinical in elderly populations. Moreover, a hypotensive effect in older adults was even larger in high-intensity intermittent exercise when compared to other exercise modalities such as resistance training and moderate continuous training (Pimenta et al., 2019). The repeated exposure to high-intensity intervals during badminton play may enhance nitric oxide bioavailability and improve endothelium-dependent vasodilation, processes that are central to vascular health and blood pressure regulation (Rippe & Angelopoulos, 2019). The dynamic nature of the sport, involving rapid changes in movement direction and velocity, may provide a more potent stimulus for arterial remodelling compared to repetitive, predictable movements characteristic of closed-skill exercise. Tanaka et al. (2019) stated that physical activity reduces BP level by enhances the vascular compliance. In previous studies on BP, resistance training has been found to be related with BP (Ashton et al., 2020).

However, not all studies have reported significant blood pressure-lowering effects of high-intensity intermittent exercise interventions in older adults. A systematic meta-analysis of 13 studies found that while systolic and diastolic blood pressure tended to improve with intermittent training, the reductions were not statistically significant compared to control groups (Mattioni Maturana et al., 2021). These discrepancies may be partly due to variations in training intensity across studies. Further analysis from the same study indicated that training at or above 80% $\dot{V}O_2max$ led to better hemodynamic responses (Huang et al., 2019). In the present study, differences in blood pressure levels between groups may be attributed to greater engagement in moderately vigorous intermittent activities. Even slight reductions in blood pressure within the normal range can be clinically significant, particularly in aging adults. While the absolute differences in systolic blood pressure (Δ7 mmHg) and mean arterial pressure (Δ5 mmHg) between the high playing time (HPT) and closed-skill exercise (CSE) groups may seem small, they are meaningful. A reduction of just 5 mmHg in blood pressure has been associated with a 35% lower risk of stroke and coronary heart disease (Dewhurst-Trigg et al., 2018; Filippone et al., 2021) both of which are common and major causes of preventable illness and mortality in older adults.

3.6 Conclusion

The findings of this study suggest that extended participation in recreational badminton may be associated with modest improvements in blood pressure and body composition among older adults, suggesting the nature of badminton as intermittent high-intensity nature may confer specific cardiovascular benefits. The cross-sectional design prevents causal inference, which cannot determine whether badminton participation caused these differences or whether healthier individuals maintain higher playing volumes. The purposive sampling may have introduced selection bias, the relatively small sample limits generalizability, and bioelectrical impedance cannot distinguish muscle hypertrophy from lean mass preservation. Further research, employing longitudinal methodologies and larger, more diverse cohorts, is required to validate these preliminary associations and to establish the optimal playing duration for significant health benefits. Consequently, these findings should be viewed as an initial exploration rather than conclusive evidence of badminton's efficacy as a preventive intervention against age-related cardiovascular and metabolic decline.

CHAPTER 4
STUDY 2: A CROSS-SECTIONAL ANALYSIS OF RECREATIONAL BADMINTON PLAYING AND ITS INFLUENCES ON CARDIOMETABOLIC HEALTH IN HEALTHY OLDER ADULTS

4.1 Introduction

Badminton is among the most widely played sports worldwide. This racquet sport accommodates mixed-gender participation across various age groups and physical abilities. Over a period, the game has evolved to feature faster-paced play and longer rallie s(Gomez et al., 2020). The intermittent nature of badminton, which involves a combination of short and long high-intensity rallies, engages both the aerobic (approximately 30%) and anaerobic systems (approximately 60–70%) (Phomsoupha & Laffaye, 2015). Consequently, regular badminton play can enhance hand-eye coordination, general speed, upper-body strength, and cardiovascular fitness (Preeti et al., 2019).

In recent years, there has been increasing participation in racquet sports as recreational physical activity (Demeco et al., 2022). In a nationwide prospective study by (Chao et al., 2021), regular participation in racquet sports is associated with the lowest risk of cardiovascular- related diseases and the lowest risk of all-cause mortality. A sociodemographic survey of more than 7000 Taiwanese volunteers found that regular badminton playing was associated with higher levels of HDL, a biomarker positively associated with a decreased risk of coronary heart disease (Nassef et al., 2019). In addition to its cardiovascular benefits, recreational badminton positively affects metabolic health, particularly in combating insulin resistance and lipid profile changes commonly seen in aging populations. Age-related factors such as reduced skeletal muscle mass and increased visceral fat contribute to decreased insulin sensitivity (Chao et al., 2021) and elevated low-density lipoprotein (LDL) cholesterol levels (Chao et al., 2021).

Engaging in physical activity such as badminton mitigates these issues by promoting muscle engagement and reducing visceral adiposity, thereby improving insulin sensitivity and regulating lipid metabolism (Mancusi et al., 2020; Park & Seo, 2020; Ross et al., 2002). There is some evidence to indicate that regular moderate to high-intensity intermittent exercise produced significant improvements in body composition (Sultana et al., 2019), lipid profile (Nazari et al., 2020) and glucose control (Liu et al., 2021).

Although badminton training may provide various health benefits, limited research has examined whether the duration of recreational badminton participation influences cardiometabolic health indicators. Specifically, it remains unclear whether a higher or lower volume of weekly badminton play yields greater cardiometabolic health benefits in older adults. Therefore, this study aims to investigate whether different levels of recreational badminton participation are associated with variations in cardiometabolic indices among healthy elderly players. It is hypothesized that older adults with higher weekly volumes of recreational badminton participation will exhibit more favorable cardiometabolic health outcomes compared to both non-players and those with lower playing time.

4.2 Methodology of Study

4.2.1 Study Design

The study employed purposive sampling to select participants based on their specific attributes relevant to the research objective. Purposive sampling was chosen to deliberately recruit older adults who actively participate in recreational badminton, as this subgroup possesses specific experiences essential for examining the relationship between badminton-playing duration and cardiometabolic health outcomes. Clear inclusion criteria included age above 55 years, consistent recreational badminton playing for at least the past 6 months, and willingness to participate in laboratory-based measurements. This method ensured that participants had sufficient experience in badminton to meaningfully contribute to the study objectives. However, it is acknowledged that purposive sampling could introduce selection bias, as individuals who volunteer might differ systematically from those who do not volunteer in terms of motivation, health consciousness, or fitness levels. To mitigate potential bias, participants were recruited from diverse badminton clubs across different districts within Negeri Sembilan, Malaysia, thereby ensuring representation of various levels of badminton participation and minimizing the potential influence of club-specific culture or training patterns. All study procedures were approved by the Research Ethics Committee (REC/06/2022-PG/MR/127) and completed in accordance with the requirements of the Helsinki Declaration (2013).

4.2.2 Participant Sampling

The sample size calculation was initially based on a 1% population estimate of elderly badminton players. To address the reviewers' concerns, further justification is provided as follows: According to the census data from the Department of Statistics Malaysia (DOSM, 2021), approximately 14% of the population in Negeri Sembilan comprises older adults aged 55 years and above. Consultation with the management of local badminton clubs indicated that roughly 1% of this older adult population actively participates in badminton at a recreational level. Additionally, this estimate aligns closely with participation rates found in recent regional studies, such as the survey conducted by Demeco et al. (2022), which reported similar engagement levels (approximately 0.8%-1.2%) in racquet sports among older adults in urban and semi-urban areas of Southeast Asia. This information was verified through direct communication and informal surveys with badminton clubs across Negeri Sembilan, providing a practical and locally relevant foundation for the 1% estimate used in sample size calculation. Thus, the selected population estimate is empirically supported by regional demographic trends and local observational data, offering sufficient justification for the chosen sampling parameters. In order to ascertain that any changes in the measurement conducted in this study are due to participation in badminton, closed skilled-exercise (CSE) group, defined as individual who performed skills on stable and predictable environment such as walking, running were introduced was deliberately selected as a control condition to isolate the unique effects of recreational badminton playing on cardiometabolic health indicators. All the subjects in this study is the similar subject from Study 1.

4.2.3 Study Protocol

All selected participants were instructed to arrive at the laboratory at 8:00 AM in a fasting state. They were reminded to abstain from food and beverages, except plain water, for at least 8 to 12 hours before their arrival. Upon arrival, they received a brief explanation of the test procedures and potential risks. After resting for 10 minutes, a capillary blood sample was collected from the fingertip to measure blood glucose, creatinine, uric acid, triglycerides, high-density lipoprotein cholesterol, and total cholesterol concentrations, following the respective manufacturers' guidelines. Participants then completed physical activity logs, weekly badminton-playing records, and the modified Physical Activity Scale for the Elderly (PASE) questionnaire. Before leaving the laboratory, they were provided with breakfast. Stratification analysis was performed based on the median value of weekly badminton-playing time, as recorded in the weekly badminton-playing logs and the modified PASE questionnaire. Based on this analysis, participants were categorized into either the high-playing time (HPT) or low-playing time (LPT) group.

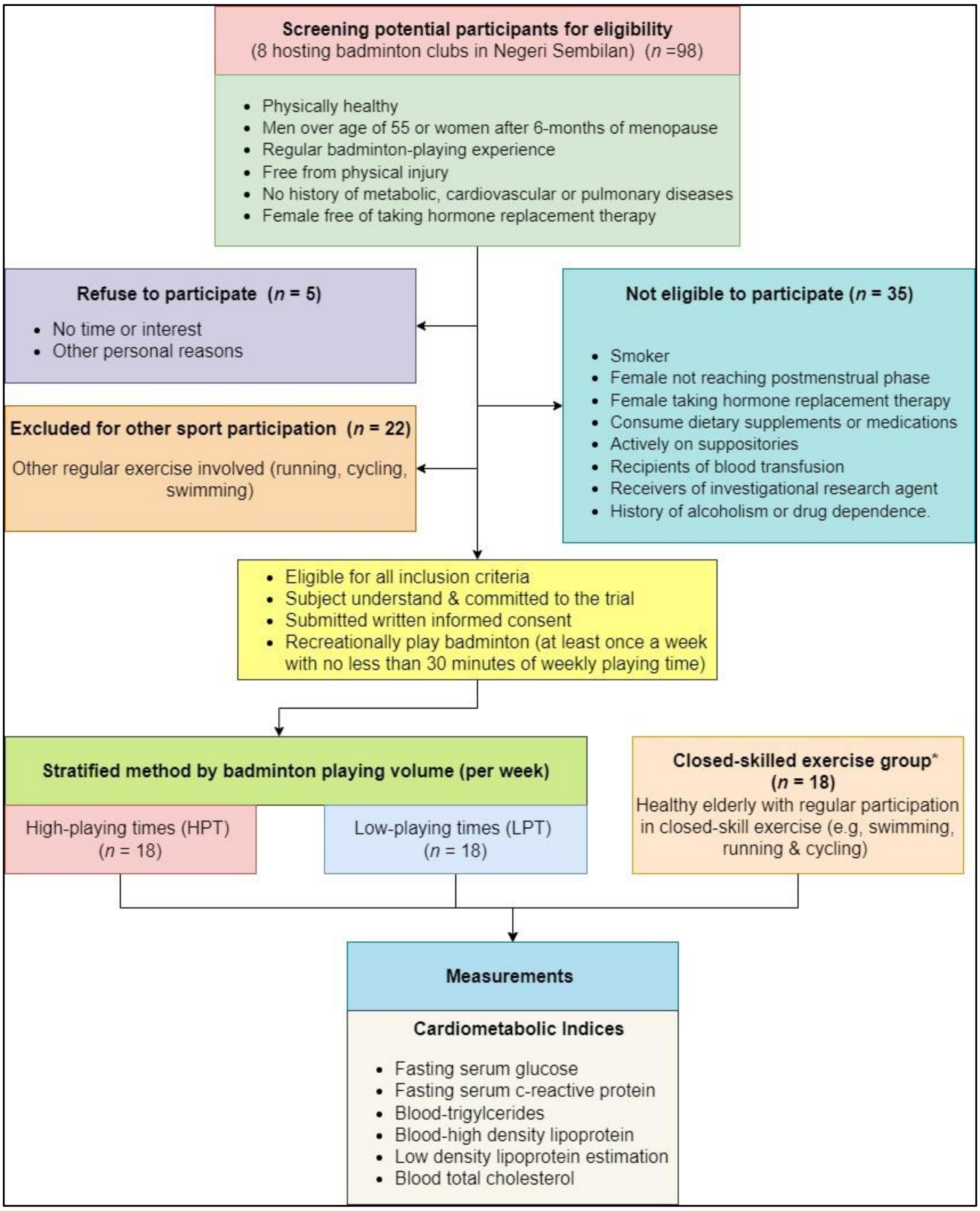

Figure 4.1 Flow Diagram of Participant Screening, Enrolment, and Measurement Performed in Study 2.

4.3 Measurement

4.3.1 Anthropometric Measurements

The waist-to-hip ratio measurement procedure adhered strictly to the standardized protocols outlined by the International Society for the Advancement of Kinanthropometry (ISAK). Waist circumference was measured using a non-elastic Seca 201 measuring tape (Seca Ltd, Hamburg, Germany) placed horizontally at the midpoint between the inferior margin of the last palpable rib and the superior border of the iliac crest. Participants were instructed to stand upright, feet together, and arms relaxed at the sides, with measurements taken at the end of a normal exhalation. Hip circumference was similarly measured at the level of the maximum circumference of the buttocks, horizontally aligned and parallel to the floor. Measurements were conducted twice at each site, with a third measurement taken if discrepancies exceeded 0.5 cm. The average of two closely aligned measurements was used for analysis to enhance accuracy and reliability.

4.3.2 Blood Biomarker Analysis

Venous blood samples were collected by a qualified medical technologist using 2 mL Vacuette® tubes without additives and 6 mL Vacutainer® tubes containing ethylenediaminetetraacetic acid (EDTA). A 10 μL aliquot of whole blood from the no-additive tubes was analyzed for lipid biomarkers, including triglycerides (TG), total cholesterol (T-Cho), and high-density lipoprotein cholesterol (HDL), using the PTS Panels® Lipid Panel (CardioChek PA, PTS Diagnostics, Indianapolis, USA). Low-density lipoprotein cholesterol (LDL) was calculated using Friedewald's formula. Whole blood samples from EDTA tubes were kept at ambient temperature for 20 minutes before centrifugation at 4,000 rpm for 8 minutes using a Hettich EBA 20 centrifuge (Andreas Hettich GmbH & Co., Tuttlingen, Germany). The extracted serum was analyzed for glucose, uric acid (UA), and C-reactive protein (CRP) concentrations. CRP measurements followed the manufacturer's guidelines standard protocol, with samples diluted 21-fold (Stukas et al., 2020).

4.3.3 Physical Activity, Badminton-Playing Time and Group Stratification Analysis

GPAQ was used to determine physical activity levels as previously described by (Goenarjo et al., 2020). Metabolic equivalents (MET-min·week-1) are obtained by measuring the total amount of time and energy expended for a variety of activities over the course of a week. A modified version of the Physical Activity Scale for Elderly (PASE) questionnaire and the weekly badminton playing records were used to evaluate the badminton playing time. Ranking the total playing time (hr-week-1) reported by the badminton playing group served as the framework for the stratification of the badminton group. The badminton playing group selected ranks #18 and #19 with a combined playing time of 6.6 hr·week-1 and 7.5 hr·week-1, respectively, out of a total of 36 qualified participants. Hence, the median of 7.05 hr·week-1 was used as the cut- off value to divide the badminton group into HPT (9.72 hr·week-1) and LPT (3.34 hr·week-1).

4.3.4 Statistical Analysis

Differences in badminton playing history characteristics were analyzed using an independent samples t-test. A one-way repeated measures analysis using Brown-Forsythe and Welch ANOVA was conducted to examine differences in physical attributes (height, weight, BMI, and age), total physical activity levels, blood lipid biomarkers (TG, T-Cho, HDL, and LDL), and other blood biomarkers (glucose, UA, and CRP) between groups. Post hoc analyses to identify the sources of significant effects were performed using Dunnett's T3 multiple comparison test. All statistical analyses were conducted using GraphPad Prism software (version 9.0, GraphPad Software Inc., La Jolla, California, USA), with statistical significance set at $p<0.05$.

4.4 Result

4.4.1 Anthropometric Measurement, Badminton-Playing History and Physical Characteristics

Out of 55 participants, 32 (58.2%) were men, and 23 (41.8%) were women, as presented in Table 4.1. The number of years of badminton experience showed no statistically significant variation between the HPT and LPT groups (p>0.05). However, the HPT group demonstrated a measurably higher frequency of play per week, hours of play per day, and total weekly playing time in comparison to the LPT group (p<0.05). Moreover, vigorous physical activity, as assessed through the Global Physical Activity Questionnaire (GPAQ), was statistically greater in the HPT group than in both the LPT and CSE groups (p<0.05), while no notable difference was identified between the LPT and CSE groups (p >0.05). Additionally, total physical activity levels derived from the GPAQ remained comparable across the HPT (3397 ± 913 MET-min·wk^{-1}), LPT (3308 ± 1037 MET-min·wk^{-1}), and CSE (3180 ± 1186 MET-min·wk^{-1}) groups (p>0.05).

Table 4.1

Physical Measurement, Badminton-Playing History, and Physical Characteristicsin High-Playing Time, Low-Playing Time, and Closed-Skilled Exercise Groups.

Parameter	**HPT**	**LPT**	**CSE**
Age	64.2 ± 2.81	63.3 ± 2.59	64.9 ± 2.89
Weight (kg)	64.8 ± 4.52	6.72 ± 4.58	66.3 ± 6.39
Height (cm)	165 ± 3.95	165 ± 3.58	164 ± 3.48
BMI (kg·m^{-2})	23.9 ± 1.46	24.8 ± 2.34	24.6 ± 2.31
Waist-to-hip ratio	0.90 ± 0.19	0.91 ± 0.12	0.92 ± 0.11
Playing experience (yrs)	28.6 ± 1.33	24.3 ± 3.03	-
Badminton playing frequency (day·week^{-1})	4.72 ± 1.13[a]	2.28 ± 1.02	-
Badminton playing hours (hrs·day^{-1})	2.14 ± 0.56 [a]	1.51 ± 0.50	-
Total badminton playing time (hrs·week^{-1})	9.72 ± 2.16 [a]	3.34 ± 1.53	-
Total physical activity level (METs)	3397 ± 913	3308 ± 1037	3180 ± 1186
Light intensity physical activity	1224 ± 160	1218 ± 513	1360 ± 452
Moderate intensity physical activity	1167 ± 252	1290 ± 409	1181 ± 477
Vigorous intensity physical activity	1114 ± 198	823 ± 248	716 ± 370

[a] Significantly different from LPT (p<0.05)

4.4.2 Fasting Serum [Glucose]

Group mean differences in fasting serum [glucose] were assessed following different groups (HPT, LPT, and CSE group) is shown in Table 4.2. There was no trial order effect across all different conditions (p>0.05). However, a one-way ANOVA test revealed that there were significant differences between HPT and CSE group, F(2,42.8)=3.34, p= 0.045, ηp2= 0.74, for fasting serum [glucose].

Unpaired t-test with Welch's correction reported significant differences in HPT relative to CSE group, 93.0 ± 3.1 vs. 97.2 ± 5.9 mmHg; p = 0.012, d = 2.71; mean differences =-4.23, 95% CI = [-7.44, -1.02]. Meanwhile, there is no significant different in HPT relative to LPT group, 93.0 ± 3.1 vs. 95.6 ± 5.5; p=0.086, d = 1.78; mean differences = -2.65, 95% CI = [-5.70, 0.400] and LPT in relative to CSE group, 93.0 ± 3.1 vs97.2 ± 5.9; p=0.41, d=0.84; mean differences = -1.58, 95% CI = [-5.43, 2.26].

