A STUDY ON THE EFFECT OF GAME BASE BALANCE TRAINING AND GENDER DIFFERENCE ON ATTENTION AND MEMORY BY EYE TRACKING METHOD

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by

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LIST OF ABBREVIATIONS

ADHD	Attention Deficit Hyperactivity Disorder
BESS	Balance Error Scoring System
BPS	Behavioural Pattern Separation
cTBS	Continuous theta-burst stimulation
CVS	Caloric vestibular stimulation
ETG	Eye tracking glasses
FIBOD	Fitness Balance Board
FVF	Functional Visual Field
GVS	Galvanic vestibular stimulation
LDI	Lure Discrimination Index
MST	Mnemonic Similarity Task
PAR-Q	Physical Activity Readiness Questionnaire
QR	Quick response
RT	Reaction time
SMI	SensoMotoric Instruments
SPSS	Statistical Package for Social Sciences
VRT	Vestibular Rehabilitation Therapy
VST	Visual Search Task

LIST OF APPENDICES

KAJIAN TERHADAP KESAN LATIHAN KESEIMBANGAN BERASASKAN PERMAINAN DAN PERBEZAAN JANTINA TERHADAP PERHATIAN DAN MEMORI DENGAN PENGGUNAAN KAEDAH PENJEJAKAN MATA

ABSTRAK

Latihan keseimbangan berasaskan permainan terbukti berkesan dalam meningkatkan kognisi kerana lebih banyak sumber kognitif dapat diperuntukkan untuk menangani tugas kognitif akibat peningkatan kemampuan keseimbangan. Di samping itu, terdapat perbezaan jantina dalam kemampuan kognitif. Oleh itu, dalam kajian ini, latihan keseimbangan berasaskan permainan dijalankan untuk mengkaji kesannya terhadap peningkatan perhatian visual dan memori kerja dalam kalangan pelajar universiti lelaki dan wanita yang sihat. Tujuan kajian ini adalah untuk mengkaji kesan latihan keseimbangan dan perbezaan jantina terhadap perhatian visual dan memori kerja. Kajian ini adalah kajian intervensi dengan percubaan terkawal secara rawak. Populasi sasaran ialah pelajar dari Universiti Sains Malaysia, Kubang Kerian yang memenuhi kriteria subjek dan lulus ujian saringan. Terdapat tiga ujian saringan iaitu Ujian *Ishihara Color Blindness*, Soal Selidik *Physical Activity Readiness* (PAR-Q) dan Penilaian Prestasi Keseimbangan dari *Fitness Balance Board* (*FIBOD*). Saiz sampel ialah 48 peserta. Kajian ini juga berminat dengan perbezaan jantina dalam kognisi. Oleh itu, lelaki dan wanita yang sama bilangan telah direkrut dan dibahagikan secara rawak kepada kumpulan eksperimen atau kumpulan kawalan. Intervensi telah dilakukan dengan menggunakan *FIBOD* dan Space Shooter. Ujian pra dan pasca merangkumi *Balance Error Scoring System* (*BESS)* untuk mengukur kemampuan keseimbangan; *Visual Search Task* untuk mengukur perhatian; dan *Mnemonic Similarity Task* untuk mengukur memori. Kedua-dua penilaian kognitif telah dijalankan dengan penjejakan mata. Kumpulan kawalan hanya menjalani ujian pra dan pasca dan berjanji tidak melakukan latihan keseimbangan yang lain. Selain ujian pra dan pasca, kumpulan eksperimen juga menjalani intervensi selama satu bulan, dengan tiga sesi (15 minit