Overall, the fasting serum [glucose] was not significantly changes after administration between HPT in relative to LPT group and LPT in relative to CSE group, respectively (all, p>0.05). Therefore, a null hypothesis in which there is no significant differences in blood glucose concentration following overnight fasting between HPT, LPT and CSE group in elderly recreational badminton players is accepted.

4.4.3 Serum [C-Reactive Protein]

The group mean differences in serum [CRP] were assessed following different groups (HPT, LPT and CSE group). There was no trial order effect across all different conditions (p>0.05). A one-way ANOVA revealed no significant differences for serum [CRP] between HPT, LPT and CSE group. Therefore, a null hypothesis in which no significant differences in serum [CRP] levels between HPT, LPT and CSE group in elderly recreational badminton players is accepted.

4.4.4 Serum [Uric Acid]

The group mean differences in serum [uric acid] were assessed following different groups (HPT, LPT and CSE group). There was no trial order effect across all different conditions (p>0.05). A one-way ANOVA revealed no significant differences for serum [CRP] between HPT, LPT and CSE group. Therefore, a null hypothesis in which no significant differences in serum [CRP] levels between HPT, LPT and CSE group in elderly recreational badminton players is accepted.

4.4.5 Blood [Triglycerides]

The group mean differences in blood [triglycerides] were assessed following different groups (HPT, LPT and CSE group). There was no trial order effect across all different conditions ($p>0.05$). A one-way ANOVA revealed no significant differences for blood [triglycerides] between HPT, LPT and CSE group. Therefore, a null hypothesis in which no significant differences in blood [triglycerides] levels between HPT, LPT and CSE group in elderly recreational badminton players is accepted.

4.4.6 Blood [Total Cholesterol]

The group mean differences in blood [T-Cho] were assessed following different groups (HPT, LPT and CSE group). There was no trial order effect across all different conditions ($p>0.05$). A one-way ANOVA revealed no significant differences for blood [T-Cho] between HPT, LPT and CSE group. Therefore, a null hypothesis in which no significant differences in blood [T-Cho] levels between HPT, LPT and CSE group in elderly recreational badminton players is accepted.

4.4.7 Blood [Low-Density Lipoprotein]

The group mean differences in blood [HDL] were assessed following different groups (HPT, LPT and CSE group). There was no trial order effect across all different conditions ($p>0.05$). A one-way ANOVA revealed no significant differences for blood [HDL] between HPT, LPT and CSE group. Therefore, a null hypothesis in which no significant differences in blood [HDL] levels between HPT, LPT and CSE group in elderly recreational badminton players is accepted.

4.4.8 Blood [High-Density Lipoprotein]

The group mean differences in blood [LDL] were assessed following different groups (HPT, LPT and CSE group). There was no trial order effect across all different conditions ($p>0.05$). A one-way ANOVA revealed no significant differences for blood [LDL] between HPT, LPT and CSE group. Therefore, a null hypothesis in which no significant differences in blood [LDL] levels between HPT, LPT and CSE group in elderly recreational badminton players is accepted.

Table 4.2

Blood Metabolic Biomarkers (Blood Glucose, CRP, Uric Acid, Triglycerides, HDL, LDL and T-Cho)

Parameter	**HPT**	**LPT**	**CSE**	**HPT *vs.* LPT** ***t***	**HPT *vs.* CSE** ***t***	**LPT *vs.* CSE** ***t***
Blood glucose (mg/dL)	93.0 ± 3.10*	95.6 ± 5.49	97.2 ± 5.85	1.78	2.71	0.84
Serum (C-reactive protein, CRP)	0.18 ± 0.22	0.28 ± 0.28	0.34 ± 0.22	1.10	2.10	0.69
Blood uric acid (mg/dL)	6.03 ± 1.58	5.89 ± 1.27	6.80 ± 1.77	0.29	1.39	1.79
Blood triglycerides (mg/dL)	59.2 ± 13.8	63.0 ± 16.1	71.4 ± 18.4	0.76	2.20	1.43
Blood HDL (mg/dL)	67.8 ± 4.94	64.0 ± 7.79	61.9 ± 8.65	1.74	2.50	0.76
Blood LDL (mg/dL)	120 ± 3.49	122 ± 7.17	126 ± 10.2	1.09	2.45	1.42
Blood T-Cho (mg/dL)	203 ± 7.8	201 ± 14	205 ± 15	0.40	0.53	0.75

* = Significantly different from CSE (p<0.05)

4.5 Discussion of Study

The present finding found that participants engaging in higher volumes of badminton play demonstrated significantly lower fasting serum glucose concentrations compared to the closed-skilled exercise control group (93.0 ± 3.1 vs 97.2 ± 5.9 mg/dL, p=0.012), representing a 4.3% reduction. This finding occurred despite all three groups maintaining comparable total physical activity levels, suggesting that the intermittent high-intensity nature of badminton may confer specific glycaemic benefits beyond general physical activity. The present results support previous research demonstrating that vigorous-intensity physical activity produces superior glycaemic outcomes compared to moderate-intensity exercise alone (Galloza et al., 2017).

Previous study shows that glucose level declines with age Consequently, measures focused on enhancing glucose management may also reduce the incidence of hypertension, particularly in older individuals. The present study found that the group with the highest level of vigorous-intensity activities also showed significantly lower fasting serum glucose as compared to closed skilled-exercise group by 4.3% ($p<0.05$). In support of this, Wu and colleagues discovered in their meta-analysis that high-intensity exercise increases glucose consumption and that the improvement in the glycaemic state is followed by an increase in lean body mass (Wu et al., 2024).. Furthermore, chronic engagement in high-intensity intermittent exercise enhances mitochondrial oxidative phosphorylation capacity, which facilitates more efficient glucose utilization, particularly relevant in aging populations experiencing age-related mitochondrial dysfunction (Nordin et al., 2021). The characteristic movement patterns in badminton explosive lunges, rapid directional changes, overhead shots, and sustained positional play recruit large muscle groups across both upper and lower extremities, potentially maximizing the muscle mass engaged in glucose uptake during exercise.

A study in Korea found that combining low and moderate-intensity aerobic exercise, such as walking for 30 minutes or more five times a week, is likely to enhances glycaemic control (HbA1c concentration below 6.5%) (Park et al., 2019). According to Goyal et al. (2020) older adults should do moderate-intensity aerobic activity (50 to 70% of maximum heart rate) at least three times a week and resistance exercise at least twice a week to enhances insulin resistance. Moreover, the outcome from current findings supports previous research into this brain area which links physical activity and glucose. Shur et al. (2021) and colleague found a positive associated between low-intensity exercise and glucose level in elderly women. The relative intensity of physical activity fundamentally influences physiological adaptations to insulin resistance, as it directly relates to the quantity of active muscle mass recruited during exercise (Shur et al., 2021).This interpretation receives support from previous study who demonstrated that combining varied-intensity aerobic exercise patterns produces superior glycaemic control (HbA1c $<6.5\%$) compared to steady-state moderate-intensity activity (Park et al., 2019).

Chronic intervention in high-intensity intermittent exercise also boosts mitochondrial oxidative phosphorylation which aids in active glucose consumption especially in the older population (Nordin et al., 2021). However, contrary to the initial hypothesis, no significant differences emerged in lipid profiles (triglycerides, total cholesterol, HDL, LDL), inflammatory markers (CRP), or uric acid concentrations between groups. These null findings contrast with epidemiological evidence suggesting cardiometabolic benefits of racquet sports. Chao et al., (2021) reported that racquet sport participation associates with the lowest cardiovascular disease risk and all-cause mortality, while Nassef et al., (2019) found that regular badminton playing correlated with higher HDL concentrations in Taiwanese adults. Several factors may explain these discrepancies. These results are due to the lack of lipid metabolic disorders in the present study, which only includes healthy older adults. These results also are because the level of blood glucose of the participants improved as blood glucose influences the lipid profile (Gordon et al., 2014)

4.6 Conclusion

In conclusion, the findings of this study demonstrated that under similar daily physical activity levels, older adults with a greater time of badminton-playing group (HPT) had a more significant influence on glycaemic state than those with a lower time of badminton-playing group (LPT). It is anticipated that the present study would lead to a better understanding of how recreational badminton affects cardiometabolic health, especially in the population of older adults. The public may profit from the knowledge gained through this study. This is because the results of the current study could inform the public about the potential advantages of playing badminton for cardiovascular health, especially in the aging population, and this could raise awareness of the benefits of both physical activity and recreational badminton playing. Future longitudinal intervention research examining populations with metabolic dysfunction, employing comprehensive mechanistic assessments, and investigating optimal participation parameters will provide more definitive evidence regarding badminton's therapeutic potential for cardiometabolic health management. Such research will inform evidence-based physical activity recommendations and public health strategies for promoting healthy aging through accessible, socially engaging recreational activities.

CHAPTER 5
STUDY 3: THE EFFECTS OF LONG-TERM PARTICIPATION IN BADMINTON (OPEN-SKILLS VS CLOSE-SKILLS) ON PHYSICAL FUNCTION IN HEALTHY ELDERLY

5.1 Introduction

Physical inactivity has increasingly been recognized as a significant global public health concern. According to the World Health Organization (WHO, 2020), approximately one in four adults globally does not meet the recommended levels of physical activity, contributing substantially to the global burden of non-communicable diseases. Recent studies indicate considerable regional variations in physical inactivity, with prevalence rates ranging from as low as 5% among older adults in Sweden to as high as 29% in Portugal (Cunningham et al., 2020). Moreover, physical inactivity among elderly populations is notably higher, with previous research reporting that up to 60% of older adults worldwide fail to engage in regular physical activity, leading to increased risks of disability, morbidity, and mortality (Cunningham et al., 2020).

Physical activity has been identified as a lifestyle factor that may minimize the influences of aging on physical function in through maintaining mobility, physical functioning, bone mineral density, muscle strength, and balance (Culpin et al, 2018). Previous study revealed a correlation between physical activity level and falling risk in elderly (Cunningham et al., 2020). Participation in physical activity within an appropriate range has been shown to reduce the risk of hip fractures in the general population (Armstrong et al., 2020). A study conducted by Shur et al., 2 stated that physical activity reduces the age-related decline in functional capacity and maintains muscle strength and mass among adults aged 65-85 years. It has conclusively been shown that maintaining participation in physical activity during old age preserves physical function to sustained longer in daily lifestyle (Pandey et al., 2019). Furthermore, physical activity preserves muscle quality in elderly who physically active (Losa-Reyna et al., 2019; Thomas et al., 2019). This is in line with Thomas et al. (2019) mentioned that physical activity are effective methods to maintain an intact balance control and prevent falls. Flexibility also can be improved through physical activity which helps elderly to minimize risk of back pain (Eckstrom et al., 2020). Culpin et al. (2018) shown that physical activity reduces risk of functional limitation and early disability among older adults. Cohen et al. (2014) demonstrated that muscle weakness and frailty reduced through moderate-intensity physical activity. Longitudinal studies confirmed the effectiveness of physical activity to enhance cardiovascular endurance (Pinckard et al., 2019). The study indicated that high-training volume of aerobic exercise improved cardiovascular endurance. This is supported by Alves et al. (2016) where training volume was found to be positively associated with cardiovascular endurance.

Traditionally, it has been argued that different types of sports influence physical function differently. Based on the study by of sport could be divided into two motor skills, open and closed skills. Open-skilled sports such as basketball, tennis, or fencing require fast reactions to unexpected stimuli in a fast-paced, dynamic setting (Möhring et al., 2022). Conversely, closed-skilled activities like running, swimming, or cycling are performed at a pace that is determined by the individual (Koch & Krenn, 2021). Möhring et al. (2022) indicated that the unpredictable nature of open-skilled sports has been hypothesised to be more physically demanding and involve a greater expenditure of cognitive effort. Culpin et al. (2018) found that older individuals who participated in racquet sports had a better physical function performance compared to elderly who jogged frequently. It has conclusively been demonstrated that older exercisers who had participated in open-skilled sports for at least three months had better muscle strength than the closed-skilled exercise group. These findings corroborated a subsequent study by Grosprêtre & Gabriel, (2021), which found that the open-skilled group was better at enhancing physical performance than the closed-skilled group. Although open-skilled sports have been shown to have positive impacts, some studies have concluded that these activities do not increase improved physical performance any more than closed-skilled sports do.

Despite the well-established benefits of regular exercise participation for health, limited evidence exists regarding whether the type of sport particularly open-skilled versus closed-skilled activities differentially influences health-related fitness components in elderly populations. To address this knowledge gap, the current study hypothesizes that long-term recreational participation in badminton, an open-skilled sport characterized by dynamic and unpredictable movement patterns, leads to superior physical function outcomes (e.g., strength, flexibility, balance, and cardiovascular endurance) compared to participation in closed-skilled sports or sedentary lifestyles among healthy elderly individuals. Specifically, this study aims to determine differences in health-related fitness outcomes between elderly recreational badminton participants, closed-skilled exercise participants, and non-active controls, and evaluate whether cumulative playing time in recreational badminton positively correlates with improvements in these fitness components.

5.2 Methodology of Study

5.2.1 Study Design

A cross-sectional observational research design was used in this study. It focused on badminton players who had been regularly participating in the sport for more than 10 years and compared them with individuals engaged in walking, running, or swimming, which are classified as close-skilled exercises. The 10-year criterion aimed to capture chronic adaptations from long-term participation rather than acute effects Badminton was selected as an example of an "open-skilled" sport, as it requires immediate responses to unpredictable stimuli in a dynamic environment. In contrast, walking, running, and swimming were categorized as "closed-skilled" exercises because they are typically performed in stable, predictable environments at a self-determined pace. The closed-skill group was essential as a comparison to determine if physical function differences were specifically due to badminton's open-skilled nature versus general exercise benefits. This allowed the current study to isolate whether movement unpredictability in open-skills offers unique advantages over closed-skilled activities. Additionally, the study included individuals who had not engaged in regular exercise over the past two years, assigning them to the control (CON) group. The rationale selecting subject who not engaged in regular exercise over the past two years as control (CON) group to establishing a sedentary baseline where detraining effects would be evident. Two years ensures participants are not benefiting from residual training effects Functional physical fitness was assessed through various tests, and the results were compared among recreational badminton participants (RBP), close-skilled participants (CSP), and the CON group. All study procedures were approved by the

Research Ethics Committee (REC/06/2022-PG/MR/127) and completed in accordance with the requirements of the Helsinki Declaration (2013).

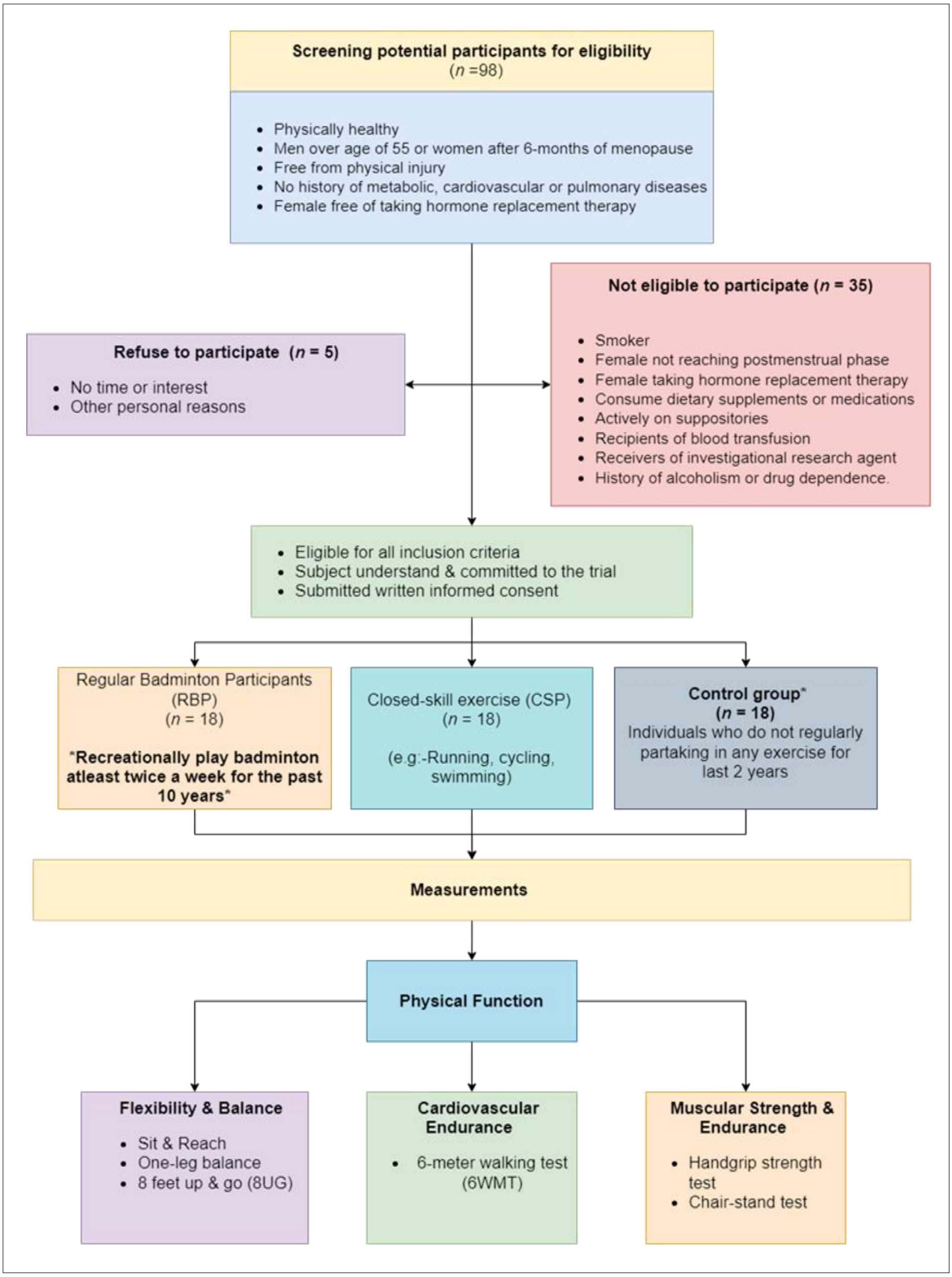

Figure 5.1 Flow Diagram of Participant Screening, Enrolment, and Measurement Performed in Study 3.

5.2.2 Participants Sampling

The required sample size for this study was calculated using statistical formula by Charan & Biswas, (2013) for population proportion by considering 95% confidence interval, 5% level of precision, 1% estimated population of elderly badminton players (estimated from interview and email communication data from badminton clubs across Negeri Sembilan and census data from Department of Statistics Malaysia, DOSM).

$$\text{Sample Size} = \frac{Z_{1-a/2}{}^{2}p(1-p)}{d^{2}} \quad (5.1)$$

Briefly, the value represents a standard normal variate (at 5% type 1 error ($p < 0.05$) with a value of 1.96. The 'p' value defines as expected proportion ('p' value considered significant below 0.05) in population and 'd' defined as the absolute error or precision. Hence, based on a 1% estimated population of elderly badminton players, and a 5% absolute and type 1 error, a total of 16 sample size was estimated in each target condition (RBP, CSP and CON group) as follow:

$$\frac{1.96^{2} \times 0.01\,(1 - 0.01)}{0.05^{2}} = 15.8 \quad (5.2)$$

In order to ascertain that any changes in the measurement conducted in this study are due to participation in badminton (recreationally playing badminton at least twice a week for the last 10 years), closed-skilled exercise group, defined as individuals who performed exercise on the stable and predictable environment (e.g.: running, swimming, cycling) in last 2 years and control group, defined as individual who do not partaking in any exercise were also been introduced. All the subject in the study were different from Study 1 and Study 2.

5.2.3 Study Protocol

The physical function tests were administered in a specific sequence designed to minimize fatigue-induced variability and ensure participant safety. The tests were ordered from least physically demanding to most strenuous to prevent early fatigue from influencing subsequent test outcomes.Specifically, the testing began with anthropometric measurements (weight, height, waist-to-hip ratio), as these are non-fatiguing procedures. Following this, the chair-sit and reach test was performed first due to its low-intensity nature, providing a gentle warm-up to participants while minimizing the risk of muscle strain.Subsequently, the static one-leg balance test was conducted. This test requires focused attention and minimal muscular exertion, hence it followed the flexibility assessment, leveraging the participants neuromuscular state to accurately measure static balance. The dynamic balance and mobility test (8-foot up and go) followed immediately after static balance testing. Since this test introduces moderate physical exertion and coordination challenges, its position here is deliberate, ensuring participants' responses were minimally influenced by muscular fatigue. After assessing mobility, the handgrip strength test was performed to evaluate maximal muscular strength. This test was deliberately placed at this juncture, as it predominantly engages upper-body musculature, allowing lower-body muscle groups some recovery time before moving to the subsequent lower-body strength and endurance assessments.The 30-second chair-stand test, measuring lower body muscular endurance, followed grip strength measurement. Due to the increased muscular effort required, placing this test toward the end allowed adequate spacing from earlier tests, ensuring that upper-body fatigue from grip strength testing did not influence lower-body performance outcomes. Lastly, the 6-minute walk test (6MWT), the most physically demanding component, was strategically positioned at the end. This placement ensured that participants were able to put forth maximal aerobic effort without affecting their performance on previous tests. Additionally, completing all other tests prior to this endurance measure reduced the impact of potential fatigue from the 6MWT on performance metrics in preceding tests.

5.3 Measurement

5.3.1 Anthropometric measurement

Using the validated stadiometer (Seca 220; Seca, Ltd, Hamburg, Germany), the anthropometric measurements of weight (kg) and height (cm) were calculated in accordance with the procedures outlined in Nordin et al. (2021). For the body mass index (BMI) calculation, the measurements of weight (kg) and height (cm) were taken.

When determining the waist-to-hip ratio, the Seca 201 tape (Seca, Ltd., Hamburg, Germany) been used to measure the waist circumference at the centre point between the last palpable rib at the lowest margin and the top of the iliac crest while applying continual pulling strain.

5.3.2 Flexibility and Balance

The chair sits and reach are a test of lower body flexibility and has the advantage of inflicting less stress on the lower back and spine (Culpin et al., 2018). The participant was told to place one leg out to the side in a bent position, completely extend the other leg with the heel resting on the floor in 90° dorsiflexion and sit close to the edge of a chair (44 cm in height). The participants been asked to slowly bend forward while maintaining their spine in the straightest position possible, extend their leg as far as they could, and hold that position for two seconds. A negative score was given for falling short of the toes by the given distance (cm). A measuring ruler recorded the distance.

The one-leg balance is a simple balancing test and measures static balance. Elderly fall risk is frequently predicted using this method (Preeti et al., 2019). The participant was instructed to stand if they could on their favoured limb without assistance. The higher score obtained after two tries was applied to further analysis. As for dynamic balance and mobility, the 8 feet up and go (8UG) test will be utilized. The participants started with their backs pressed against the back rest of an armless chair (44-cm in height). The participants were instructed to stand up and walk around a cone situated 8 feet away, and sit back down on the starting chair, as quickly and safely as possible. The time taken was measured with a stopwatch.

5.3.3 Cardiovascular Endurance

The 6-meter walking test (6MWT) proved to be effective at estimating peak oxygen absorption in older people (Culpin et al., 2018). A trundle wheel was used to measure a 30-m track, with cones marking the turning positions at either end. The players had six minutes to cover as much ground as they could. If any participant needs to take a break during the test, a seat will be available at the end of the track. Each minute interval was announced to the participants, and they received verbal praise. The

6-min were timed using a stopwatch. After completing the 6MWT, the precise distance travel was taken.

5.3.4 Muscular Strength and Endurance

The Jamar Hydraulic Dynamometer was used to measure grip strength (Model 5030J1, Sammons Preston Inc., Bolingbrook, Ill, USA) as it provides the most dependable strength measurement. The Southampton procedure been used, in which the participants were instructed to sit down with their backs pressed against the chair back rest while the investigator measured the weight of the hand dynamometer. The participants were then told to squeeze as firmly as they could and to release their grip as soon as the needle, which represented the force in kg, stopped rising. Every participant received words of encouragement. The second grip position, which has been regarded to be the most dependable and consistent position (Jumat et al., 2021) remained constant among the five possible handle positions throughout the investigation.

The chair-stand test was selected to measure muscular endurance safely. In this test, participants in were asked to begin by settling on a straight-back, armless chair in the middle (44-cm in height). The participant then was instructed to stand up straight and then return to their seated posture while resting their arms across the participant's opposite shoulder. The 30-second intervals were timed using a stopwatch, and the number of accumulated errors were noted.

5.3.5 Physical Activity Level, Badminton-Playing History, and Physical Characteristics

Physical activity levels were measured with the Global Physical Activity Questionnaire (GPAQ), where the duration of designated activities and the related energy use per week were expressed in metabolic equivalents (MET-min/week^{-1}) (Goenarjo et al., 2020). Weekly badminton participation was determined using documented badminton sessions and an adapted form of the Physical Activity Scale for the Elderly (PASE) questionnaire.

5.3.6 Statistical Analysis

An independent samples t-test was used to analyze differences in badminton playing history characteristics. Brown-Forsythe and Welch ANOVA were conducted to assess differences between groups in physical characteristics (height, weight, BMI, and age), total physical activity levels, and physical function indices (flexibility, balance, muscular strength, and cardiovascular endurance). Post hoc analyses using Dunnett's T3 multiple comparison test were performed to identify the sources of any significant effects. All statistical analyses were conducted using GraphPad Prism software (version 9.0, GraphPad Software Inc., La Jolla, California, USA), with statistical significance set at $p<0.05$.

5.4 Result

5.4.1 Anthropometric Measurement, Badminton-Playing History and Physical Characteristics

Table 5.1
Physical Measurement, Badminton-Playing History, and Physical Characteristics in Recreational Badminton Participants, Close-skilled Participants and Control Groups.

Parameter	RBP	CSP	CON
Age	64.2 ± 2.81	63.3 ± 2.59	64.9 ± 2.89
Weight (kg)	64.8 ± 4.52	6.72 ± 4.58	66.3 ± 6.39
Height (cm)	165 ± 3.95	165 ± 3.58	164 ± 3.48
BMI ($kg \cdot m^{-2}$)	23.9 ± 1.46	24.8 ± 2.34	24.6 ± 2.31
Waist-to-hip ratio	0.90 ± 0.19	0.91 ± 0.12	0.92 ± 0.11
Playing experience (yrs)	28.6 ± 1.33	24.3 ± 3.03	-
Badminton playing frequency ($day \cdot week^{-1}$)	4.72 ± 1.13[a]	2.28 ± 1.02	-
Badminton playing hours ($hrs \cdot day^{-1}$)	2.14 ± 0.56 [a]	1.51 ± 0.50	-
Total badminton playing time ($hrs \cdot week^{-1}$)	9.72 ± 2.16 [a]	3.34 ± 1.53	-
Total physical activity level (METs)	3397 ± 913	3308 ± 1037	3180 ± 1186
Light intensity physical activity	1224 ± 160	1218 ± 513	1360 ± 452
Moderate intensity physical activity	1167 ± 252	1290 ± 409	1181 ± 477

Vigorous intensity physical activity	1114 ± 198	823 ± 248	716 ± 370

[a] Significantly different from CSP (p<0.05)

5.4.2 Physical Function measurement

Chair sit-reach analysis in the RBP, CSP, and CON is illustrated in Table 5.2. There was a significant main effect on the difference in flexibility (F=7.25, p<0.05; Table 5.2 in chair sit-reach. Post hoc tests revealed that the RBP had significantly higher (12.3 ± 1.27 cm) compared to CSE (9.06 ± 3.00 cm) (p<0.05), but no difference compared to CON group (8.50 ± 4.52 cm) (p>0.05). Balance between the RBP, CSP, and CON groups shown in Table 5.2. There was significant main effect one-leg balance (F=11.6, p<0.05; Table 5.2 in one-leg balance. Post hoc tests revealed that RBP had significantly higher (6.28 ± 0.96 s) compared to CSP (4.56 ± 0.78 s) (p<0.05) and CON group (5.00 ± 1.28s) (P<0.05). Equivalently, Table 5.2 shows the 8UG significantly higher in RBP (6.28 ± 0.96s) compared to CSP (4.56 ± 0.78s) (p<0.05) and CON group (5.00 ± 1.28s) (p<0.05). Grip strength analysis in the RBP, CSP, and CON shown in Table 5.2. There was a significant main effect on the difference in muscular strength (F = 13.0, P<0.05; Table 5.2 in grip strength. Post hoc tests revealed that the RBP had significantly higher (44.1 ± 4.70 kg) compared to CSP (37.4 ± 6.00 kg) (p<0.05) and CON (36.7 ± 3.21 kg). 30s-chair stand (TMT) between the RBP, CSP, and CON groups is illustrated in Table 5.2. There was no significant main effect on time to 30s-chair stand between RBP (13.6 ± 1.9) (p>0.05), CSP (12.8 ± 4.08) (p>0.05) and CON (13.0 ± 2.43) (p>0.05). 6MWT analysis in the RBP, CSP, and CON is illustrated in Table 5.2. There was a significant main effect on the difference in cardiovascular endurance (F=24.0, p<0.05; Table 5.2 in 6MWT. Post hoc tests revealed that the RBP had significantly higher (586.1 ± 64.1) compared to CSP (494.1 ± 40.3) (p<0.05) and CON group (469.1 ± 53.0) (p<0.05).

Table 5.2
Physical Function Domain

	RBP	CSP	CON	RBP vs CSP *p* value	RBP vs CON *p* value	CSP vs CON *p* value
Physical Function						
One-leg balance(s)	58.8±10.8	47.8 ±7.03	46.6 ±19.9	0.024*	0.012*	0.964
8UG (s)	6.23±0.93	4.56±0.78	5.0 ±1.23	0.000*	0.001*	0.404
Sit and reach (cm)	12.2±1.27	9.06 ±3.00	8.5 ± 4.51	0.012*	0.026*	0.867
Handgrip test (kg)	44.0±4.70	37.4±6.0	36.7±3.21	0.000*	0.000*	0.892
30s-Chair-stand test (s)	13.6±1.88	12.8 ±4.08	13.0 ±2.43	0.710	0.810	0.984
6WMT (m)	586.1±64.1	494.1 ±40.3	469.1 ±52.97	0.000*	0.000*	0.346

*Significantly different $p < 0.05$

5.5 Discussion

In agreement with the observed results, significant differences were found in flexibility, static balance, dynamic balance, handgrip strength, and cardiovascular endurance between recreational badminton players (RBP) and the other groups (CSP and CON). The current study expected badminton players to outperform other groups across all physical function tests based on literature suggesting open-skilled sports provide superior benefits. Specifically, badminton participation was significantly associated with improved flexibility as indicated by the chair sit-and-reach test, better static balance measured through the one-leg balance test, superior dynamic balance performance as measured by the 8-ft up and go (8UG) test, higher handgrip strength, and increased cardiovascular endurance based on the 6-minute walk test (6MWT). These findings align with previous research indicating that open-skilled sports may enhance multiple components of physical fitness more effectively compared to closed-skilled activities or sedentary behaviors (Culpin et al., 2018). However, contrary to expectations, no significant differences were observed in the 30-second chair-stand test, suggesting that lower-body muscular endurance was comparable across all groups. This might reflect the specificity of badminton, which primarily involves agility and upper-body muscular strength rather than sustained lower-body muscular endurance. The current study thus highlights badminton's effectiveness as an open-skilled sport in promoting various aspects of health-related fitness among elderly populations, although its impact may vary depending on the specific physical function assessed

It is somewhat surprising that no significant differences were found for chair stands between all the groups in this condition. These results corroborate the findings of a great deal of the previous work, which stated that lower-body strength and endurance had significantly decreased by 12% in male elderly and 14% in elderly women (Milanović et al., 2013). Research has shown that there is no significant difference in the chair stand test between active elderly individuals and those with long sedentary times (Jeon & Kim, 2020). However, this result has not previously been described. Previous studies indicated a significant improvement in upper limb strength, static balance, agility and dynamic balance after a 12-week exercise program, which included the chair-stand test as one of the outcome measures (J. Liu et al., 2019). Furthermore, the chair-stand test has been correlated with walking speed, standing balance, and balance, indicating that the performance outcome is enhanced in active elderly who exercise regularly (Ward et al., 2015).

Contrary to expectations, this study did not find a significant difference in sit-and-reach between all the groups. This result is in line with those of previous studies that found chair sit-and-reach test had no significant difference between different ageing groups ($p > 0.05$) (Milanović et al., 2013). However, this finding is contrary to previous studies, which have suggested that the elderly in open-skills exercise have better flexibility (Zhou et al., 2019). Previous studies demonstrated that participation in an 8-month exercise led to a 17.4% improvement in the sit and reach test among the elderly (Carvalho et al., 2009). This suggests that structured training can significantly enhance flexibility in this population. Furthermore, previous studies highlighted the positive effects of dance on the physical fitness and well-being of the elderly (Douka et al., 2019). As traditional dance involves open skills that require adaptability and coordination, it may have a positive impact on flexibility, including the sit and reach test (Douka et al., 2019). In contrast, close-skills activities, which involve predictable and well-defined movements, may not offer the same level of improvement in flexibility. It can be inferred that open-skills activities such as traditional dance may lead to greater improvements in the sit and reach test compared to close-skills activities (Gebretensay et al., 2019).

Surprisingly, no differences were found in static and dynamic balance between all the three groups. These results are in line with those of the previous study. Previous findings have shown that the balance test performance results declined with advancing age in both groups (Baker et al., 2003a). It is encouraging to compare this figure with a previous study that showed that standing time on one leg decreases linearly (Oshita & Yano, 2010). The ability to stand on one leg has been reported to been decrease after the age 60 (Morioka et al., 2012). Moreover, the current study results are in agreement with the previous research which showed measured posture stability using 8UG in subjects aged 20 or older and found that stability decreased after the age of 60 years (Morioka et al., 2012). An alternative explanation for this result is that it is due to balance decline with chronological age, along with muscular endurance and strength (Era et al., 2006). On the other hand, the one-legged balance with eyes open has been reported to not improve in pre-frail elderly females following a 1-year regular exercise program for prevention once a week (Sugimoto et al., 2014). This suggests that the frequency and duration of the exercise program may influence its effectiveness in improving one-leg balance in the elderly (Culpin et al., 2018). This finding is contrary to previous studies, which have suggested that whole-body vibration exercise combined with balance and muscle strengthening exercises improved step length, knee extensor muscle strength, and maximum standing time on one leg in elderly women (Kawanabe et al., 2007). Furthermore, standing on one leg for 4 minutes a day positively contributed to the balance skills of elderly adults aged between 70 and 80 years (Aksay et al., 2021). These findings highlight the potential benefits of incorporating one-leg balance exercises into exercise programs for the elderly.

The current study highlights the beneficial effects of recreational badminton participation on elderly physical function. However, deeper comparisons with prior relevant studies examining elderly-focused physical activity interventions are essential to contextualize these findings more effectively. For instance, when considering flexibility improvements, our results align with Carvalho et al. (2009), who observed enhanced flexibility following structured exercise programs. However, unlike Zhou et al. (2019), who reported significantly better flexibility in elderly participating in open-skilled exercises, our findings indicate no substantial difference between open-skilled and closed-skilled exercises in flexibility. This contrast might suggest varying impacts of different open-skilled sports or differences in the intervention duration and intensity.

Similarly, for balance and mobility, although the present results showed significant improvements in the badminton group, it is beneficial to discuss these outcomes considering interventions like traditional dance (Douka et al., 2019) and boxing exercises (Janyacharoen et al., 2018), which also reported improved balance and mobility in elderly populations. Exploring potential mechanisms or factors contributing to comparable or differential outcomes across these open-skilled interventions would enrich the understanding and applicability of our findings. Lastly, our results regarding cardiovascular endurance, assessed via the 6MWT, concur with Chomiuk et al. (2013), demonstrating improved cardiovascular performance in physically active elderly groups. However, elaborating on the relative efficacy compared to other aerobic-intensive exercises, such as traditional dance or aerobic walking, could offer valuable insights into specific advantages associated with badminton.

5.6 Conclusion

In summary, this cross-sectional investigation examined physical function differences among elderly individuals engaged in long-term recreational badminton, closed-skilled exercise, or sedentary lifestyles. The findings reveal a complex pattern of outcomes that partially support the hypothesis that open-skilled sports provide superior functional benefits. Specifically, recreational badminton participants demonstrated significantly superior performance in flexibility, static and dynamic balance, upper-body strength, and cardiovascular endurance compared to both closed-skilled exercisers and sedentary controls. These results suggest that badminton, a dynamic, open-skilled activity, might be especially beneficial in elderly populations. These findings promoting open-skilled recreational sports as part of comprehensive strategies for healthy aging and functional preservation. By combining physical challenge, cognitive engagement, and social interaction within an inherently enjoyable activity format, badminton represents a promising avenue for enhancing quality of life and compressing morbidity in aging populations. Future research should build upon these foundations to develop evidence-based guidelines for integrating badminton and similar activities into public health initiatives targeting active aging and functional longevity.

CHAPTER 6
STUDY 4: THE INFLUENCES OF LONG-TERM BADMINTON (OPEN-SKILLS VS CLOSE-SKILLS) PARTICIPATION ON COGNITIVE FUNCTION IN ELDERLY

6.1 Introduction

Global increases in body mass index, elevated blood pressure, and cardiovascular disease have been partially attributed to reduced physical activity, which has resulted from changes in labor organization, transportation, and increased sedentary behaviour (Chao et al., 2021). The impact of these changes on health is well documented. The World Health Organization (WHO) identifies physical inactivity as the fourth leading cause of global mortality, estimating that it contributes to 3.2 million deaths annually (McAloon et al., 2016). Older adults experience high rates of functional decline, hospitalization, cognition, and subsequent disability (Pedone et al., 2005). Culpin et al. (2018) stated that physical inactivity can lead to dementia especially among elderly who physical inactive. Dementia defined as clinical syndrome elicited by neurodegeneration of the brain, commonly caused by underlying pathologies such as Alzheimer's disease, vascular dementia, front temporal dementia and Lewy body (Mehta & Schneider, 2021). Cognitive function is defined as the psychological process which underlie how human beings understand, remember, communicate, think, making decision and critical task such as problem solving (Kato et al., 2018).