per sesi) dalam seminggu. Untuk menganalisis data, *SMI BeGaze* dan Pakej Statistik untuk Sains Sosial telah digunakan. Ujian statistik yang telah digunakan untuk menganalisis data yang dikumpulkan ialah ukuran berulang *ANOVA*. Terdapat dua ukuran hasil dalam setiap ujian kognitif, masa tindak balas dan ketepatan. Untuk perhatian visual, terdapat kesan interaksi yang signifikan dalam masa tindak balas antara kedua-dua kumpulan dari ujian pra hingga pasca, F (1, 46) = 16.80, p < .014, η_p^2 = .268. Bagi ketepatan perhatian visual, terdapat kesan interaksi yang signifikan, F (1, 46) = 20.47, p < .000, η_p^2 = .308. Bagi perbandingan perhatian visual antara jantina, tidak ada perbezaan yang signifikan dalam masa tindak balas, F (1, 46) = 1.64, p = .213, η_p^2 = .069 serta dalam ketepatan, F (1, 46) = 0.11, p = .745, η_p^2 = .005 antara jantina dari uijian pra hingga pasca. Bagi memori kerja, tidak ada kesan interaksi yang signifikan pada masa tindak balas, F (1, 46) = 2.01, p = .163, η_p^2 = .042 dan ketepatan F (1, 46) = 0.06, p = .805, η_p^2 = .001 antara kedua-dua kumpulan dari ujian pra hingga pasca. Bagi perbandingan memori kerja antara jantina, tidak ada perbezaan yang signifikan dalam masa tindak balas, F (1, 46) = 0.81, p = .378, η_p^2 = .035 dan ketepatan F (1, 46) = 2.79, p = .109, η_p^2 = .112 antara jantina dari ujian pra hingga pasca. Latihan keseimbangan asas permainan yang digunakan dalam kajian ini dapat meningkatkan prestasi kognitif dalam kalangan pelajar universiti yang sihat. Kumpulan eksperimen menunjukkan peningkatan prestasi dalam perhatian visual dan memori kerja antara ujian pra hingga pasca. Namun, kumpulan eksperimen hanya berprestasi lebih baik daripada kumpulan kawalan dalam perhatian visual tetapi bukan dalam memori kerja. Tambahan pula, tiada perbezaan jantina yang signifikan dalam perhatian visual dan persembahan memori kerja.

A STUDY ON THE EFFECT OF GAME BASE BALANCE TRAINING AND GENDER DIFFERENCE ON ATTENTION AND MEMORY BY EYE TRACKING METHOD

ABSTRACT

Game base balance training was shown to be effective in improving cognition as more cognitive resources can be allocated to deal with cognitive tasks due to improve balance ability. In addition, there is gender difference in cognitive performances. Thus, in this study, game base balance training was conducted to examine its effect on improving visual attention and working memory among healthy male and female university students. The aim of this study is to investigate the effect of balance training and gender difference on visual attention and working memory performances. This study is an interventional study with randomized controlled trial. The target population is students from University Sains Malaysia, Kubang Kerian who fulfil the subject criteria and pass the screening tests. There were three screening tests which were the Ishihara Color Blindness Test, Physical Activity Readiness Questionnaire (PAR-Q) and Balance Performance Assessment from Fitness Balance Board (FIBOD). The sample size is 48 participants. As this study is also interested in gender differences in cognition, an equal number of male and female was recruited and randomly assigned to either the experimental or control group. The intervention was carried out using FIBOD with Space Shooter. Pre and post-tests included Balance Error Scoring System (BESS) to measure balance ability; Visual Search Task to measure attention; and Mnemonic Similarity Task to measure memory. The two cognitive assessments were conducted with eye tracking. The control group only underwent the pre and post assessments and was refrained from doing other balance training. Other than the pre and post assessments, the experimental group also underwent the intervention for one month, with three 15-minutes sessions in a week. To analyse the data, SMI

BeGaze and Statistical Package for Social Sciences were used. The statistical test used to analyse the collected data was Repeated Measures ANOVA. There were two outcome measures in each cognitive tests, response time and accuracy. For visual attention, there was a significant interaction effect in response time between the two groups from pre to post assessment, F (1, 46) = 16.80, $p < .014$, $\eta_p^2 = .268$. As for the accuracy in visual attention, there was a significant interaction effect, F (1, 46) = 20.47, $p < .000$, $\eta_p^2 = .308$. To compare visual attention between gender, there were no significant difference in response time F (1, 46) = 1.64, $p = .213$, $\eta_p^2 = .069$ as well as in accuracy F (1, 46) = 0.11, $p = .745$, $\eta_p^2 = .005$ between gender from pre to post assessments. For working memory, there is no significant interaction effect in response time F (1, 46) = 2.01, $p = .163$, $\eta_p^2 = .042$ and accuracy F (1, 46) = 0.06, $p = .805$, $\eta_p^2 = .001$ between the two groups from pre to post assessments. To compare working memory between gender, there were no significant difference in response time F (1, 46) = 0.81, $p = .378$, $\eta_p^2 = .035$ as well as in accuracy F (1, 46) = 2.79, $p = .109$, $\eta_p^2 = .112$ between gender from pre to post assessments. Game base balance training used in this study was able to improve cognitive performances among healthy university students. The experimental group showed improved performance in visual attention and working memory between pre and post assessments. Yet, the experimental group only performed better than the control group in the visual attention task but in not the working memory task. No significant gender differences were found in both visual attention and working memory performances after the intervention.

CHAPTER ONE

INTRODUCTION

1.1 Introduction

This chapter provides a brief background introduction to this study that begins with the relationship between physical activities and cognitive functions. The introduction is then focused on the research tools that were used in this study. They included Fitness Balance Board with Space Shooter which is a video game, eye tracking, and two cognitive assessments which are Visual Search Task and Mnemonic Similarity Task. It then continues with the problem statement and study rationale. Finally, the research questions, objectives and hypotheses of this study are introduced.