Physical activity appears to reduce the rate of cognitive decline in aging (McMorris et al., 2011). The benefits derived from exercise intervention programs have differed in their effects on cognition (Srinivas et al., 2021). It has been demonstrated that older adults who participate in moderate-intensity exercise showed significantly greater performance in an executive function task (Chang et al., 2011). It has conclusively been shown that elderly performed cardiovascular exercise cardiovascular has been predictive of greater global cognitive function after a six year follow up (Silveira-Rodrigues et al., 2021). A systematic review by Whitty et al. (2020) found changes in the cognitive functions of memory and processing speed in elderly participants following 8 weeks of resistance training, and 1 year after cessation of the intervention. These results corroborate the findings of a great deal of the previous work by Culpin et al. (2018) who showed significant benefits to memory following 24-weeks of resistance training.

It can be assumed that some sports have a higher positive impact on cognition than others based on the literature review by Bidzan-Bluma & Lipowska, (2018). According to Koch & Krenn, (2021), sports could be characterized as either demanding mostly open motor skills or closed motor skills. Open-skilled sports like basketball, tennis, or fencing require quick reactions to unexpected stimuli in a fast- paced, dynamic setting (Möhring et al., 2022). Conversely, closed-skilled activities like running, swimming, or cycling are performed at a pace that is determined by the individual (Pancar et al., 2020). The unpredictable nature of open-skilled sports has been hypothesised to be more cognitively demanding and involve a greater expenditure of cognitive effort (Möhring et al., 2022). Culpin et al. (2018) found that older individuals who participated in racquet sports had 6% faster choice reaction times and 3% faster simple reaction times than older adults who jogged frequently. Loprinzi & Kane, (2015) demonstrated that older exercisers who had participated in open-skilled sports for at least three months had 7% more task-switching capacity than the closed-skilled group. These findings corroborated a subsequent study by Culpin et al. (2018), which found that the open-skilled group was better at transitioning between tasks than the closed-skilled group.

Although open-skilled sports have been shown to have positive impacts, some studies have concluded that these activities do not increase cognitive function any more than closed-skilled sports do.

6.2 Methodology

6.2.1 Study Design

To investigate the effects of long-term badminton participation on cognitive function, a cross-sectional observational research design was chosen, as conducting a longitudinal study presented significant challenges. This study examined individuals who had been regularly playing badminton for more than 10 years and compared them with those engaged in walking, running, or swimming, which are classified as closed-skilled exercises. Badminton was selected as an example of an open-skilled sport, as it requires rapid responses to unpredictable stimuli in a dynamic environment. In contrast, walking, running, and swimming were categorized as closed-skilled exercises, as they are performed in stable, predictable environments at a self-determined pace. Additionally, individuals who had not engaged in regular exercise over the past two years were assigned to the control (CON) group. Functional physical fitness was assessed using various tests, and the results were compared among recreational badminton participants (RBP), closed-skilled participants (CSP), and the CON group. All study procedures were approved by the Research Ethics Committee (REC/06/2022-PG/MR/127) and completed in accordance with the requirements of the Helsinki Declaration (2013).

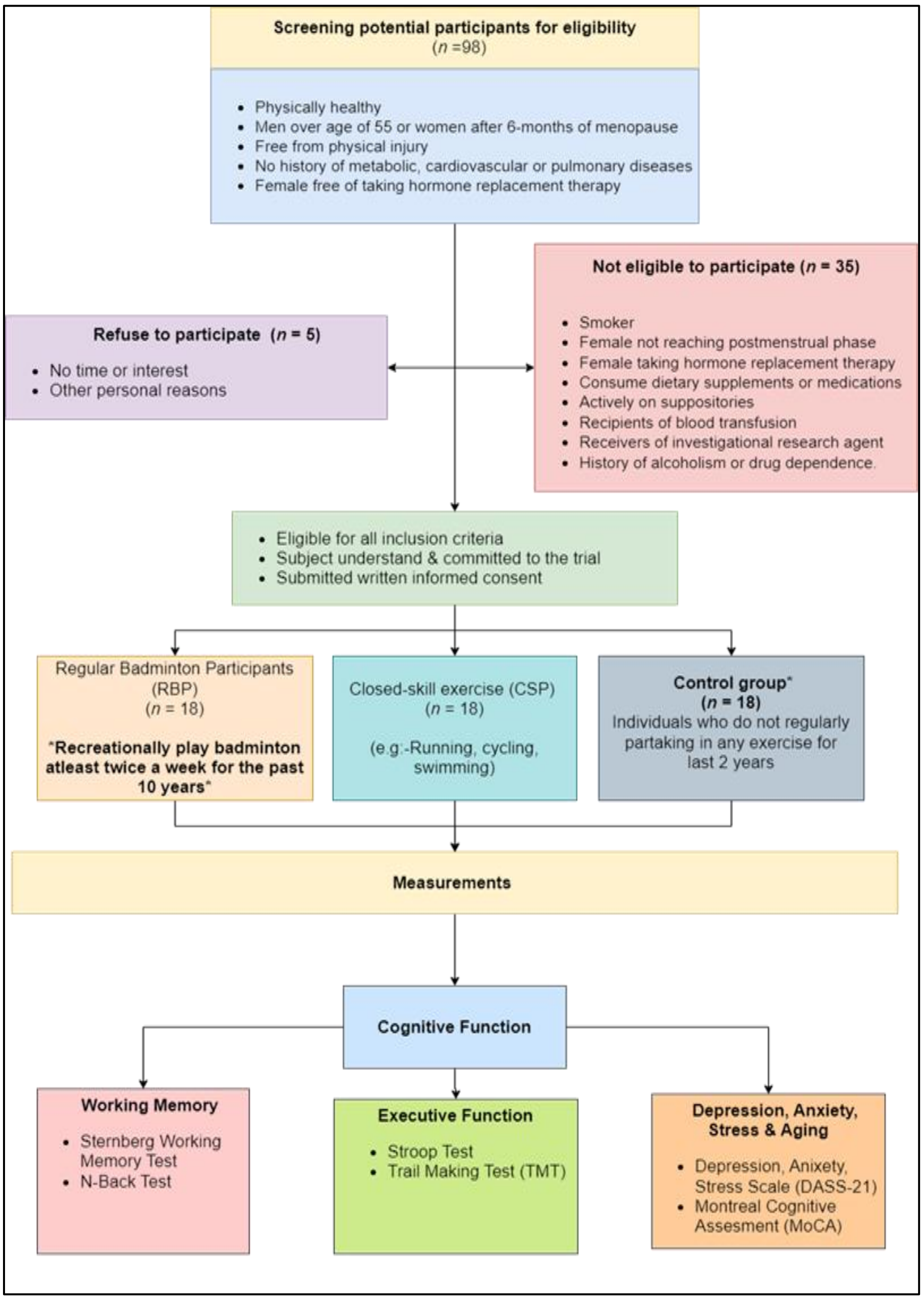

Figure 6.1 Flow Diagram of Participant Screening, Enrolment, and Measurement Performed in Study 4.

6.2.2 Participants Sampling and Technique

To ensure that observed differences in cognitive outcomes are attributable solely to the mode of physical activity, distinct and transparent recruitment procedures were implemented for the closed-skilled exercise (CSP) and control (CON) groups. Potential CSP participants were recruited primarily from local sports clubs, community centers, and recreational programs that offer closed-skilled activities such as running, swimming, and cycling. Recruitment methods included flyers, online advertisements, information sessions, and purposive sampling techniques targeting individuals who engaged in these activities at least twice weekly over the past two years, with eligibility criteria specifying an age of 55 years or older, regular participation in closed-skilled exercise, and no concurrent involvement in open-skilled sports. In parallel, control participants were sourced from the general community through public advertisements, community health centers, local newspapers, informational booths at community events, and social media outreach, with inclusion criteria requiring an age of 55 years or older, minimal engagement in structured exercise (fewer than one session per week) over the past two years, and no participation in organized sports or fitness programs. All potential participants underwent a standardized screening interview to verify eligibility, provided informed consent prior to enrollment, and were matched on key demographic factors such as age, gender, and educational background to minimize confounding variables, thereby enhancing the methodological rigor of the study

6.2.3 Study Protocol

Upon arrival, participants are greeted at the reception where their identity and appointment time are confirmed, and they receive a welcome packet that includes an overview of the study, informed consent forms, and a detailed schedule. In a private setting, a trained medical assistant reviews the consent form, addresses any questions, and secures the participant's signature, followed by a brief health screening conducted by a medical technician to ensure eligibility and safety. Participants then attend an orientation session in a briefing room where the principal investigator explains the study objectives, significance, and testing procedures in a clear, step-by-step manner, including demonstrations of each cognitive task (such as the N-back test, Sternberg working memory task, Trail Making Test, and Stroop test) along with practice trials, and an opportunity for questions and clarifications. Following the orientation, participants are escorted to the measurement station for anthropometric assessments, where height, weight, and waist-to-hip ratios are measured using standardized instruments, and the data are recorded immediately for accuracy. Subsequently, participants are divided into small groups to facilitate the administration of cognitive tests under standardized conditions, with examiners closely monitoring performance and providing additional guidance as necessary. After completing the cognitive assessments, participants move to a quiet area to fill out structured questionnaires, such as the DASS-21 and MoCA, with available assistance to clarify any questions regarding the items. The protocol concludes with a debriefing session where the procedures of the day are summarized, the use of their data is explained, and participants are invited to offer feedback; they also receive a thank-you note and any follow-up instructions, ensuring a comprehensive and well-organized experience from start to finish.

6.3 Measurements

6.3.1 Anthropometric Measurements

Using the validated stadiometer (Seca 220; Seca, Ltd, Hamburg, Germany), the anthropometric measurements of weight (kg) and height (cm) been calculated. For the body mass index (BMI) calculation, the measurements of weight (kg) and height (cm) will be taken. When determining the waist-to-hip ratio, the Seca 201 tape (Seca, Ltd., Hamburg, Germany) were used to measure the waist circumference at the centre point between the last palpable rib at the lowest margin and the top of the iliac crest while applying continual pulling strain.

6.3.2 Working Memory

Working memory was measured using two instruments, N-back task and Sternberg working memory task. The N-back task is a computer software task which needs the subject to refresh the mental set persistently while reacting to past boosts. According to Kato et al. (2018), the N-back is a useful measurement for the working memory due to the high reliability compared to the traditional method. Each test comprised 14 preliminaries and had an improvement length of 0.4s, a between boost interim of 1.4s, and 0-back, 1-back, and 2-back conditions. Subjects are required to react to the boosts utilizing the numerical keypad. The subject performance was evaluated as % right (0-back = the number right/14×100;1-back = the number right/13×100; 2-back assignment = the number right/12×100) and the mean response time were assessed too. To do this test, the subject will observe a progression of number improvements and were approached to demonstrate when the introduced number was equivalent to the recently introduced number.

The Sternberg Working Memory Task was administered using a psychological measurement tool (Inquisit® version 6.0, Millisecond Software, Seattle, USA), as described by Jumat et al., 2021. Each trial consisted of a sequence of two to five white digits, each displayed for 1200 milliseconds. Participants received visual feedback on the accuracy of their responses. All responses were recorded on the computer, then extracted and tabulated for further analysis.

6.3.3 Executive Function

Executive functions were measured using the instruments Trail Making Test (TMT) and Stroop test. The Trail Making Test (TMT) were used to measure the attention variables. (Inquisit® version 6.0, Millisecond Software, Seattle, USA). The TMT consists of two parts: the TMT-A (rote memory) and TMT-B (executive functioning). The TMT-A uses all numbers, whereas the TMT-B alternates numbers and letters. The TMT is scored by how long it takes to complete the test. The time includes correction of errors prompted by the examiner. pasting something here and then press the Paraphrase button.

The Stroop test been conducted using (Inquisit® version 6.0, Millisecond Software, Seattle, USA). Briefly, participants were instructed to react to a sequence of text strings using a custom keyboard as rapidly and precisely as possible (Goenarjo et al., 2020). The reaction time and accurate response were record. The duration of each Stroop test is 90 seconds. The reliability (% CV) of Stroop test were determined on two different days, in 5 participants. The coefficient of variation was found to be 2.1% (Nordin et al., 2021).

6.3.4 Depression and Aging

The Depression, Anxiety, and Stress Scale-21 (DASS-21) was used to assess negative emotional states. Each participant responded to 21 statements by indicating the extent to which each applied to them, using a scale of 0 to 3. Individual scores for depression, anxiety, and stress were then calculated (Natu et al., 2018). Aging was measured using the Montreal Cognitive Assessment (MoCA) (Culpin et al., 2018). The

MoCA, which takes approximately 10 minutes to complete, evaluates multiple cognitive domains, including memory, visuospatial ability, executive function, attention, and language. Scores for correct responses were totaled, with an additional point awarded to individuals with ≤12 years of education. A score of 26 out of 30 is the recommended cut-off for mild cognitive impairment.

6.3.5 Badminton-Playing History, Physical Activity Analysis

Total time spent and energy expenditure for specific activities in a week is measured and converted to metabolic equivalents (MET-min·week-1) and physical activity levels will be determined using the GPAQ (Goenarjo et al., 2020). The badminton-playing time been evaluated using the weekly badminton-playing records and a modified Physical Activity Scale for Elderly (PASE) questionnaire

6.4 Result

6.4.1 Anthropometric and Physical Characteristics

Table 6.1

Physical Measurement, Badminton-Playing History, and Physical Characteristics in Recreational Badminton Participants, Close-skilled Participants and Control Groups.

Parameter	RBP	CSP	CON
Age	64.2 ± 2.81	63.3 ± 2.59	64.9 ± 2.89
Weight (kg)	64.8 ± 4.52	6.72 ± 4.58	66.3 ± 6.39
Height (cm)	165 ± 3.95	165 ± 3.58	164 ± 3.48
BMI ($kg{\cdot}m^{-2}$)	23.9 ± 1.46	24.8 ± 2.34	24.6 ± 2.31
Waist-to-hip ratio	0.90 ± 0.19	0.91 ± 0.12	0.92 ± 0.11
Playing experience (yrs)	28.6 ± 1.33	24.3 ± 3.03	-
Badminton playing frequency ($day{\cdot}week^{-1}$)	4.72 ± 1.13[a]	2.28 ± 1.02	-
Badminton playing hours ($hrs{\cdot}day^{-1}$)	2.14 ± 0.56 [a]	1.51 ± 0.50	-
Total badminton playing time ($hrs{\cdot}week^{-1}$)	9.72 ± 2.16 [a]	3.34 ± 1.53	-
Total physical activity level (METs)	3397 ± 913	3308 ± 1037	3180 ± 1186
Light intensity physical activity	1224 ± 160	1218 ± 513	1360 ± 452
Moderate intensity physical activity	1167 ± 252	1290 ± 409	1181 ± 477
Vigorous intensity physical activity	1114 ± 198	823 ± 248	716 ± 370

[a] Significantly different from CSP (p<0.05)

6.4.2 Cognitive Function Measurement

The SWMT analysis in the RBP, CSP, and CON is shown in Table 6.2. There was a significant main effect on the difference in reaction times (F=3.66, p<0.05) and % accuracy (F = 7.63, p<0.05) in SWMT. Post hoc tests revealed that the RBP had significantly shorter response times (898.9 ± 309.1 ms^{-1}) compared to CON (1129 ± 232.6 ms^{-1}) (p<0.05), but no difference compared to CSP group (934.2 ± 3.91 ms-1) (p>0.05). Likewise, mean % accuracy was higher in RBP (97.6 ± 3.90 ms-1) compared to CON (95.28 ± 3.92 ms-1) (p<0.05), with no significant difference compared to CSP group (91.2 ± 6.59 ms^{-1}) (p>0.05). Additionally, CSP group had significantly higher %

accuracy compared CON (p<0.05). Conversely, the one-back task analysis revealed no significant differences in reaction time between the three groups (p>0.05). TMT between the RBP, CSP, and CON groups is demonstrated in Table 6.2. There was no significant main effect on the time to complete the task (s) for both TMT-A (F=0.38, p>0.05) and TMT-B (F=1.70, p>0.05). Correspondingly, the Stroop Task (colour naming) showed the results indicated that the distinction in reaction times between the RBP (21.7 ± 5.0s), CSE (21.9 ± 5.6s), and CON (23.4 ± 9.8s) was not statistically significant. MoCA analysis in the RBP, CSP, and CON is illustrated in Table 6.2. There was a significant main effect on the difference in aging (F=3.80, p<0.05; Table 6.2 in MoCA. Post hoc tests revealed that the RBP had significantly higher (27.4 ± 2.55) compared to CON (24.4 ± 4.60) (p<0.05), but no difference compared to CSP group (26.8 ± 2.76) (p>0.05). DASS-21 analysis in the RBP, CSE, and CON is shown in Table 6.2. There was no significant main effect on the difference in depression, anxiety, and stress between all groups (p>0.05); Table 6.2 in DASS-21.

Table 6.2
Cognitive Function Domain

	RBP	**CSP**	**CON**	**RBP vs CSP *p* value**	**RBP vs CON *p* value**	**CSP vs CON *p* value**
Working memory						
Sternberg (Reaction time, s)	898.9±309.1	934.2±277.2	1129.2± 232.6	0.922	0.040*	0.094
Sternberg (Accuracy, %)	97.61±3.89	95.28±3.92	91.22±6.58	0.343	0.002*	0.046*
N-back (ms)	864.2±279.6	858.3±280.3	730.4±101.2	0.700	0.215	0.244
Executive Function						
TMT A (ms)	24.0±8.88	24.3±13.1	26.94±11.2	0.995	0.710	0.764
TMT B (ms)	70.8±48.0	49.89±27.1	51.22±36.1	0.236	0.280	0.994
Stroop task (ms)	21.8±5.01	21.9±5.67	23.4±9.77	0.997	0.7768	0.812
Aging						
*MoCA sco*re	27.4±2.55	26.8±2.76	24.4±4.61	0.830	0.030*	0.113
DASS-21						
Depression	1.56±2.23	3.39±3.27	3.50±3.22	0.159	0.128	0.993
Anxiety	3.83±1.47	3.89±2.37	4.78±3.13	0.997	0.477	0.518
Stress	5.11±3.53	7.06±4.14	23.4±9.77	0.641	0.000*	0.000*

**Significantly Different* $p < 0.05$

6.5 Discussion

The current findings found that under the condition of equivalent daily physical activity level, were found in the recreational badminton participants (RBP) when compared to those in close-skills participants (CSP). In this cross-sectional observational analysis, our current results imply that the elderly lifespan of individuals who spend more time involved in badminton playing may exhibit better performance in cognitive function. This result may be due to the open-skills nature of badminton that requires constant rapid decisions in unpredictable situations, which may be more cognitively demanding than closed-skill exercises. The dynamic environment forces players to continuously process changing stimuli, react quickly, and adapt strategies.

The outcome showed that participating in badminton groups was positively associated with cognitive function in healthy elderly. The badminton groups showed significantly faster reaction time in SWMT compared to the closed-skills group. These results reflect a previous study that found that elderly individuals who regularly participated in physical exercise, particularly open-skill exercises. (Zhu et al., 2020). A possible explanation for this might be that open-skill exercises may affect reaction time differently in the elderly compared to close-skill exercises (W. Guo et al., 2016). Additionally, this study supports evidence from clinical observations that demonstrated exercise preserved voluntary step reaction times in older adults, indicating a potential positive effect on reaction time (Melzer et al., 2009). It is encouraging to compare this figure with the clinical observation that mentioned resistance exercise has been found to be effective in preventing age-related cognitive decline, particularly in inhibitory control and working memory among elderly individuals (Ikudome et al., 2017).

As for the accuracy response, the outcome of the current study demonstrated a faster accuracy response. These results agree with the findings of other studies, in which reported that open-skill exercise athletes achieved higher visual-spatial working memory scores than closed-skill exercise athletes and sedentary individuals (Gökçe et al., 2021). However, the findings of the current study do not support the previous research. Older adults exhibited slower and less accurate performance on the working memory task compared to younger adults, indicating age-related differences in working memory accuracy (Verhaeghen et al., 2019). These relationships may partly be explained by due to stress may impact older adults' ability to inhibit task-irrelevant brain regions, potentially affecting working memory accuracy (Marshall et al., 2018). Furthermore, the current study also demonstrated that the RBP group have a better N-back performance compare than others group. These result support the previous findings that demonstrated closed-skill exercise interventions could have more neuropsychological benefits for the elderly in terms of increasing attentional resources during high cognitive load tasks, such as the N-back task (Tsai & Wang, 2015). There are several possible explanations for this result. Previous study observed detailed differences in behavioural and electrophysiological performances between elderly groups engaged in open- or closed-skill exercise modes and indicating distinct effects on cognitive functions (Tsai et al., 2017). In accordance with the present results, previous studies have demonstrated that elderly adults with higher global cognitive function at baseline showed improved N-back task performance, suggesting a positive impact of cognitive function on N-back performance (Pergher et al., 2018). These findings indicate that the type of physical exercise and cognitive function can influence N-back performance in the elderly.

Another finding that stands out from the results reported earlier is the result or the executive function measurement. For the Stroop task, the RBP group demonstrated a better Stroop task performance compare the two group. This also accords with previous study, which showed that elderly who participants in racket sport with at least 20 years of experience, had a 3.1% faster simple reaction time and 6.1% faster choice reaction time, when compared to a running group. (Eggenberger et al., 2016). The current study also is consistent with those of other studies which found that only open-skilled exercisers had faster reaction times when compared to sedentary elderly (Guo et al., 2016). However, contrary to the result of Stroop task, this study did not find a significant difference between TMT A and TMT B between all the group. This inconsistency may be due to the reason motor speed processing was affected by the age factor (Amjad et al., 2019).

Surprisingly, MoCA score was found significantly higher in RBP group compared to CSP and CON group. This finding is consistent with that of previous study who showed that aerobic exercise significantly improved MoCA scores in older adults with mild cognitive impairment (Kobayashi-Cuya et al., 2018). Similarly, this finding broadly supports the clinical observation who observed an increase in MoCA scores in healthy elderly subjects following resistance training. It is encouraging to compare this figure with previous findings who reported significant improvements in MoCA scores in mild cognitive impairment patients undergoing aerobic exercise therapy (Gu et al., 2019). It seems possible that these results are due to the type of exercise also appears to influence its impact on cognitive function. Previous literature demonstrated that multicomponent aerobic exercise, mind–body exercise, and conventional aerobic exercise all showed significant beneficial effects on MoCA scores in elderly individuals with mild cognitive impairment (Hu et al., 2020). These result mirror those of the previous studies that have examined Tai Chi and conventional exercise were both found to improve global cognitive function as measured by MoCA in older adults (Marshall et al., 2018).

As for the DASS-21 score, the RBP group demonstrated a better score for depression domain compared to CSP and CON group. This finding broadly supports the work of other studies in this area linking exercise with depression. For instance, a systematic review of meta-analyses found that exercise interventions had significant effects in reducing depressive symptoms in the elderly (Cui et al., 2021). Additionally, a randomized controlled trial demonstrated that a mind-body intervention targeting physical activity and stress-response pathways effectively reduced depressive symptoms in older adults (Mokhtari et al., 2013). It is encouraging to compare this outcome with clinical observation who demonstrated that exercise had a broader effect in reducing depressive symptoms compared to control conditions (Liu et al., 2021). These relationships may partly be explained by different types of exercise and their effects on depression in the elderly. For example, a 12-week Pilates exercise program was found to reduce depression and improve balance in the elderly (Mokhtari et al., 2013). Similarly, a comparison between open-skill and closed-skill exercises showed that both types of exercises decreased depression and improved balance in the elderly (Chen et al., 2019). Moreover, a study on elderly Chinese women revealed that moderate and vigorous exercise levels were associated with lower depression scores (Chen et al., 2019).

It is somewhat surprising that no differences were noted in the anxiety domain of DASS-21 between all three groups. This finding is contrary to previous studies which have suggested that exercise is associated with reduced anxiety levels in the elderly (Kazeminia et al., 2020). In contrast to the findings, high-resistance exercise has been found to reduce anxiety and lower the risk of depression in elderly men (Janyacharoen et al., 2018). A combined interventions such as dance and relaxation have been effective in reducing anxiety and depression and improving the quality of life in cognitively impaired elderly individuals (Cassilhas et al., 2010). Furthermore, different types of exercise have been shown to lower the risk of depression in the elderly, with the mental health benefits of exercise being more pronounced in individuals with anxiety and depression (Bouzid et al., 2015). These factors may explain the relatively good correlation between exercise and depression.

Although the data from the N-back and Stroop tasks initially appeared to suggest differences among the recreational badminton participants (RBP), closed-skilled participants (CSP), and the control (CON) group, further statistical analysis indicated that these differences were not statistically significant (N-back: $p>0.05$; Stroop: $p>0.05$). It is crucial to note that non-significant findings imply that any observed numerical differences may be attributable to chance or sample variability rather than a robust effect of the intervention. Therefore, these results should be interpreted with caution, and claims regarding superior cognitive performance in these domains are not supported by statistically significant evidence. Future research with a larger sample size or more sensitive measurement tools might be necessary to further investigate potential trends observed in these tasks.

6.6 Conclusion

This study underscores the distinct benefits of recreational badminton in enhancing cognitive and physical functions among the elderly. Our findings reveal that elderly badminton players demonstrated superior cognitive abilities, particularly in working memory and executive functions. These results indicate that badminton, a dynamic, open-skilled activity, might be especially beneficial in elderly populations. Future research should delve into underlying mechanisms and compare these effects with other exercise forms, providing valuable insights for aging-related health. Future research should build on the present findings by employing a multi-pronged approach. First, a longitudinal study design is recommended to monitor cognitive changes over extended periods, which will allow for the assessment of causal relationships between long-term badminton participation and cognitive function in the elderly. In parallel, mechanistic studies are needed to explore the underlying neural substrates. These studies could incorporate advanced neuroimaging techniques (such as fMRI and PET) and electrophysiological measures (e.g., EEG) to identify the specific brain regions and neural pathways involved in the cognitive benefits associated with open-skill exercises. Furthermore, it is imperative to conduct randomized controlled trials comparing the effects of open-skilled sports like badminton with closed-skilled exercises to determine differential impacts on various cognitive domains. Lastly, future investigations should consider potential moderating factors such as baseline physical activity, gender, and comorbid health conditions to offer a more comprehensive understanding of the exercise-cognition relationship

CHAPTER 7
STUDY 5: EFFECT OF SINGLE BOUT EXERCISE MODALITIES ON MULTI-DOMAIN COGNITIVE FUNCTION IN RECREATIONALLY ACTIVE OLDER ADULTS

7.1 Introduction

The relationship between physical exercise and cognitive function throughout the lifespan has been consistently reported, with special focus on its role during aging, when cognitive decline is prevalent (McMorris et al., 2011). Most research has focused on the effects of long-term exercise routines, exploring how consistent exercise influences cognitive functioning. Recently, however, there has been a growing interest in the cognitive benefits of single-bout exercise, as independent interventions combined with regular exercise programs (Nanda et al., 2013). This change is based on the hypothesis that physical activity induces physiological changes such as increased heart rate, shifts in plasma catecholamine levels associated with enhanced stimulation and the production of brain-derived neurotrophic factors that support hippocampal growth, all of which may aid cognitive enhancement (Sok et al., 2021).

Cognitive functions refer to the mental processes involved in acquiring and processing knowledge (Mandolesi et al., 2018). Executive functions, which are higher-order cognitive processes, are important for regulating thoughts and actions, including working memory, cognitive flexibility, and problem-solving, all of which are important, for daily functioning (Moreau & Chou, 2019). Regular physical activity has been related with improvements in various cognitive domains, particularly in processing speed, visuospatial abilities, and executive functions, especially among older adults. Over the past two decades, research has regularly shown, the cognitive benefits of exercise, with a notable attention on effects in executive function (Zheng et al., 2022). This is especially important given the vulnerability of executive functions to age-related decline. However, while several studies suggest a positive link between exercise and cognitive enhancement across different domains, the overall impact of exercise on cognitive health is not unclear. Further investigation is needed to determine how various forms of exercise may influence this relationship.

Different types of exercise may affect cognition in distinct ways, depending on their cognitive demands and skill requirements, classifying them as open-skill or closed-skill activities. Open-skill exercises, such as badminton, require rapid responses to unpredictable stimuli in dynamic, fast-paced settings (Liu et al., 2021). As one of the world's most widely played sports, badminton includes mixed-gender participation and allows participation by individuals of different ages and abilities. With its intermittent actions, badminton engages both aerobic (70%) and anaerobic (30%) energy systems (Phomsoupha & Laffaye, 2015). The high physical requirement in badminton may contribute to aerobic capacity, cardiovascular health, metabolic function, body composition, cardiac adaptation, and muscle performance (Liu et al., 2019). In contrast, closed-skill exercises, such as swimming and running, take place in predictable environments and demand less cognitive effort (Tsai et al., 2017). Open-skill exercises, however, require adaptive behaviors and motor responses to unpredictable stimuli, engaging more involving more cognitive functioning than the self-paced, stable-environment closed-skill exercises (Koch & Krenn, 2021). Studies indicate that open-skill exercises enhance visuospatial attention, inhibitory control, problem-solving, cognitive flexibility, and reduce reaction time compared to closed-skill exercises (Wu et al., 2020). Additionally, improvements in executive network efficiency have been connected to open-skill exercises, highlighting a favorable combination of physical and cognitive training.

To date, most research has focused on the inhibitory aspect of executive function which has led to the relative neglect of other subcomponents, including short-term memory and, more broadly, working memory (Chang et al., 2011), which is also known to deteriorate with aging. In the acute exercise literature, inconsistencies can be found, with some suggesting a positive effect of acute exercise on working memory and others find no effect toward working memory (Griebler et al., 2022). Interestingly, acute exercise produced stronger effects more substantial effects (small to moderate effects) on working memory compared to chronic exercise (Rathore & Lom, 2017).

The present study had the objective to explore the impact of a single bout of badminton (open-skill) or closed-skill on recreationally active older adults, comparing these s to those stemming from one session of sedentary activity. This study's findings aim to enhance understanding of the influence of acute exercise on cognitive health

7.2 Methodology

7.2.1 Study Design

A quasi-experimental study design was implemented among an eligible population in Negeri Sembilan, Malaysia. Participants were purposively recruited via email and social media platforms. Initially, a total of ninety-nine physically capable elderly individuals (aged >60 years) were screened for eligibility in the open-skills group, with 33 participants participating in all tests, questionnaires assessments and cognitive function assessment. The elderly individuals (aged >60 years) appeared to represent the target demographic where these exercise interventions could be most beneficial for maintaining cognitive function. The badminton group (RBP) consisted of elderly individuals participating recreationally in badminton, while the closed-skills participant group (CSP) included those involved in cycling, swimming, and gym circuit activities. The control group (CON) was recruited from a regularly participating senior community centre. This selection criterion allowed for that any differences observed within the badminton group could be attributed to varying levels of game participation. Participants will be considered recreational badminton players if they have engaged in badminton for a minimum of 30 minutes per session, at least twice per week, over the past 12 months. The intensity of play should be moderate to vigorous, which is operationalized as activities achieving a metabolic equivalent (MET) value of 4.5 or above (Phomsoupha & Laffaye, 2015). This definition ensures that the selected participants have a consistent and adequate level of exposure to the physical and cognitive demands of the sport. All study procedures were approved by the Research Ethics Committee (REC/06/2022-PG/MR/127) and completed in accordance with the requirements of the Helsinki Declaration (2013).

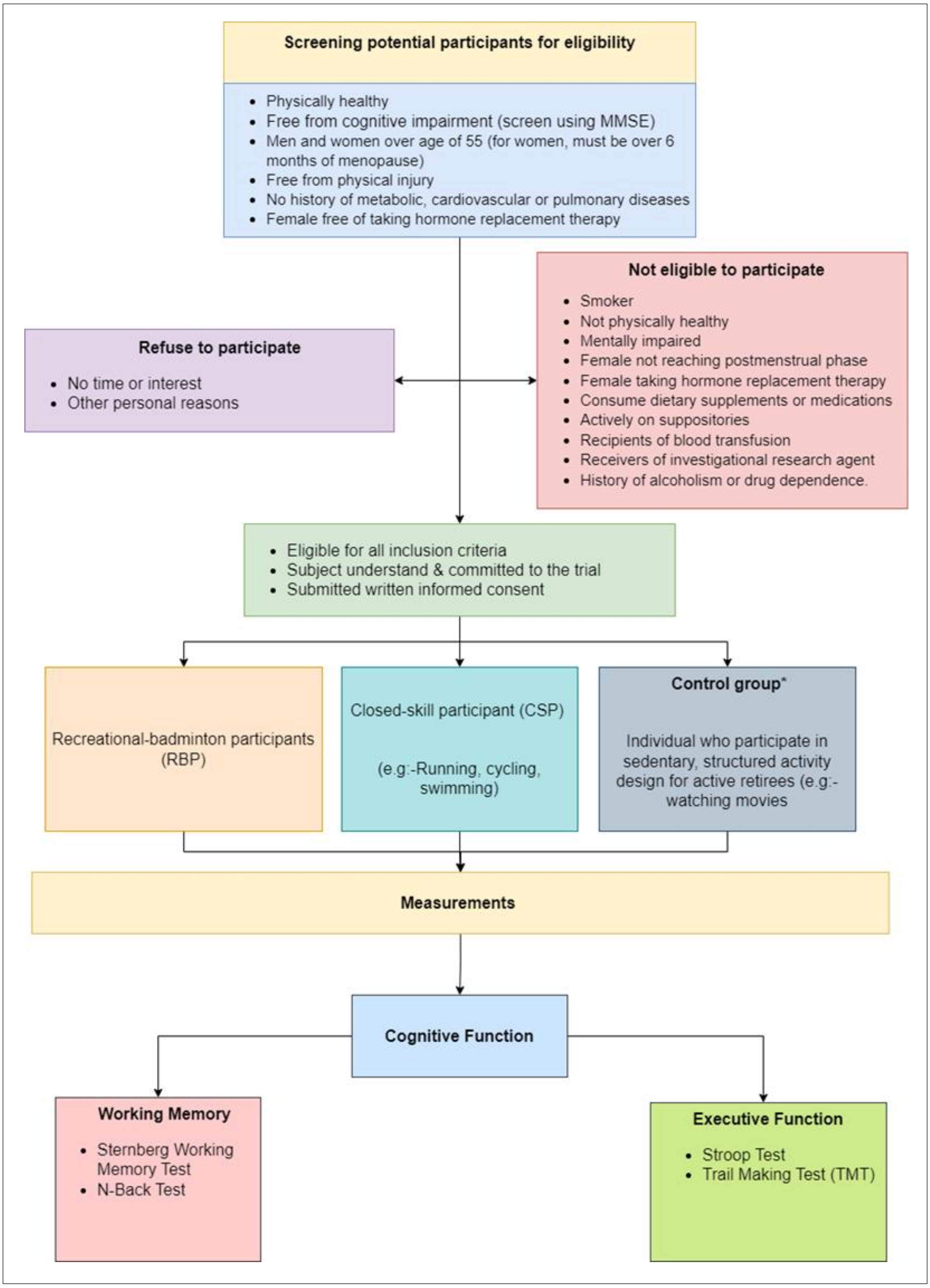

Figure 7.1 CONSORT of participant requirement. Consolidated Statement of Reporting Trials: RBP; recreational-badminton participants, CSP; close-skilled participants, CON; control group.

7.2.2 Participants Sampling and Technique

The sample size for this study were calculated using statistical formula by Charan & Biswas, (2013) for population proportion by considering 95% confidence interval, 5% level of precision, 1% estimated population of elderly badminton players (estimated from interview and email communication data from badminton clubs across Negeri Sembilan and census data from Department of Statistics Malaysia, DOSM).

$$\text{Sample Size} = \frac{Z_{1\text{-}a/2}{}^{2}\,p(1\text{-}p)}{d^{2}} \tag{7.1}$$

Briefly, the value represents a standard normal variate (at 5% type 1 error ($p < 0.05$) with a value of 1.96. The 'p' value defines as expected proportion ('p' value considered significant below 0.05) in population and 'd' defined as the absolute error or precision. Hence, based on a 1% estimated population of elderly badminton players, and a 5% absolute and type 1 error, a total of 16 sample size was estimated in each target condition (RBP, CSP and CON group) as follow:

$$\frac{1.96^{2} \times 0.01\,(1-0.01)}{0.05^{2}} = 15.8 \tag{7.2}$$

In order to ascertain that any changes in the measurement conducted in this study are due to participation in badminton (recreationally playing badminton at least twice a week for the last 10 years), closed-skilled exercise group, defined as individuals who performed exercise on the stable and predictable environment (e.g: running, swimming, cycling) in last 2 years and control group, defined as individual who do not partaking in any exercise were also been introduced. All the subject in this study different from the previous study.

7.2.3 Study Protocol

All participants who completed the screening procedure were instructed to report to the Physiology and Nutrition Laboratory at the Faculty of Sport Science and Recreation, Universiti Teknologi MARA, Malaysia. The study included physically healthy elderly individuals, aged 60 and above, who frequently participate in recreational badminton. Upon arrival, participants were provided with a detailed explanation of the study's objectives and procedures. Their weight, height, and waist-to-hip ratio were recorded. The research focused on analysing the lower range of Metabolic Equivalent (MET) values associated with various physical activities in an older population. The activities evaluated assessed were badminton (MET 4.5), cycling (3.5), swimming (4), and gym circuit training (3). To regulate the comparison of MET values, the activities were adjusted to match the MET output of a 30-minute tennis session, which had the maximum-minimum MET value. Consequently, the exercise durations were adjusted as follows: 30 minutes for badminton, 50 minutes for table tennis, 40 minutes each for cycling and swimming, and 50 minutes for gym circuit training. Control sessions consistently lasted 60 minutes. Within 30 minutes of completing their activities, participants returned to the laboratory to answer a questionnaire and undergo cognitive assessments, including the N-Back Task, Stroop Task, and Trail Making Test (TMT).

7.3 Measurements

7.3.1 Anthropometric Measurements

Participants' weights (in kilograms) and heights (in centimeters) were measured using a validated standardized stadiometer (Seca 220; Seca, Ltd., Hamburg, Germany) to calculate their body mass index (BMI). Waist-to-hip ratios were calculated by measuring waist circumference at the midpoint between the last palpable rib and the iliac crest using the Seca 201 tape (Seca, Ltd., Hamburg, Germany), ensuring standardized tension

7.3.2 Working Memory

Working memory was assessed using the N-back task and the Sternberg Working Memory Task. The N-back task, a computer-based software task, requires participants to update their mental set-in response to previous stimuli continuously (Jacola et al., 2014). This task includes 14 trials featuring stimuli appearing for 0.4 seconds, with an inter-stimulus interval of 1.4 seconds, under conditions of 0-back, 1-back, and 2-back. The Sternberg Working Memory Task was administered through the Inquisit® software (version 6.0, Millisecond Software, Seattle, USA) (Zakrzewska & Brzezicka, 2014). Each trial involved displaying a sequence of two to five white digits, each for 1200 milliseconds. Participants received visual feedback on the accuracy of their responses. All responses were recorded on the computer for subsequent extraction and analysis.