1.2 Background of study

Physical activities are known to benefit us in many different ways, including physical fitness, emotional well-being, and cognitive performances (Zeng et al., 2017; Mandolesi et al., 2018). There is a wide range of physical activities, ranging from physically demanding cardiovascular or cardiorespiratory fitness to motor fitness that requires balance, fine coordination, and movement planning. Physical activity, regardless of types, intensity, and duration, provides positive effects on various systems in our body, including motor, cardiovascular, cardiorespiratory, and immunology (Bidzan-Bluma and Lipowska, 2018).

When looking into the relationship between physical activity and cognitive function, it is common to think that physical activity improved cognitive function by increasing the blood flow or vascularization to the brain, thus increasing the amount of oxygen and nutrients reaching the brain. Besides, physical activity can induce structural and functional changes in our brain to improve our functioning (Mandolesi et al., 2018). This is possible through the experience-dependant plasticity of our brain, by having the positive influences provided by physical activities (Singh et al., 2019).

Many past researches have intended to study the relationship between physical activities with cognitive functions (Rogge *et al.*, 2017; Stanmore *et al.*, 2017a; Huang, 2020). However, it is important to note that both of these terms are very broad constructs to measure. Hence, in this study, the measurement of physical activity has been specified to balance ability while the measurement of cognitive functions is focusing on two constructs, attention, and memory.

Past studies on balance and cognitive performances have been focusing on older people (Goto et al., 2018), especially people with cognitive impairment, such as patients with Alzheimer's disease. This is because balance and cognitive impairments are the common symptoms among them (Tangen et al., 2014; Bahureksa et al., 2016). These impairments increased their fall risks and decreased their quality of life (Fernando et al., 2017; Zhang et al., 2019). Thus, these past studies have intended to improve their balance ability through balance training, and at the same time, improve their cognitive functions (Cui et al., 2018; Lam et al., 2018).

In this study, instead of older people with Alzheimer's disease, the participants were university students. In examining the benefits of physical activities among students, the improvement in their cognitive functions is important because it will have an effect on their academic achievement (McPherson et al., 2018; Singh et al., 2019). The effect of physical activity has shown to enhance the learning and recalling process of students by activating the sensorimotor regions of their brain (Kontra et al., 2015). Other past studies have also shown that vigorous physical activity in school is able to improve memory, attention as well as the academic performance of students (McPherson et al., 2018; Phan et al., 2018). Therefore, it is crucial to deepen and specify our understanding of the effect of physical activities for the sake of students' cognitive functions improvement.

This study aims to identify the effect of balance training on the attentional and memory performances of students. In the present study, the balance ability of the participants is measured and trained by using a balance board called Fitness Balance Board (FIBOD). To complement the lack of biofeedback and objective measurement of the other balance boards, FIBOD provides training as well as measurements on fall risk, ankle injury risk, sway velocity, overall stability index, medial-lateral stability index, and anterior-posterior stability index (*Techcare - Fibod*, 2020). This makes FIBOD to be more than just a balance training device to the participants.

One problem with balance training is the individual's motivation to persist with it. Balance training with repetitive movements alone may be too boring and discourages them from continuing. FIBOD overcomes this problem by incorporated video games into balance training. In this way, the training involves requires the participants to train their balance ability in a cognitively challenging environment. It adds attractiveness and interactive elements into the training. The scores in the game can be a source of extrinsic motivation for the participants to continue with the training (Subramanian et al., 2020). Comparative studies revealed that the combination of motor and cognitive demands during physical training can result in greater enhancement in cognitive performances than motor training alone (Ordnung et al., 2017).

There are six training elements in FIBOD. They are center, vertical, horizontal, static, dynamic, and rotation Each game involves different elements of balance training. In this study, the game that was used is Space Shooter. Space Shooter required the participants to move in left, right, front, and back direction to move the board, which is the spaceship in the game to avoid enemy and travel as far as possible. The participants also need to maintain balance on the center of the board when they are getting rewards in the game. The training elements involved are center (maintain the board in a central position), horizontal (moving left and right), vertical (moving front and back), and dynamic (a combination of horizontal and vertical).

Other than having the FIBOD balance board to measure and improve the balance ability of participants in this study, eye tracking was also used alongside with the attentional and memory task at pre-test and post-test. Visual Search Task (VST) and Mnemonic Similarity Task (MST) were used to assess participant's visual attention and working memory performance respectively.