7.3.3 Executive Function

Executive function was evaluated using two measures: the Trail Making Test (TMT) and the Stroop test, both administered via Inquisit® software (version 6.0, Millisecond Software, Seattle, USA) (Hirota et al., 2010).The TMT assesses attentional capacities and is divided into two segments: TMT-A is designed to assess visual scanning and processing speed. In this task, participants are required to sequentially connect numbered circles as quickly as possible. This test primarily reflects the efficiency of visual attention and psychomotor speed, rather than rote memory. In contrast, TMT-B incorporates an additional executive function component by requiring task-switching between numbers and letters. The Stroop test required participants to respond to text strings on a custom keyboard, prioritizing speed and accuracy (Goenarjo et al., 2020). This test, lasting 90 seconds per session, measured reaction times and response accuracy. The reliability of the Stroop test was quantified through a coefficient of variation analysis, yielding a reliability of 2.1% from data collected from five participants.

7.3.4 Statistical Analysis

Descriptive statistics were used to summarize the basic characteristics of the participants. To analyze differences in cognitive function, including working memory and executive function, a one-way repeated measures ANOVA was conducted. The Brown-Forsythe and Welch tests were applied to ensure robustness. Dunnett's T3 multiple comparison tests were used for a detailed analysis of significant differences. In cases where significant disparities were observed, 95% confidence intervals were reported to indicate the probable range of true values within the sample population. Effect sizes were calculated using partial eta squared (ηp^2) and Cohen's d (dz), classified as trivial (0–0.19), small (0.20–0.49), moderate (0.50–0.79), or large (>0.80). All statistical analyses were performed using GraphPad Prism software (version 9.0).

7.4 Results

7.4.1 Anthropometry and Physical Characteristics

Table 7.1 presents the demographic and anthropometric data of the study cohort, which comprised three groups: RBP, CSP, and CON. These groups exhibited no significant differences in general demographic and anthropometric characteristics. Statistical analysis indicated that the levels of physical activity between the RBP and CSP groups were not significantly different ($p>0.05$). In contrast, both exercise groups engaged in significantly more physical activity than the CON group ($p<0.05$). Additionally, the years of sports experience and the weekly frequency of sports activities did not differ significantly between the RBP and CSP groups (p > 0.05). However, the RBP group tended to spend slightly more time in daily sports activities than the CSP group, although this difference was not statistically significant (p>0.05).

Table 7.1
The anthropometric, health and physical characteristics in RBP, CSP and CON groups

	RBP	**CSP**	**CON**
Age	65.7±4.7	65.0±4.4	64.2±2.6
Weight	64.8±4.5	67.2±4.5	66.3±4.5
Height	165±3.9	165±3.5	164±3.4
Playing experience (years)	30.2±6.4	34.5±7.4	-
Playing frequency (days/weeks)	3.57±1.2	3.50±1.2	-
Playing hours (hours/weeks)	7.92±1.7	7.0±3.5	-
IPAQ physical level (MET-min/weeks)	3687±270.2	3581±324.9	3255±416.0

7.4.2 Psychometric Measurements

Figure 7.1 presents a comparison between groups (RBP vs. CSP vs. CON) and within groups (Baseline: BL vs Post-exercise: PE) across various cognitive tasks, including the N-back task, SWMT, Stroop task, and TMT. A one-way repeated measures ANOVA for N-back reaction time revealed no significant group differences [$F(2, 96) = 0.56$, $p = 0.57$] and % accuracy [$F(2, 96) = 0.01$, $p=0.98$,], whereas the main effect of time was significant for reaction time [$F(1, 96) = 0.14$, $p=0.70$] but not for accuracy [$F(1, 96) = 0.58$, $p=0.44$]. Planned comparisons using Bonferroni corrected unpaired samples t-tests revealed that in terms of reaction time, the RBP group (812.3± 25.0.; t(32) = 1.755, P=0.08, 95% CI = [-32.43 to 6.323], d: 0.42) significantly outperformed both the CSP (825±35; t(32) = 1.755, P=0.08, 95% CI = [-36.09 to 2.659], d: 0.42) and CON groups (842.1±41.6; t(32) = 3.050, P=0.08, 95% CI = [-49.14 to -10.39], d: 0.88). However, no significant difference between the CSP and CON group in reaction time (*p*>0.05) was observed. Although trends in reaction time were observed, the ANOVA did not reveal statistically significant differences among the groups (*p*= 0.57). Therefore, claims of superior performance based on reaction time must be tempered, and no definitive conclusions regarding group differences in reaction time can be drawn. Accuracy trends paralleled these findings, with the RBP group (75.7± 10.4 t(32) = 2.080, *p*<0.001, 95% CI = [14.75 to 25.06], d: 0.45) demonstrating better % accuracy compared to the CON group (70.7±12.1; t(32) = 10.66, *p*<0.001, 95% CI = [14.75 to 25.06], d: 0.45), as did the CSP group (55.1±9.7; t(32) = 6.378, *p*=0.045, 95% CI = [9.521 to 21.61], d: 2.08). Yet, there was no significant difference in % accuracy between the BAD and CSP groups (*p*>0.05). Time-dependent changes following single exercise session in accuracy using Holm-Bonferroni corrected paired samples t-tests were notable only in the RBP group, showing a significant improvement post-acute exercise (BL: 76.9±9.8 vs. PE: 75.7±10.4; t(32) = 10.96, P=0.045, 95% CI =[15.24 to 26.02], d: 0.12), while the CSP and CON groups demonstrated no such effect (*p*>0.05).

Analysis of reaction time in SWMT revealed a significant main effect of group [F(2, 96) = 10.80, *p*<0.05], but not of time [F (1, 96) = 1446, *p*=0.232], and the time x group interaction [F(2, 64) = 2.636, *p*=0.07]. Notably, the reaction time in the RBP group (1205.1± 24.1 ms; t(32) = 5.120, *p*<0.001, 95% CI = [-45.25 to -19.58], d: 0.76) was significantly faster than that of the CON group (1227.4±34.2 ms; t(32) = 5.120, *p*<0.001, 95% CI = [-45.25 to -19.58], d: 0.76), as was the reaction time in the CSP group (1238.1±24.6 ms t(32) = 1.457, *p*=0.155, 95% CI = [-34.66 to -8.979], d: 1.38) compared to the CON. However, there was no significant difference between the RBP and CSP groups (*p*>0.05). In terms of accuracy, there was a significant main effect of group [F (2, 96) = 75.37, *p*<0.001], but the main effect of time was not significant [F(1, 96) = 0.433, P=0.512]. The % accuracy in the RBP group (77.8 ± 7.51; t(32) = 7.964, *p*<0.001, 95% CI = [8.106 to 16.00], d: 1.88) was significantly higher compared to the CON group (65.7± 5.35; t(32) = 7.964, *p*<0.001, 95% CI = [8.106 to 16.00], d: 1.88), as did the accuracy in the CSP group (74.7 ± 8.52; t(32) = 5.305, *p*<0.001, 95% CI = [-

0.8271 to 7.070], d: 0.39). However, the comparison between RBP and CSP groups in terms of % accuracy revealed no significant difference (p>0.05).

Analysis of reaction time in Stroop task indicated a significant difference between time x group interaction [$F(2, 96) = 1.483$, $P = 0.2322$], significant main effect of group [$F(2, 96) = 3.0305$, p=0.0409] and no significant main effect of time ($F(2, 96) = 2.056$, $P = 0.1549$]. Conversely, in terms of % accuracy, the results were more varied. While the time x group interaction was not significant [$F(2, 96) = 1.483$, p=0.2322], there was a significant main effect of group ($F(2, 96) = 28.92$, p<0.001]. However, the main effect of time was not significant [$F(1, 96) = 0.006977$, P=0.9336] Post-hoc comparison revealed a significant difference between the RBP group (79.9 ± 6.35; t (32) = 4.948, p<0.001, 95% CI = [3.669 to 10.29], d: 1.05) and the CON group (73.5 ± 5.93; t (32) = 4.948, p<0.001, 95% CI = [3.669 to 10.29], d: 1.05). However, no significant differences were found when comparing the RBP group with the CSP group (both p>0.05).

For the TMT-A test, the time x group interaction was significant [$F(2, 96) = 9.647$, P=0.0002], a significant main effect of group also was found [$F(2, 96) = 17.53$, p<0.0001]. The main effect of time was not significant [$F(1, 96) = 0.00536$, p=0.9418]. Post-hoc analyses revealed a significant difference between the RBP and CON groups, with the RBP group completing TMT-A faster (26.09 ± 3.97 vs. 32.36 ± 5.92; t(32) = 4.661, p<0.0001, 95% CI = [-9.824 to -4.540], d: 1.26) and significant difference between CSP and CON group, with CSP completing TMT-A faster (25.18 ± 3.18 vs. 32.36 ± 5.92; t(36.44) = 2.528, p=0.016, 95% CI = [-8.915 to -3.631], d: 1.53). However, no significant differences were observed between the RBP and CSP groups (p>0.05). For the TMT-B test, significant main effect of group [$F(2, 96) = 70.82$, p<0.001] were present. In the post-hoc analysis, the RBP group (45.42 ± 10.9, t(32) = 8.729, p<0.001, 95% CI = [-25.87 to -15.16], d: 2.11), significantly outperformed the control group (65.93±8.70; t(32) = 8.729, p<0.001, 95% CI = [-25.87 to -15.16], d: 2.11), as did the CSP group (50.00 ± 8.47; t(32) = 7.388, p<0.001, 95% CI = [-21.30 to -10.58], d: 1.88) compared to the CON group (65.93±8.70; t(32) = 7.388, p<0.001, 95% CI = [-21.30 to -10.58], d: 1.88). No significant difference was found between the RBP and CSP groups (p>0.05).

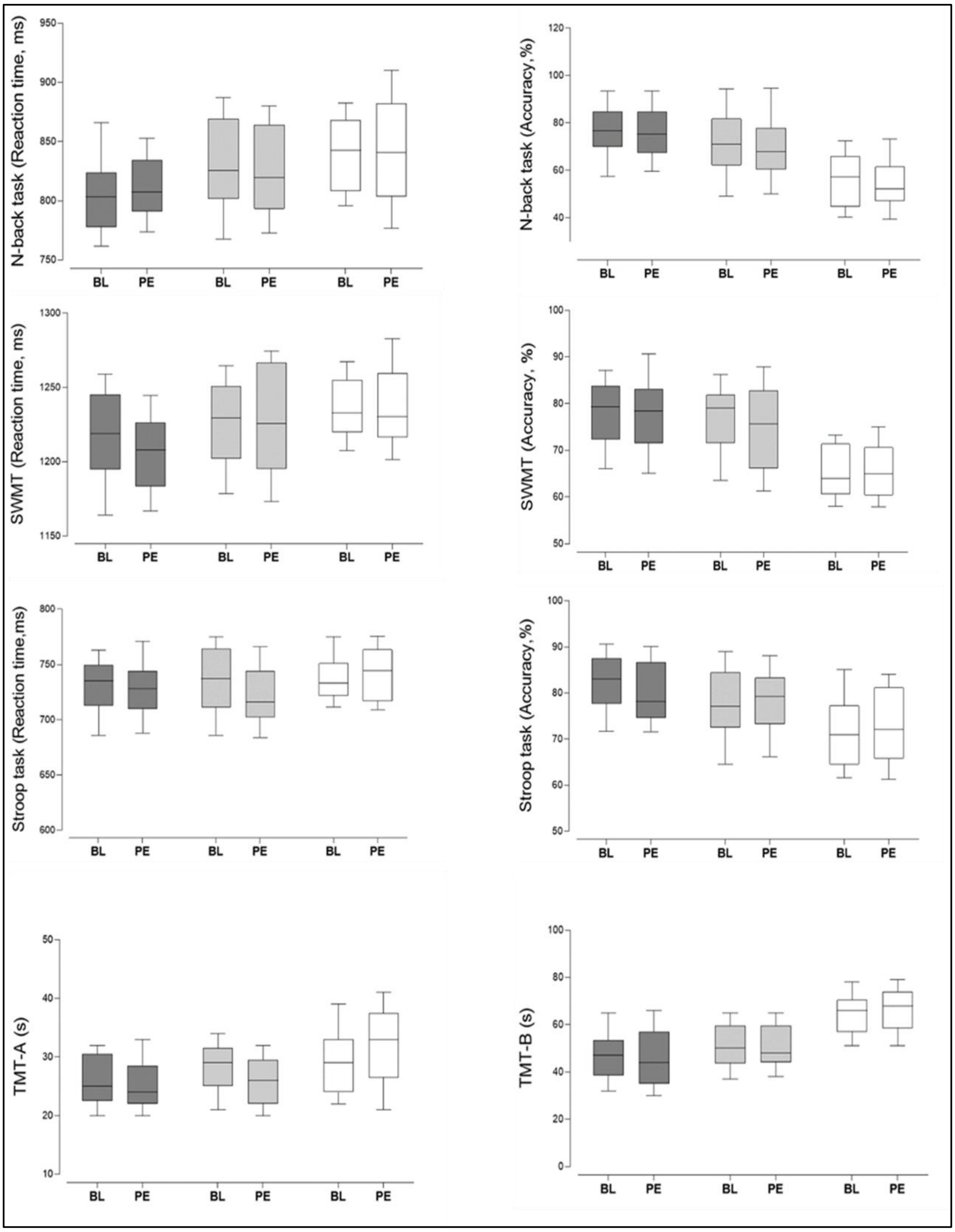

Figure 7.2 Box plots illustrate group comparisons of recreational-badminton participants (RBP, dark grey), closed-skill exercise (CSP, light grey), and control (CON, white), as well as within-group changes from baseline (BL) to post-single session exercise (PE) across various cognitive tasks

7.5 Discussion

Following several psychometric measurements, the results shown that participants in the badminton group performed better than those in the closed-skills and control groups in tasks measuring working memory and executive function. In particular, the badminton group showed considerably faster, meaningfully faster reaction times and greater accuracy across several cognitive tasks, such as the N-back and Stroop tasks, highlighting the cognitive benefits of participating in badminton. Although both exercise groups demonstrated cognitive improvements compared to the control group, the benefits were greater in the badminton group, especially in tasks requiring rapid information processing and task-switching. The result due to the nature of badminton as an open-skill sport requiring constant adaptation to unpredictable stimuli such fast shuttlecock movements, opponent strategies, rapid decision-making (Liu et al., 2021). This engages more cognitive processing than closed-skill exercises like swimming or cycling, which occur in stable, predictable environments with repetitive movements (Koch & Krenn, 2021). These findings provide useful insights into the cognitive advantages of specific exercise types in older adults, suggesting that open-skill sports may provide specific cognitive advantages not seen in rigid activities.

This study showed that participants in the RBP group exhibited significant improvements in working memory performance and reaction time, compared to the CSP group and the CON group. These findings are consistent with previous studies that suggest open-skill sports, such as badminton encourage greater cognitive flexibility and quicker reaction times due to the unpredictable and dynamic nature of the activity (Wu et al., 2021). In contrast to close-skill sports, which typically involve repetitive and less cognitively demanding tasks, open-skill sports require continuous modification to external stimuli, which may explain the enhanced cognitive performance observed in the badminton group. The improvements in reaction time and accuracy among badminton players further support corroborate the notion that dynamic sports positively affect processing speed and decision-making (Pancar et al., 2020)

The badminton group demonstrated measurable improvements in executive function, particularly in task-switching and inhibition, compared to the closed-skill group. These findings align with research highlighting the cognitive benefits of sports that require rapid decision-making and adaptability (Feng et al., 2023). The superior performance of the badminton group on the Trail Making Test (TMT) and Stroop Test suggests that open-skill sports enhance executive function due to the cognitive demands of these activities (Möhring et al., 2022). These results in agreement studies showing that regular participation in open-skill sports improves cognitive control and flexibility, particularly in older adults (Tsai & Wang, 2015).

Our findings show that the badminton group consistently performed better than both the close-skill and control groups in tasks assessing cognitive processing speed and accuracy. The improvements in the N-back task and Stroop test suggest that participation in open-skill sports improves both cognitive speed and precision. This is due to more substantial concentration demands during gameplay (Formenti et al., 2021). Prior research has indicated that dynamic sports contribute to faster cognitive responses because of the need for quick and accurate decision-making in unpredictable environments (Sok et al., 2021). This may account for the badminton for higher performance levels in both reaction time and accuracy compared to the close-skill group (Gu et al., 2019).

This study also found that the badminton group exhibited the most notable time-dependent improvements in cognitive function. These results indicate that regular participation in open-skill sports may prolonged cognitive benefits, particularly in tasks involving inhibitory control and working memory (Tsai & Wang, 2015). Although both the badminton and closed-skill groups showed post-exercise improvements, the changes were more evident in the badminton group, highlighting the role of complex motor coordination in promoting prolonged cognitive benefit (Behringer et al., 2011).

The findings of this study have significant implications for cognitive and emotional health in older adults, particularly those involved in recreational physical activities. The superior performance of the badminton group in working memory, executive function, and processing speed indicates demonstrates that open-skill sports, which require continuous adaptation to dynamic environments, yield cognitive advantages distinct from those provided by close-skill exercises (Möhring et al., 2022). These results have practical relevance for designing cognitive health interventions targeting aging populations. Open-skill sports such as badminton in regular physical activity programs may be an effective approach to mitigating age-related cognitive decline and fostering cognitive stability (Gu et al., 2019). Furthermore, the emotional well-being improvements observed in the badminton group, such as lower levels the depression and anxiety, underscore the possibility of these activities to promote both mental and emotional health. These findings imply that open-skill sports may be integrated into interventions for older adults, addressing both cognitive and emotional aspects of well-being.

Our findings provide further support for the growing body of evidence on the acute cognitive benefits of physical exercise, particularly when comparing open-skill and closed-skill activities. Consistent with earlier studies (e.g., Wu et al., 2021; Tsai & Wang, 2015), the superior performance of the badminton group in tasks measuring working memory and executive function underscores the unique advantages of cognitively demanding, open-skill sports. Unlike several investigations that reported only modest improvements with acute exercise (Griebler et al., 2022), this study demonstrated not only statistically significant reductions in reaction time but also meaningful gains in task accuracy.

These discrepancies may be attributed to differences in the cognitive demands of the exercise modalities. Whereas prior research on chronic exercise interventions (McMorris et al., 2011) has largely focused on long-term adaptations, our acute exercise design highlights that even a single bout of open-skill activity can rapidly mobilize neurophysiological mechanisms such as increased catecholamine release and brain-derived neurotrophic factor (BDNF) upregulation (Sok et al., 2021) which in turn facilitate immediate improvements in cognitive processing speed and flexibility.