Visual search is a process that occurs in our daily life. In the process of visual search, objects that enter our visual field compete for our attention. Thus, VST is a useful way to study the distribution of visual attention (Madrid and Hout, 2019). Using eye tracking with VST could provide more data about our eye movement than just the response time on our attention performance (Krasich, Biggs and Brockmole, 2019). Other than directing attention to a targeted stimulus, daily activities also require us to recognize and differentiate between peoples, objects, or places. This involved our memory performance at encoding and retrieval phases (Stark and

Stark, 2017). To investigate the participant's memory performance more thoroughly, eye tracking was used during MST to complement the results from MST with eye data.

1.3 Problem statement

Being physically active can increase the cortical thickness of the brain regions associated with learning, such as the hippocampus and basal ganglia (Chaddock-Heyman et al., 2015). In addition to changes in gray matter volume, physical activity also resulted in an increased volume of the corpus callosum, which made up of white matter. Corpus callosum integrates information between the left and right hemispheres. The change in corpus callosum may enhance the cognition and behaviors of an individual (Chaddock-Heyman et al., 2018).

Even though the role and importance of physical activities are known to many people, the younger generation becomes more sedentary when compared to previous generations with the emerging of technologies (Quan, Pope and Gao, 2018; Gao and Lee, 2019). This is the outcome of technology advancement. The current young generation is obsessed with electronic devices such as mobile phone and home video game console. They use these electronic devices to connect with other people as well as for entertainment purpose. Hence, to follow the current trend, physical activities could be conducted using electronic devices and incorporating video games. This is known as exergaming, by combining physical activity and cognitively demanding tasks to offer improvement in cognitive functioning (Huang, 2020). The intervention used in this study is a type of exergame. It is a game base balance training, which required the participants to play a game using FIBOD balance board.

In addition, even though exergame or game base balance training have been proved to be effective to improve cognitions, there are many different types of exergame or game base balance training available (Stanmore *et al.*, 2017a; Piech and Czernicki, 2021). The most common types of exergame used in the past literatures are Nintendo Wii and Xbox Kinect (Pacheco *et al.*, 2020; Yang *et al.*, 2020). In the search of past literature, the application of FIBOD balance board in research was scarce (Khor *et al.*, 2018). Thus, it is unclear whether the game base balance training used in this study is as effective as those used in the past studies.

The effect of balance training on attention and memory is crucial to people of different age groups and different health conditions. Past studies in this area have been focusing on individuals with ADHD and older adults (Bledsoe, Semrud-Clikeman and Pliszka, 2011; Ren et al., 2014; Goetz et al., 2017; (Rogge *et al.*, 2017; Dunsky, 2019). However, the past study on healthy young adults is scarce. Thus, this present study can play a role to fill in the research gap. This study is important to this field of research by addressing the role of balance on the two cognitive constructs, attention, and memory among healthy young adults by using FIBOD balance board. This could provide an in-depth understanding of whether balance, as an element of physical activity, can improve attention and memory among normal population instead of clinical and aged populations.

1.4 Study rationale

Exergame requires the player to be physically active when they are playing the video game (Stanmore *et al.*, 2017b). To encourage people to be active, exergame has benefits over traditional training, which is repetitive in nature that tend to demotivate people to adhere. On the other hand, exergame will increase people's motivation and thus adherence to engage with the exercises as it is fun. In addition, exergame also can involve social interaction. The players can play with or against their peers. Peer participation will enhance their enjoyment, motivation, and interest to participate in the exergame (Staiano, Abraham and Calvert, 2012). Moreover, exergame is also able to provide dual-task as it comprised motor training and cognitive training simultaneously (Eggenberger et al., 2016; Willaert et al., 2020). In this study, FIBOD balance board allows the participants to train for balance. The game conditions also involve the participants' cognition to plan for suitable movement. Thus, other than keeping the player physically active, exergaming also has cognitive benefits (Predovan et al., 2019).

There are two main underlying mechanisms of exergaming on cognitive functions. The first mechanism is that exergames tend to increase our attentional span by increasing physiological arousal and motor control skills (Huang, 2020). This is because physical exercises involve many different movements such as moving limbs, jumping, and squatting. They also increase the arousal of our physiological responses such as increased heartbeat and blood pressure. The second mechanism is that exergame also involves mental exercises. The player needs to watch and memorize the movements of the exercise. This involves the higher-order cognition to remember and manipulate with the remembered information (Huang, 2020).

All these components of exergame can ensure that it is a promising and sustainable physical activity that will keep people to be motivated to participate consistently and frequently. This is essential to promote physical and cognitive benefits to people through their engagement with the exergame. In short, the finding of this study is important for people to improve their cognitive function after playing exergame.