Importantly, the present study extends previous literature by providing a direct comparison between open-skill and closed-skill exercise modalities within the same experimental framework. This design allowed us to explicitly identify the specific cognitive processes that are preferentially enhanced by the unpredictable and dynamic nature of open-skill sports. Consequently, our work contributes to the field by not only confirming the benefits of acute exercise on cognitive function but also by delineating the distinct roles that exercise modality plays in mediating these effects. Future research should build on these findings by exploring the long-term implications of integrating open-skill activities into exercise programs for aging populations.

7.6 Conclusion

The currents study indicated that participation in open-skill sports, specifically badminton, yields significant cognitive and emotional benefits for older adults compared to close-skill activities such as cycling and swimming. Participants in the badminton group demonstrated significant cognitive enhancements most notably in working memory, executive function, and processing speed when compared to both closed-skill exercisers and controls. However, the data did not reveal statistically significant changes in measures of depression, anxiety, or stress following the exercise intervention. Therefore, while open-skill exercise appears promising for cognitive health, no conclusive evidence was found to support improvements in emotional outcomes. While this study focused on the acute effects of a single bout of exercise, the results suggest that integrating open-skill sports into regular physical activity programs could be a valuable strategy for promoting cognitive health and emotional resilience in aging populations. Future research should explore the long-term impact of consistent participation in such sports to better understand their role in mitigating age-related cognitive decline.

CHAPTER 8
GENERAL DISCUSSION

8.1 Introduction

The aging process is often accompanied by a gradual decline in physical, physiological, and cognitive performance, which can significantly impair quality of life and independence in elderly individuals. Despite these challenges, there is growing evidence that active participation in recreational sports offers a viable pathway to mitigating these declines and promoting healthy aging. Among various physical activities, badminton a dynamic, open-skill sport that requires agility, strategy, and sustained aerobic effort has garnered attention for its potential to enhance not only physical health but also cognitive function in older adults.

This thesis investigates the multifaceted benefits of recreational badminton on elderly individuals, addressing critical gaps in the literature. While the benefits of physical activity on cardiometabolic health and cognitive function are well-documented, few studies have explored the unique contributions of open-skill sports like badminton, particularly in aging populations. Prior research has predominantly focused on younger cohorts or closed-skill activities such as swimming and cycling, leaving the effects of badminton on elderly-specific outcomes underexplored. Furthermore, existing studies have seldom examined the interplay between playing frequency, physical function, and cognitive performance, nor have they accounted for emotional well-being, an equally vital component of successful aging.

The overarching aim of this research is to evaluate the influence of recreational badminton on physical, physiological, and cognitive outcomes in elderly participants. Specifically, the objectives span five key areas: examining the effects of playing frequency on blood pressure and body composition; investigating impacts on cardiometabolic indices; evaluating long-term participation on physical and cognitive function; and comparing single bouts of exercise across multiple activities to delineate badminton's unique contributions. These objectives are grounded in the hypothesis that badminton, as an open-skill sport, may confer distinct benefits by engaging both motor and cognitive systems more dynamically than closed-skill activities.

8.2 Recreational Badminton & Physiological Outcome

The influence of badminton on cardiometabolic health is particularly striking. The study reveals that HPT participants show greater improvements in glycaemic control compared to LPT participants, reflecting the sport's capacity to positively affect metabolic regulation. These results align with broader evidence indicating that sustained physical activity improves insulin sensitivity and lipid profiles, essential for reducing the risk of type 2 diabetes and cardiovascular diseases. The dynamic and intermittent nature of badminton, characterized by rapid bursts of activity interspersed with recovery, likely contributes to these outcomes by mimicking high-intensity interval training a proven approach to enhancing cardiometabolic health.

The body composition changes observed among badminton participants extend beyond simple weight loss to encompass favourable alterations in fat distribution and muscle mass preservation. HPT participants demonstrated significant reductions in visceral adiposity, a metabolically active fat depot strongly associated with insulin resistance, systemic inflammation, and cardiovascular disease risk. Concurrently, maintenance or enhancement of lean body mass, particularly in the lower extremities, suggests that badminton provides sufficient mechanical loading to counteract sarcopenia, the age-related loss of muscle mass that contributes to functional decline and metabolic dysregulation.

The study reveals that HPT participants show greater improvements in glycaemic control compared to LPT participants, reflecting the sport's capacity to positively affect metabolic regulation. These results align with broader evidence indicating that sustained physical activity improves insulin sensitivity and lipid profiles (Boden et al., 2001), essential for reducing the risk of type 2 diabetes and cardiovascular diseases (Oja et al., 2017). The improvements in glycaemic control observed among badminton participants reflect enhanced glucose uptake by skeletal muscle through both insulin-dependent and insulin-independent mechanisms. The repeated muscle contractions during badminton play activate AMP-activated protein kinase (AMPK) pathways, facilitating glucose transporter type 4 (GLUT4) translocation to the cell membrane independent of insulin signalling. This mechanism is particularly beneficial for individuals with insulin resistance or prediabetes, providing an alternative pathway for glucose clearance that is preserved even when traditional insulin signalling is impaired. The dynamic and intermittent nature of badminton, characterized by rapid bursts of activity interspersed with recovery (Phomsoupha & Laffaye, 2015) likely contributes to these outcomes by mimicking high-intensity interval training a proven approach to enhancing cardiometabolic health.

This research also highlights the importance of badminton as an accessible and adaptable form of physical activity for the elderly. Compared to conventional exercise modalities, badminton engages participants in a socially interactive and cognitively stimulating environment, potentially increasing adherence and long-term participation. The unique combination of aerobic and anaerobic demands in badminton provides a holistic workout that not only addresses cardiovascular fitness (Wee et al., 2017) but also promotes muscular strength and endurance (Sonoda et al., 2018). Furthermore, its open-skill nature requiring agility, coordination, and quick decision-making distinguishes badminton as a comprehensive intervention for physiological and functional health (Liu, et al., 2021).

8.3 Effect on Cognitive Function

Participation in recreational badminton yields profound cognitive benefits for elderly individuals, emphasizing its role as an effective intervention for mitigating age-related cognitive decline. This study demonstrates that elderly badminton players, particularly those with high playing time (HPT), exhibit significant enhancements in working memory, executive function, and processing speed compared to low playing time (LPT) participants and non-players. These improvements align with the complex demands of badminton, which require players to process dynamic spatial information, execute rapid decision-making, and sustain attention during gameplay (Yılmaz et al., 2022). The combination of physical exertion and cognitive engagement in badminton is a key driver behind its effectiveness in promoting neuroplasticity and preserving cognitive function in older adults.

One of the standout findings is the comparative advantage of badminton over closed-skill activities such as swimming and cycling. Unlike these activities, which involve repetitive and predictable movements (Pancar et al., 2020), badminton's open-skill nature necessitates constant adaptation to unpredictable stimuli, fostering higher levels of cognitive engagement (Wang et al., 2023). The demands of anticipating an opponent's actions, strategizing in real-time, and executing precise motor responses contribute to the sport's unique ability to stimulate both cortical and subcortical brain regions (Heilmann et al., 2022). This type of stimulation is critical for maintaining cognitive resilience against aging-related structural and functional decline. Regular badminton participation promotes structural and functional neuroplasticity. Neuroimaging studies of athletes engaged in open-skill sports have demonstrated increased gray matter volume in regions including the hippocampus, prefrontal cortex, and basal ganglia structures critically involved in memory formation, decision-making, and motor control. These structural adaptations are complemented by functional changes, including enhanced connectivity within the default mode network and between task-positive networks, reflecting more efficient neural processing and integration.

At the molecular level, exercise-induced elevations in brain-derived neurotrophic factor (BDNF) play a pivotal role in mediating cognitive benefits. BDNF promotes neurogenesis in the hippocampus, enhances synaptic plasticity, and supports the survival and differentiation of newly formed neurons. The intermittent high-intensity nature of badminton may particularly effectively stimulate BDNF production, as evidence suggests that variable-intensity exercise protocols produce greater elevations compared to steady-state activity. Additional neurotrophic factors, including insulin-like growth factor 1 (IGF-1) and vascular endothelial growth factor (VEGF), contribute to the neurogenic and angiogenic processes underlying cognitive improvements.

Additionally, the emotional benefits of badminton further bolster cognitive outcomes. This study highlights significant reductions in stress and anxiety levels among badminton players, creating a psychological environment conducive to optimal cognitive performance. The social and interactive nature of the sport provides a sense of community and engagement, counteracting the isolation often experienced in older age (Abdou et al., 2018; Talebi et al., 2017). Physiologically, regular exercise normalizes hypothalamic-pituitary-adrenal (HPA) axis function, reducing baseline cortisol levels and enhancing cortisol recovery following acute stressors. Chronically elevated cortisol, common in sedentary elderly individuals, exerts neurotoxic effects particularly in the hippocampus, impairing memory consolidation and retrieval. By modulating HPA axis function, badminton may protect against glucocorticoid-induced cognitive impairment. Furthermore, badminton provides opportunities for mastery experiences, social connection, and absorption in engaging activity factors that enhance self-efficacy and psychological resilience. The flow states often reported by participants during gameplay reflect optimal psychological functioning characterized by complete absorption, intrinsic motivation, and loss of self-consciousness. These positive psychological experiences activate reward circuitry involving the ventral tegmental area and nucleus accumbens, promoting dopaminergic signalling that supports motivation, learning, and positive affect.

Reduced stress, combined with enhanced emotional well-being, mitigates the detrimental effects of chronic stress on memory and executive functioning, thereby amplifying the cognitive benefits derived from regular participation.

8.4 Physical Function Improvement

Recreational badminton participation has been shown to significantly enhance multiple dimensions of physical function in elderly individuals, addressing critical aspects of flexibility, balance, strength, and cardiovascular endurance. These findings underline badminton's value as a comprehensive physical activity that mitigates age-related functional decline and promotes independence in older adults. Participants in this study demonstrated marked improvements in flexibility, as evidenced by enhanced performance in the chair-sit and reach test. The improvements in flexibility observed among badminton participants reflect adaptations in both muscle-tendon units and joint structures. The dynamic stretching inherent in badminton movements including lunges, reaches, and overhead shots promotes muscle elongation and reduces passive stiffness. Regular exposure to end-range movements enhances sarcomere serial addition, increasing optimal muscle length and functional range of motion. Additionally, the variable movement patterns in badminton, unlike repetitive closed-skill activities, challenge flexibility across multiple planes of motion and joint angles, producing more comprehensive improvements than static stretching protocols alone. This outcome is particularly significant given that flexibility diminishes with age, impacting functional tasks such as bending and reaching, which are essential for daily living.

Balance, a cornerstone of fall prevention and mobility, also improved notably among badminton players (Sighamoney et al., 2018). The study observed superior performance in one-leg balance tests and dynamic balance assessments in participants engaged in high-frequency badminton play (Sighamoney et al., 2018). The balance improvements observed among badminton participants reflect adaptations across multiple sensory and motor systems involved in postural control. Proprioceptive acuity, the ability to sense body position and movement, showed marked enhancement following badminton training. This improvement likely results from increased sensitivity of muscle through regular exposure to varied loading conditions and joint positions. Enhanced proprioception enables more accurate detection of postural perturbations and more precise corrective responses. These findings suggest that the dynamic movements requiring rapid changes in direction, footwork, and postural adjustments contribute to enhanced proprioceptive control and stability (Malwanage et al., 2022). Improved balance is crucial for reducing the risk of falls, a leading cause of injury and disability in elderly populations (Preeti et al., 2019).

In addition to balance and flexibility, badminton players exhibited significant gains in muscular strength, particularly grip strength as measured by dynamometry, and in lower-body strength as reflected in the 30-second chair-sit-to-stand test. The demand of the sport for repeated bursts of high-intensity activity, combined with sustained aerobic engagement, likely stimulates neuromuscular adaptation and enhances overall strength (Hassan et al., 2017). The strength improvements observed among badminton participants encompass both neural and muscular adaptations. The explosive movements required in badminton including jumps, lunges, and rapid direction changes necessitate rapid force production, stimulating high-threshold motor unit activation. Over time, these neural adaptations are complemented by structural changes including muscle fiber hypertrophy, particularly of type II (fast twitch) fibers responsible for power production. Cardiovascular endurance also improved, as evidenced by longer distances covered in the 6-minute walk test. These outcomes align with badminton's aerobic and anaerobic demands, which together foster cardiovascular health and stamina. The 6-minute walk test improvements reflect enhanced cardiovascular efficiency, muscular endurance, and movement economy. Participants demonstrated increased walking speed and reduced perceived exertion at submaximal workloads, indicating improved cardiorespiratory fitness. These functional capacity improvements translate directly to enhanced ability to perform daily activities without excessive fatigue, maintaining independence and quality of life. The correlation between 6-minute walk test performance and mortality risk in elderly populations underscores the clinical significance of the observed improvements.

8.5 Single Bout Exercise Effect

The effects of single bouts of recreational badminton on cognitive and physiological performance offer compelling insights into the acute benefits of open-skill sports in aging populations. This study reveals that even brief sessions of badminton can elicit significant enhancements in cognitive domains such as working memory, executive function, and processing speed when compared to closed skill. These findings suggest that the dynamic and unpredictable nature of badminton, which engages both physical and cognitive systems (Preeti et al., 2019), triggers immediate neurophysiological responses including heightened neural activation and improved connectivity across brain regions involved in decision-making and memory (Jaworski et al., 2020). The comparative analysis of metabolic equivalent (MET) values underscores the unique nature of badminton, which contribution to overall exertion levels in single exercise sessions. Activities such as cycling and swimming were adjusted to match badminton's MET output for a standardized comparison, badminton consistently demonstrated greater cognitive benefits. This finding challenges the assumption that cognitive benefits of exercise depend solely on intensity or cardiovascular demand. While the cardiovascular fitness hypothesis proposes that cerebral perfusion improvements mediate cognitive benefits, the superior effects of badminton despite matched metabolic demands suggest additional cognitive-engagement mechanisms. The continuous requirement for attentional focus, decision-making, and motor coordination in badminton provides cognitive training effects that complement the physiological benefits of physical exertion. This distinction likely arises from the sport's complex task requirements, including rapid visual-motor integration, strategic planning, and the need for spatial awareness, which collectively amplify its impact on cognitive function during and immediately after participation (Culpin et al., 2018).

Furthermore, badminton's acute physiological benefits complement its cognitive effects. The sport's intermittent high-intensity bursts, interspersed with recovery periods, closely mimic high-intensity interval training (HIIT), known for its efficacy in improving cardiovascular efficiency and metabolic responses (Fernandez-Fernandez et al., 2012). Participants exhibited improvements in metrics such as heart rate recovery and perceived exertion, suggesting that single bouts of badminton not only challenge the aerobic and anaerobic systems but also enhance physiological resilience to stress (Huang et al., 2014). Single exercise bouts stimulate the release of lactate, which crosses the blood-brain barrier and serves as an alternative energy substrate for neurons. Lactate also functions as a signalling molecule, promoting BDNF expression and neuroplasticity-related gene transcription. The intensity-dependent lactate production during badminton play may contribute to its superior acute cognitive effects compared to moderate-intensity steady-state activities that produce less lactate accumulation. These acute adaptations provide a foundation for long-term health benefits when badminton is performed consistently (Wu et al., 2024).

8.6 Practical Implications

The findings from this research underscore the potential of recreational badminton as a practical and impactful intervention to improve health outcomes in elderly populations. The capability of the sport to enhance physical, physiological, and cognitive domains provides a compelling case for its integration into community-based exercise programs aimed at promoting healthy aging. Policymakers and healthcare providers can incorporate badminton as part of broader public health strategies to combat age-related declines, leveraging its accessibility, cost-effectiveness, and widespread appeal. The evidence which showed significant improvements in cardiometabolic health, particularly glycaemic control, supports the inclusion of badminton in interventions targeting chronic conditions such as diabetes and hypertension. Structured badminton programs can complement medical treatments by offering a dynamic form of physical activity that simultaneously addresses aerobic and anaerobic fitness. Tailoring the frequency and intensity of participation to individual capabilities, as highlighted in the study, ensures that the sport is both safe and effective across varying fitness levels.

Moreover, the unique ability of badminton which provide cognitive benefits, especially in enhancing executive function and reducing stress, make it an ideal activity for combating cognitive decline and emotional distress in older adults. Rehabilitation centers and mental health programs can integrate badminton into therapeutic regimens, using it not only to stimulate cognitive resilience but also to foster social interactions and alleviate isolation. The open-skill nature of badminton, which requires constant adaptation and decision-making, further reinforces its role as a dual-purpose intervention that targets both mental acuity and emotional well-being. The study also highlights the value of badminton as an adaptable exercise modality for single-bout sessions, offering immediate benefits in both physical and cognitive performance. This adaptability makes it suitable for use in time-constrained settings such as senior centers, where short, impactful sessions can be designed to engage participants effectively. Future practical applications may include integrating wearable technology to monitor participants' physiological and cognitive responses during sessions, providing real-time feedback to optimize individual benefits.

8.7 Future Research Directions

The findings of this study open several avenues for future research aimed at enhancing our understanding of the multifaceted benefits of recreational badminton for elderly populations. First, the longitudinal studies are needed to explore the long-term effects of regular badminton participation on physical, physiological, and cognitive health. As this research provides compelling evidence for its acute and short-term benefits, longitudinal data will offer deeper insights into its role in mitigating age-related decline and fostering resilience over extended periods. Secondly, there is a need to investigate the differential impacts of badminton based on individual characteristics, such as gender, skill level, and baseline physical or cognitive capabilities. This study focused predominantly on recreationally active older adults, but future work should examine its applicability to diverse cohorts, including sedentary individuals, professional players, and those with pre-existing health conditions. Tailoring interventions to specific subgroups will allow for more personalized and effective applications of badminton as a health-promoting activity.

Third, the integration of advanced monitoring technologies, such as wearable devices and motion capture systems, can provide richer data on physiological and biomechanical responses during gameplay. These tools will enable researchers to capture real-time metrics such as heart rate variability, muscle activation patterns, and movement efficiency, offering a more granular understanding of the mechanisms underlying the observed benefits. Such insights could inform the design of optimized training regimens tailored to maximize the health outcomes of badminton participation. Fourth, future studies should expand the ecological validity of research by including competitive elements and social interactions inherent in badminton matches. Introducing scenarios with opponents or team play could reveal additional cognitive and emotional benefits, such as enhanced problem-solving skills, stress management, and social bonding. This line of inquiry will also bridge the gap between controlled laboratory settings and real-world applications, ensuring the findings are both relevant and practical. Finally, cross-disciplinary research should explore the interplay between badminton and other interventions, such as dietary modifications, cognitive training, and psychological therapies. Understanding how badminton complements or synergizes with these approaches could pave the way for holistic health strategies that address the multidimensional challenges of aging. Additionally, studies examining the cost-effectiveness of implementing badminton-based programs in public health initiatives will strengthen the case for its widespread adoption.

8.8 General Conclusion

This study provides robust evidence supporting the significant role of recreational badminton in promoting physical, physiological, and cognitive health among elderly individuals. The findings demonstrate that badminton, as an open-skill sport, effectively enhances key health metrics, including blood pressure regulation, body composition, cardiometabolic indices, physical function, and cognitive performance. These results underscore the sport's multifaceted benefits, positioning it as a viable intervention for addressing the challenges of aging and improving quality of life in older populations.