Investigating the relationship between balance and cognition is crucial to people of different groups. People with Attention Deficit Hyperactivity Disorder (ADHD) exhibit the symptoms of deficits in attention and hyperactivity. They are also known to have problems with their motor functions (Bledsoe, Semrud-Clikeman and Pliszka, 2011; Ren et al., 2014; Goetz et al., 2017). Most children with ADHD are also found to have poor balance ability

(Lotfi et al., 2017). The findings of this study could be essential to the rehabilitation professionals to design and plan rehabilitation programs or treatment for them to modify the behavioral problems of individuals with ADHD.

Physical and cognitive functions undergo deterioration in the process of aging. Older adults show poorer performance on balance, attention, and memory as compared to the younger people (Rogge et al., 2017; Dunsky, 2019). Past studies have shown that different types physical training has the potential to induce structural and functional brain plasticity in older adults. Recently, trainings that consist of cognitive and physical aspects simultaneously were also shown to improve motor functions and cognitive performances in older adults (Eggenberger et al., 2016). An example of such training is video game training.

While classical video games being played sedentarily, video games that requires movement, also known as exergames required the performance of physical activities while being simultaneously surrounded by a cognitively challenging environment. It has been shown that exergaming for instance can promote executive functions and cognitive processing speed in older adults (Schoene et al., 2013; Ordnung et al., 2017**.** Also, providing game-based balance training may increase older adult’s adherence to the training regime as they will be motivated by the perceived health effect from the training (Meekes and Stanmore, 2017; Subramanian et al., 2020).

Besides, this study could also benefit students. A longitudinal study on 1,400 children from the age of six to their teens was done. The results showed that participants who are physically less active as a child have significantly poorer performance on memory tests as an adolescent later. This implied the significance of the studies on physical activity and cognitive performance. Moreover, the result also indicated that being physically active in the developing years would provide cognitive benefits in the long-term run (López-Vicente et al., 2017).

However, there is a wide range of physical activities available. This study points to a specific element in physical activity, which is balance. The role of balance, as one of the components of physical activity, in enhancing attention and memory can provide guidelines to educators in planning and structuring learning syllables for students. An appropriate amount of physical education should be incorporated into academic learning so that the learning processes of students can be enhanced (Doherty and Forés Miravalles, 2019). Hence, in planning to include physical education into the syllables, educators can focus on physical activities that emphasize on balance instead of cardiovascular fitness activities that may not focus on students' balance ability.

1.5 Research questions

1.5.1 What is the effect of FIBOD balance training on visual attention performance?

1.5.2 Is there any gender difference in visual attention performance after the game-based balance training?

1.5.3 What is the effect of FIBOD balance training on working memory performance?

1.5.4 Is there any gender difference in working memory performance after the game-based balance training?

1.6 Research objectives

1.6.1 General:

To study the effect of game-based balance training and gender difference on visual attention and working memory performances

1.6.2 Specific:

1.6.2.1 To determine the effect of FIBOD balance training via Space Shooter on improving visual attention.

1.6.2.2 To identify the gender differences in visual attention after FIBOD balance training via Space Shooter.

1.6.2.3 To determine the effect of FIBOD balance training via Space Shooter on improving working memory.

1.6.2.4 To identify the gender difference in working memory after FIBOD balance training via Space Shooter.

1.7 Research hypotheses

1.7.1

$H1_0$: There is no difference in visual attention between the experimental group and the control group.

H1a: The experimental group shows greater improvement in visual attention than the control group.

1.7.2

$H2_0$: There is no gender difference in visual attention of students after FIBOD training.

H2a: There is a gender difference in the visual attention of students after FIBOD training.

1.7.3

$H3_0$: There is no difference in working memory between the experimental group than the control group.

H3a: The experimental group shows greater improvement in working memory than the control group.

1.7.4

$H4_0$: There is no gender difference in working memory of the students after FIBOD training.

H4a: There is a gender difference in the working memory of students after FIBOD training.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the relevant past studies by the other researchers focusing on balance and two cognitive aspects, attention, and memory. It starts with a brief introduction to the mechanism of balance, which is the vestibular system. Then, it is followed by the literatures about the relationship between balance and attention as well as memory. Furthermore, eye tracking is the method that was used in this study to provide complementary data for the cognitive tasks. Hence, the review of literature also consists of the studies that includes the use of eye tracking in studying attentional and memory performances. In addition, this chapter also provides the conceptual framework of this study to explain the relationship between balance and cognition discussed in this study.

2.2 Balance

Balance is the ability to maintain the condition of equilibrium in the body. This ability to stabilize the body to maintain posture with quiet standing while relying on integrating information from the eyes in the visual system, inner ears in the vestibular system, and other senses in the proprioceptive system (Estevan et al., 2018; Fusch, Fusch and Ness, 2018). Of these systems, the proprioceptive system has an important role in balance, postural and motor control. Proprioception is a conscious capacity to sense position, movement and force of body segments (Jo et al., 2016). Impaired proprioceptive system will affect the ability to balance and thus increase the risk of injury (Alloway and Alloway, 2015).

Balance can be applied to a static condition while standing on a base of support (BoS) with minimum movement, and also to a dynamic situation while maintaining a stable posture and performing some other tasks (Yoo et al., 2018).

To maintain balance, our brain receives input from various organs, coordinates the inputs, and adjusts our posture or position. These inputs include the inner ear in the vestibular system, eyes in the visual system, and other senses in the proprioceptor system (Fuchs, 2018). The vestibular system is the starting point to maintain our balance. It is in our inner ear. There are five organs in the system that contribute from different aspects to maintain our balance. They are sacculus, utricle, and three semi-circular canals (Figure 2.1). They are also known as the vestibular labyrinth. The sacculus and the utricle detect gravity and linear acceleration (Agrup, Gleeson and Rudge, 2007). The three semi-circular canals detect rotation or turning of the head. The three canals allow the brain to detect angular acceleration or deceleration in three dimensions when the brain processes inputs from all three canals. Information from the vestibular labyrinth is sent to the cerebellum to coordinate movements in order to maintain postural balance (Balmer and Trussell, 2019).

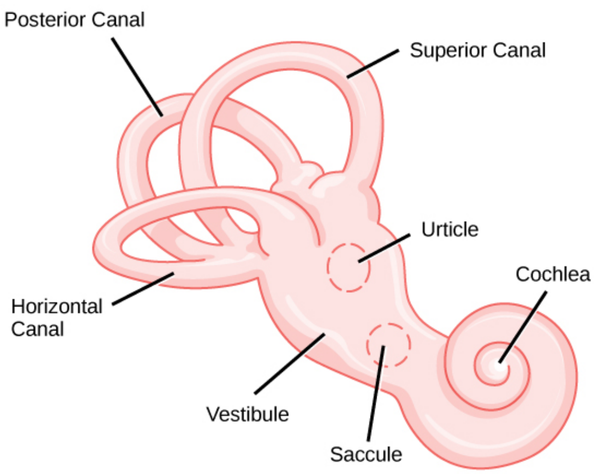

Figure 2.1 Five Organs in the Vestibular System (*Vestibular Information | Biology for Majors II*, no date).

2.3 Balance and cognition

Past studies have shown that physical activities, regardless of the types of activity, are able to improve cognitive functions (Chaddock-Heyman *et al.*, 2018; Doherty and Forés Miravalles, 2019; Chen, Hung and Chang, 2020). However, it is important to know whether balance, as a component of motor fitness, is able to contribute to cognitive function improvement, as compared to cardiovascular fitness. This is to ensure that the beneficial effects of physical activity on cognitive functions could be extended to people who have limited mobility such as older adults.

One study using balance training has done to exclude the effect of cardiorespiratory fitness on cognitive functions (Rogge et al., 2017). The study divided the participants into two groups. The first group underwent balance training while the second group underwent relaxation training. The results showed that neither of the groups showed changes in cardiorespiratory fitness. On the other hand, the balance group showed improvement in dynamic balance performance. Concerning cognitive performance, only the balance group showed improvement in memory and spatial functions (Rogge et al., 2017). Hence, among the different components of physical activities, balance training is able to affect cognitive performance while cardiorespiratory fitness may not be necessary for enhancing cognitive performance.

In addition, the relationship between physical activity and cognitive performance is thought to be mediated by emotional well-being. Neurotransmitters such as dopamine, serotonin, and norepinephrine are being released during physical activities. These neurotransmitters play a role in motivation, positive moods, and enhanced attention (Doherty and Forés Miravalles, 2019). Thus, emotional well-being as a product from physical activity improves learning processes by reducing stress and negative emotions.

In the same study mentioned above, Rogge et al. have also successfully controlled the effect of reduced stress, as a by-product of physical activity, on cognitive performance (Rogge et al., 2017). A self-report questionnaire was administered to assess the level of psychological strains before and after physical training. As a result, the balance and relaxation groups did not differ in the score pre and post-training. The result showed that the effect of reduced stress from physical training is unlikely to contribute to the improved cognitive performance in the balance group.

However, balance undergoes deterioration in the process of aging with the decline in functions of the systems involved in balance (Dunsky, Zeev and Netz, 2017; Saftari and Kwon, 2018). In a mini review, past studies examining the effect of balance and coordination exercises on different aspects of the quality of life among the elderly were gathered to provide suggestions for future practical application. The quality of life of the elderly is assessed through reduced falling risk and improved cognitive functions including attention, memory, and spatial functions (Dunsky, 2019).