The investigation revealed that consistent participation in badminton yields improvements across diverse domains. Participants with high playing time exhibited superior outcomes in cardiovascular health, glycaemic control, muscular strength, balance, and flexibility, highlighting badminton’s potential to mitigate age-related functional decline. Furthermore, the cognitive benefits of badminton, including enhanced working memory, executive function, and stress reduction, underscore its dual role in supporting both mental acuity and emotional well-being. These effects are attributed to the sport's unique demands for coordination, adaptability, and decision-making, distinguishing it from other forms of physical activity.

Practical implications of these findings advocate for integrating badminton into public health initiatives aimed at elderly populations. By leveraging badminton's accessibility and versatility, policymakers, health practitioners, and community organizations can design scalable interventions to promote active aging. The study also highlights the adaptability of badminton for time-constrained or single-session formats, making it an ideal candidate for diverse settings, from senior centers to rehabilitation programs.

Looking ahead, this research paves the way for future exploration into personalized and interdisciplinary approaches to maximize the benefits of badminton for elderly individuals. Longitudinal studies, advanced monitoring techniques, and investigations into its interplay with other interventions will further refine its application. This study contributes significantly to the broader discourse on promoting healthy aging through sustainable and enjoyable physical activity.

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APPENDICES

APPENDIX 1

Ethics Approval Letter (Study 1,2,3 & 4)

www.uitm.edu.my

UNIVERSITI TEKNOLOGI MARA

Pejabat
Timbalan Naib Canselor
(Penyelidikan dan Inovasi)

Reference : 600-TNCPI (5/1/6)
Our reference : REC/07/2023 (PG/MR/224)
Date : 3 July 2023

Assoc. Prof. Dr Raja Nurul Jannat binti Raja Hussain
(Syed Muhammad Murshid bin Syed Zubir – 2021495552)
Faculty of Sports Science and Recreation
UiTM Negeri Sembilan Branch
Seremban Campus
Persiaran Seremban Tiga/1, Seremban 3
70300 Seremban
NEGERI SEMBILAN

Dear Dr Raja Nurul Jannat,

APPROVAL LETTER - UiTM RESEARCH ETHICS COMMITTEE

Thank you for submitting your research proposal to the Research Ethics Committee (REC). After considering your application, the Committee approved your proposal titled "Influence of Recreational Badminton Playing on Physical, Physiological and Cognitive Performance in Elderly Individuals" at the Clinical Nutrition and Exercise Physiology Laboratory, UiTM Negeri Sembilan Branch.

Details of the approval are as follows:

Ref. number:	REC/07/2023 (PG/MR/224)
Approval Period:	3 July 2023 until 30 September 2023
Authorised personnel:	1. Assoc. Prof. Dr Raja Nurul Jannat binti Raja Hussain 2. Syed Muhammad Murshid bin Syed Zubir

The UiTM Research Ethics Committee operates in accordance to the ICH Good Clinical Practice Guidelines, Malaysian Good Clinical Practice Guidelines and the Declaration of Helsinki. The approval of this project is conditional upon your continuing compliance with these guidelines and declaration.

We draw to your attention the requirement that a report on this research, must be submitted every 12 months from the date of the approval or on the completion of the project, whichever occurs first. Failure to submit reports will result in withdrawal of consent for the project to proceed. Amendments, if any, to the study documents are to be submitted to the REC for approval.

If you require further information, please contact the REC Secretariat at 03-55448069/03-55442794 or email at recsecretariat@uitm.edu.my.

Yours sincerely,

EMERITUS PROFESSOR DATO' DR RAYMOND AZMAN ALI
Chairman
UiTM Research Ethics Committee

c.c.: Dean, Faculty of Sports Science and Recreation, UiTM

APPENDIX 2

Ethics Approval Letter (Study 5)

www.uitm.edu.my

UNIVERSITI TEKNOLOGI MARA

Pejabat
Timbalan Naib Canselor
(Penyelidikan dan Inovasi)

Reference : 600-TNCPI (5/1/6)
Our reference : REC/06/2024 (PG/FB/22)
Date : 14 ذوالحجه 1445H
21 June 2024

Mr Syed Muhammad Murshid bin Syed Zubir- 2021495552
(Supervisor: Dr Raja Nurul Jannat binti Raja Hussain)
Faculty of Sports Science and Recreation
UiTM Negeri Sembilan Branch
Seremban Campus
Persiaran Seremban Tiga/1, Seremban 3
70300 Seremban
NEGERI SEMBILAN

سلام عليكم ورحمة الله وبركاته and Greetings

Mr

APPROVAL LETTER - UiTM RESEARCH ETHICS COMMITTEE

Thank you for submitting your research proposal to the Research Ethics Committee (REC). After reviewing the list of documents as attached the Committee approved your proposal titled "Acute Effect of Different Exercise Modalities (Open-skills vs Close-skills) on Multi-domain Cognitive Functions in Recreationally Active Older Adults (Study 5)" at the Clinical Nutrition and Exercise Physiology Laboratory, UiTM Negeri Sembilan Branch. Details of the approval are as follows:

Approval number:	REC/06/2024 (PG/FB/22)
Approval Period:	21 June 2024 until 21 July 2024
Authorised personnel:	1. Syed Muhammad Murshid bin Syed Zubir 2. Dr Raja Nurul Jannat binti Raja Hussain

The UiTM Research Ethics Committee operates in accordance to the ICH Good Clinical Practice Guidelines, Malaysian Good Clinical Practice Guidelines and the Declaration of Helsinki. The approval of this project is conditional upon your continuing compliance with these guidelines and declaration.

Failure to submit reports will result in withdrawal of consent for the project to proceed. Amendments, if any, to the study documents are to be submitted to the REC for approval.

If you require further information, please contact the REC Secretariat at 03-55448069/03-55442794 or email at recsecretariat@uitm.edu.my.

اوسها، تقوى، موليا
"MALAYSIA MADANI"
"BERKHIDMAT UNTUK NEGARA"

Yours sincerely,

(EMERITUS PROFESSOR DATO' DR RAYMOND AZMAN ALI)
Chairman
UiTM Research Ethics Committee

c.c.: Deputy Rector (PJIM&A), UiTM Negeri Sembilan Branch

APPENDIX 3

Subject Information Sheet for Study 1 & 2 (English version)

REC 4/ 2019/BI Rev. 1

Research Ethics Committee
Research Management Centre
Universiti Teknologi MARA
40450 SHAH ALAM
Tel: 03 – 5544-8069, Faks: 03 – 5544-2096/2767

Subject's Information Sheet

Research Title
Influence of Recreational Badminton Playing on Blood Pressure and Body Composition in Elderly: A Cross-sectional Analysis with Playing Time-stratified Sampling

Introduction of Research
Recreational racquet sports participation has the potential to reduce the risk for developing cardiovascular and metabolic diseases. Moreover, regular physical activity may positively influence active memory function among the older adults. The outcome of this study is expected to informed badminton practitioners on the degree of weekly badminton participation and its effects on blood pressure and body composition indices in elderly population.

Purpose of Research
The purpose of this study is to investigate the recreational badminton playing exercise time and its influence on blood pressure and body composition in healthy elderly.

Research Procedure
Participants will be asked to attend the test at 8.00 am in Uitm Seremban 3 laboratory. A series of tests including anthropometric measurement, blood pressure and body composition will be performed. Participants will also require completing several questionnaires which aims to record the subject's badminton participation information and health status.

Participation in Research
Your participation in this research is entirely voluntary. You may refuse to take part in the study or withdraw yourself from participation in the research at any time without penalty.

Benefit of Research
Information obtained from this research will benefit the active individuals, badminton practitioners, researchers, community, and Government of Malaysia for the advancement of knowledge and future practice.

Research Risk
The risk of this study will be minor discomfort during blood pricking.

Confidentiality
Your information will be kept confidential by the investigators and will not be made public unless disclosure is required by law.

APPENDIX 4

Subject Information Form for Study 1 & 2 (Malay version)

REC 4/ 2019/BI Rev 1

Jawatankuasa Etika Penyelidikan
Pusat Pengurusan Penyelidikan
Universiti Teknologi MARA
40450 SHAH ALAM
Tel: +603-5544-8069, Faks: +603-5544-2096/2767

Borang Maklumat Subjek

Tajuk penyelidikan
Pengaruh Permainan Badminton Rekreasi terhadap Tekanan Darah dan Komposisi Badan dalam Warga Emas: Analisis Keratan Rentas dengan Persampelan Berstrata Masa Bermain.

Pengenalan penyelidikan
Penyertaan dalam sukan raket secara rekreasi berpotensi mengurangkan risiko penyakit kardiovaskular dan metabolik. Selain itu, aktiviti fizikal yang kerap dilakukan boleh mempengaruhi fungsi memori secara positif di kalangan orang dewasa pada usia yang lanjut usia. Hasil kajian ini diharapkan dapat memaklumkan kepada pengamal badminton tentang tahap penyertaan badminton mingguan dan kesannya terhadap beberapa petunjuk berkaitan kesihatan dalam populasi warga dewasa yang sudah berumur.

Tujuan penyelidikan
Tujuan kajian ini adalah untuk mengkaji kekerapan masa bermain badminton secara rekreasi dan pengaruhnya terhadap tekanan darah tinggi dan komposisi badan dalam kalangan warga emas yang sihat.

Prosedur penyelidikan
Peserta akan diminta hadir pada jam 8.00 pagi di makmal Uitm Seremban 3. Beberapa siri ujian termasuk, tekanan darah dan komposisi badan akan dilakukan. Peserta juga perlu melengkapkan beberapa soal selidik yang bertujuan untuk merekodkan maklumat penyertaan badminton dan status kesihatan subjek.

Penyertaan dalam penyelidikan
Penyertaan anda di dalam penyelidikan ini adalah secara sukarela. Anda berhak menolak tawaran penyertaan ini atau menarik diri daripada penyelidikan ini pada bila-bila masa tanpa sebarang penalti.

Manfaat penyelidikan
Maklumat yang diperolehi daripada penyelidikan ini akan memberi manfaat kepada individu yang aktif, pengamal badminton, penyelidik, masyarakat, dan Kerajaan Malaysia untuk mengembangkan ilmu dan amalan polisi kesihatan di masa hadapan.

Risiko penyelidikan
Risiko kajian ini akan menyebabkan sedikit ketidakselesaan semasa jari di cucuk ketika proses pengambilan darah.

Kerahsiaan
Maklumat anda akan dirahsiakan oleh penyelidik dan tidak akan didedahkan melainkan jika ia dikehendaki oleh undang-undang.

APPENDIX 5

Subject Information Form for Study 1 & 2 (Malay version)

REC 4/ 2019/BI Rev 1

Jawatankuasa Etika Penyelidikan
Pusat Pengurusan Penyelidikan
Universiti Teknologi MARA
40450 SHAH ALAM
Tel: +603-5544-8069, Faks: +603-5544-2096/2767

Borang Maklumat Subjek

Tajuk penyelidikan
Analisis Keratan Rentas Permainan Badminton Rekreasi dan Pengaruhnya terhadap Kesihatan Kardiometabolik dalam Orang Dewasa Lebih Tua yang Sihat

Pengenalan penyelidikan
Penyertaan dalam sukan raket secara rekreasi berpotensi mengurangkan risiko penyakit kardiovaskular dan metabolik. Selain itu, aktiviti fizikal yang kerap dilakukan boleh mempengaruhi fungsi memori secara positif di kalangan orang dewasa pada usia yang lanjut usia. Hasil kajian ini diharapkan dapat memaklumkan kepada pengamal badminton tentang tahap penyertaan badminton mingguan dan kesannya terhadap beberapa petunjuk berkaitan kesihatan dalam populasi warga dewasa yang sudah berumur.

Tujuan penyelidikan
Tujuan kajian ini adalah untuk mengkaji kekerapan masa bermain badminton secara rekreasi dan pengaruhnya terhadap indeks kardiometabolik dalam warga dewasa lanjut usia yang sihat.

Prosedur penyelidikan
Peserta akan diminta menghadiri ujian pada jam 8.00 pagi di makmal Uitm Seremban 3. Sebelum ujian bermula, para peserta diingatkan supaya berada dalam keadaan berpuasa. Satu siri ujian termasuk pengukuran antropometrik dan pengukuran darah tusukan jari akan dijalankan. Peserta juga perlu melengkapkan beberapa soal selidik yang bertujuan untuk merekodkan maklumat penyertaan badminton dan status kesihatan subjek..

Penyertaan dalar (Ctrl)
Penyertaan anda ... penyelidikan ini adalah secara sukarela. Anda berhak menolak tawaran penyertaan ini atau menarik diri daripada penyelidikan ini pada bila-bila masa tanpa sebarang penalti.

Manfaat penyelidikan
Maklumat yang diperolehi daripada penyelidikan ini akan memberi manfaat kepada individu yang aktif, pengamal badminton, penyelidik, masyarakat, dan Kerajaan Malaysia untuk mengembangkan ilmu dan amalan polisi kesihatan di masa hadapan.

Risiko penyelidikan
Risiko kajian ini akan menyebabkan sedikit ketidakselesaan semasa jari di cucuk ketika proses pengambilan darah.

Kerahsiaan
Maklumat anda akan dirahsiakan oleh penyelidik dan tidak akan didedahkan melainkan jika ia dikehendaki oleh undang-undang.

APPENDIX 6

Participation Consent Form (English version)

REC 4/ 2019/BI Rev. 1

Consent Form

To become a subject in the research, you or your legal guardian are required to sign this Consent Form.

I herewith confirm that I have met the requirement of age and am capable of acting on behalf of myself / *as a legal guardian as follows:

1. I understand the nature and scope of the research being undertaken.
2. I have read and understood all the terms and conditions of my participation in the research.
3. All my questions relating to this research and my participation therein have been answered to my satisfaction.
4. I voluntarily agree to take part in this research, to follow the study procedures and to provide all necessary information to the investigators as requested.
5. I may at any time choose to withdraw from this research without giving any reason.
6. I have received a copy of the Subjects Information Sheet and Consent Form.
7. Except for damages resulting from negligent or malicious conduct of the researcher(s), I hereby release and discharge UiTM and all participating researchers from all liability associated with, arising out of or related to my participation. I agree to hold them harmless from any harm or loss that may be incurred by me due to my participation in the research.

Name of Subject/Legal Guardian	Signature
I.C No	Date
Name of Witness	Signature
I.C No	Date
Name of Consent Taker	Signature
I.C No	Date

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APPENDIX 7

Participation Consent Form (Malay version)

REC 4/ 2019/BM Rev 1

Borang Izin

Untuk menyertai penyelidikan ini, anda atau penjaga sah perlu menandatangani Borang Izin ini.

Saya dengan ini mengesahkan bahawa saya telah memenuhi syarat umur dan berupaya bertindak bagi pihak saya sendiri/ *sebagai penjaga yang sah dalam perkara-perkara berikut:

1. Saya memahami ciri-ciri dan skop penyelidikan ini.
2. Saya telah membaca dan memahami semua syarat penyertaan penyelidikan ini.
3. Saya berpuas hati dengan jawapan pada kemusykilan saya tentang penyelidikan ini.
4. Saya secara sukarela bersetuju menyertai penyelidikan ini dan mengikuti segala atur cara dan memberi maklumat yang diperlukan kepada penyelidik seperti yang dikehendaki.
5. Saya boleh menarik diri daripada penyelidikan ini pada bila-bila masa tanpa memberi sebab.
6. Saya telah pun menerima satu salinan Borang Maklumat Subjek dan Borang Izin.
7. Selain daripada kecederaan yang disebabkan oleh kelalaian dan kecuaian penyelidik, saya dengan ini melepaskan dan menggugurkan UiTM dan semua penyelidik dari semua liabiliti berhubung dengan, wujud dari atau berkaitan dengan penyertaan saya. Saya bersetuju untuk menjadikan mereka tidak bertanggungjawab terhadap apa-apa kemudaratan atau kerugian yang mungkin akan saya tanggung disebabkan oleh penyertaan saya.

Nama Subjek/Penjaga Sah	Tandatangan
No. Kad Pengenalan	Tarikh
Nama Saksi	Tandatangan
No. Kad Pengenalan	Tarikh
Nama Penyelidik/Pengambil Izin	Tandatangan
No. Kad Pengenalan	Tarikh

Page 2 of 5

APPENDIX 8

Subject Information Data Form

UNIVERSITI TEKNOLOGI MARA

Subject Information Form

PERSONAL INFORMATION FORM			
Name			
Phone number			
Age			
Marital status	Single	Married	Divorce
Address			
Weight (kg)			
Height (cm)			
BMI (kg/m^2)			
Type of medication (if any)			
EMERGENCY CONTACT			
Name			
Phone number			
Relationship			

This form contained personal and confidential information. If found, please immediately refers to Syed Muhammad Murshid +0174258370 / linoby@uitm.edu.my

APPENDIX 9

Poster Requirement for Participants

APPENDIX 10

Data Collection Process

APPENDIX 11

Data Collection Process

APPENDIX 12

Data Collection Process

AUTHOR'S PROFILE

Syed Muhammad Murshid obtained Bachelor of Sports Science (Hons.) in 2019 from Universiti Teknologi Mara, Negeri Sembilan. His B.Sc. thesis involves study looking at sleep quality and cognitive function. Throughout the completion of this thesis, he has been working as graduate research assistant under sponsorship of Badminton World Federation (BWF).

LIST OF PUBLICATION:

Syed Murshid Syed Zubir, Adam Linoby, Raja Nurul Jannat Raja Hussain, Siti Aida Lamat, Iqbal Norhamzi, Aqil Zulkhairi, Mohad Anizu Mohd Noor, Hanno Felder (2022). Influence of recreational badminton playing on blood pressure and cognitive function in the elderly: A cross-sectional analysis with playing time-stratified sampling. DOI:10.7752/jpes.2022.09265.

Syed Murshid Syed Zubir, Adam Linoby, Raja Nurul Jannat Raja Hussain, Siti Aida Lamat, Iqbal Norhamzi, Aqil Zulkhairi, Mohad Anizu Mohd Noor, Hanno Felder (2022). A Cross-sectional analysis of recreational badminton playing and its influence on body composition and cardiometabolic health in healthy older adults. DOI:10.7752/jpes.2022.09273.

Syed Murshid Syed Zubir., Adam Linoby, Hussain, Raja Nurul Jannat Raja Hussain, Aqil Zulkhairi, Siti Aida Lamat, Hanno Felder (2021). Retrospective

Comparision of Regular Badminton and Closed-Skills Sports Participation on Cognitive Function in the Elderly: A Preminilary Analysis.

Syed Murshid Syed Zubir, Adam Linoby, Raja Nurul Jannat Raja Hussain, Tengku-Fadilah Tengku-Kamalden (2025). Effect of Single-Session Exercise Modalities on Multidomain Cognitive Functions in Recreationally Active Older Adults. DOI: 10.4719/retos.v66.110457

LIST OF CONFERENCE:

1. iSHE-SC 2021, International Sport, Health and Emerging Technologies Summit Conference (iSHE-SC) Working paper: The Effect of Sleep Quality on Cognitive Function in Ipoh Young Adults.
2. 8th International Conference on Movement, Health and Exercise (MoHE) 2022 Working paper: A Cross-sectional analysis of recreational badminton playing and its influence on body composition and cardiometabolic health in healthy older adults, Influence of recreational badminton playing on blood pressure and cognitive function in the elderly: A cross-sectional analysis with playing time-stratified sampling
3. I-SPESH 2023, 3rd International Seminar Physical Education, Sport and Health 2023. Working paper: Retrospective Comparision of Regular Badminton and Closed-Skills Sports Participation on Cognitive Function in the Elderly: A Preminilary Analysis