Balance trainings are different in types and durations in different studies. Some studies use a virtual reality training program to train the balance of older adults (Rendon et al., 2012; de Vries et al., 2018). The results showed that virtual reality training is as effective as biofeedback training in improving balance. Despite the differences, all the balance training showed improvements in older adults' postural control (Halvarsson, Dohrn and Ståhle, 2015). In addition to that, the improved sense of balance also contributed to improvement in cognitive functions (Netz, Zeev and Dunsky, 2018).

The relationship between physical exercise and cognitive function is mediated by the stimulated vestibular system from balance training. The stimulation has led to connections between vestibular nuclei and cerebellum, hippocampus, prefrontal, and parietal cortices in the brain, which are the brain areas involved in spatial functions and memory (Smith and Zheng, 2013). In other words, the stimulation of the vestibular system from balance training has improved the spatial functions and memory.

Balance training also found to improve cortical thickness in the brain regions responsible for spatial orienting and memory, such as superior temporal cortex, posterior cingulate cortex, and superior frontal sulcus. The changes in cortical thickness in the specific brain regions stimulate the visual-vestibular pathways that act as a mediator between the relationship of balance training and cognitive functions (Rogge et al., 2017). As a result, the mini review has come to a conclusion to support the effect of balance and coordination exercise on cognitive function, which could be one of the factors that determine the quality of life (Dunsky, 2019).

In addition, a study that involved proprioceptively demanding training found an improvement in working memory. One possible reason was that the training involved attention to body position and physical exertion. This may activate the prefrontal cortex, which is the brain part responsible for working memory. One past study found that participants who ran on the treadmill showed increased haemoglobin levels in the prefrontal cortex as compared to those who walked on the treadmill. The proprioceptive nature of gait and speed changes could be the possible explanation of prefrontal cortex activation. Thus, the brain part responsible for cognitive function can be activated due to the input from balance training (Alloway and Alloway, 2015).

In conclusion, balance training alone is able to show improvement in the cognitive functions after controlling for the other potential confounding variables such as cardiorespiratory improvement and emotional well-being (Rogge et al., 2017). Deterioration in balance due to aging can be improved by various types of balance training in older adults. Other than improving postural control and stability, balance training is also able to improve cognitive functions in older adults (Dunsky, 2019). Balance training stimulated the vestibular system which is connected to brain regions associated with spatial functions and memory (Smith and Zheng, 2013). Moreover, balance training also results in cortical thickness in brain regions involved in the spatial function and memory (Rogge et al., 2017).

2.4 Dual-task balance training and cognition

Balance is one of the aspects of motor coordination. It also plays an important role in physical activities or exercise. It involves a few systems working together, including the vestibular system, visual system, and somatosensory system (Rasman et al., 2018). Balance is important to maintain posture and facilitate movement.

Other than the integration of information from the visual, vestibular and proprioceptive systems, balance regulation also involves cognitive functions, such as attention and memory (Estevan et al., 2018). Balance and cognitive functions can potentially influence each other. The relationship between balance and cognitive function often requires individuals to perform on dual task, which is performing two tasks simultaneously.

Combining physical and cognitive training is known as dual-task training. Example of dual-task training is walking while counting backwards. When both cognitive and balance tasks were performed simultaneously, the performance of the individuals in the balance task was found to be deteriorated. This is known as the cost of dual-task or cognitive-motor interference (Estevan et al., 2018; Chen, Hung and Chang, 2020). Generally, simultaneous demands were thought to result in dual-task cost. However, a review has shown that dual-task training is found to offer greater benefits than sequential training of cognitive and motor training. Dual-task training was found to significantly improved cognition in healthy older and clinical populations (Tait et al., 2017).

It can be explained by the different perspectives of three models. The first model is known as the cross-domain competition model, whereby attentional resources experience competition between posture control and cognitive activity. The second model is the U-shaped interaction model that stated that physical performances can be improved or deteriorated depending on the difficulty of the secondary task. The third model is the task prioritization competition model that predicted that older adults tend to prioritize balance to cognitive performances under dual task condition (Villafaina et al., 2018).

In addition, there is one theoretical perspective to aid in the explanation of the relationship between balance and cognitive functions. According to Kahneman's Capacity Model of Attention, we have a set amount of cognitive resources ready to be distributed to a given task (Bruya and Tang, 2018). When the vestibular system is impaired, extra cognitive resources are required to maintain balance. Thus, attention, as a type of cognitive resources will be reduced from a given task. Attentional performances tend to reduce in circumstances whereby balance is being challenged. Our brain intends to prioritize cognitive resources to maintain balance at the same time when other tasks are requiring attentional resources (Bigelow and Agrawal, 2015).

With regards to dual-task training, the intervention to be used in this study is also in dual-task training. The balance training required the participants to maintain their balance on the balance board (motor aspect) while simultaneously involve in a cognitively challenging virtual environment. Thus, as compared to single task setting, our intervention is expected to offer greater benefits on the cognitive aspect of the participants. An example of dual-task setting training is exergame intervention. It combined exercise (physical training) and gaming (cognitive training). Exergame is an interactive video game that required the participants to produce physical movement in response to the visual cues presented in the virtual game environment (Stanmore *et al.*, 2017b).

2.5 Balance and attention

Past studies that assessed the relationship between balance and attention have focused on individuals with attention deficit hyperactivity disorder (ADHD) (Goetz *et al.*, 2017; Lotfi *et al.*, 2017; Haghgoo, 2018). ADHD is a neurodevelopmental disorder characterized by inattention, hyperactivity impulsive, and restless that frequently resulted in failure in academic achievement. Past studies on individuals with ADHD have shown that they are also experiencing deficits in balance (Hove *et al.*, 2015; Lotfi *et al.*, 2017; Haghgoo, 2018). The balance ability of children with ADHD has been assessed in terms of static and dynamic balance. They performed poorer in dynamic balance tasks. As mentioned earlier, balance ability is the coordination between visual, vestibular, proprioceptive, and neuromuscular systems (Fuchs, 2018). The poor dynamic balance of them is found to be related to the poorer visual and vestibular information processing (Ren et al., 2014). In terms of brain structure, ADHD children are found to have abnormal volume in the cerebellar vermis. Other than balance, the cerebellum also plays a role in attention regulation (Bledsoe, Semrud-Clikeman and Pliszka, 2011).

One study on children in ADHD was based upon the previous findings that 47% to 69% of the ADHD children who have difficulty in sustained attention and working memory also showed problems in their fine and gross motor skills (Fliers et al., 2008). Furthermore, 30% to 50% of them also experienced problems with balance and motor coordination. Children with ADHD also found to suffer from vestibular dysfunction which adds to the explanation of their poor motor skills and coordination (Lotfi et al., 2017). Hence, Vestibular Rehabilitation Therapy (VRT) was introduced as a vestibular stimulation program to children with ADHD aiming to improve their motor and cognitive functions.

VRT was developed, approved, and conducted by rehabilitation professionals to stimulate the five organs in the vestibular system. The training in VRT includes exercises on motor skills, head movement, static balance, and dynamic balance. The results showed that VRT significantly improved the gross motor skills, balance, and visual-motor coordination of the children with ADHD as compared to the control group. In relation to cognitive function especially on attention, it is found that vestibular stimulation modulates the level of consciousness and affects a child's attention to the stimuli in the environment (Haghgoo, 2018).

This was supported by another study that used VRT on children with ADHD. After VRT, there was a significant improvement in the accuracy responses but prolonged latency in responses of children with ADHD. The explanation given was that there was a decrease in their impulsivity after the intervention. Reduced impulsivity led them to have more attentional resources to be allocated to the cognitive tasks (Lotfi et al., 2017). Hence, they responded with fewer errors but used up more time in the tasks. Thus, it is suggested that behavioral therapy to modify the behaviors of children with ADHD should incorporate VRT that based on neurological conditions to efficiently address their behavioral problems (Haghgoo, 2018).

Moreover, cognitive training program can be used complementary with VRT to result in better improvement in cognitive performances (Lotfi et al., 2017).

One other study was done to assess the relationship between balance and attention among typically developing children (Abuin-Porras et al., 2018). Unlike the two studies mentioned above, the exclusion criteria of the participants for this study are the diagnosis of ADHD and psychological or serious medical condition including balance impairment. Participants involved are children aged four and five. There were 44 boys and 41 girls. Gender difference in the relationship between balance and attention was also studied. Each of the children underwent two test conditions: respond to the attention test on a seated condition and a balance board. As a result, it showed a significant relationship between balance and visual attention. There was a decrease in attention test performance when there was a demand to maintain balance. This result further supported the idea that our brain tends to prioritize balance when there is another task to compete for our attentional resources (Bigelow and Agrawal, 2015). Thus, improved in balance ability could increase the distribution of attentional resources to the other tasks. In terms of gender difference, girls performed better than boys in the seated condition; boys showed improved performance while girls showed worsen performance in the condition that demands balance.

Another study investigated the transfer effect of video game balance training onto cognition. The transfer effect of training is defined as the occurrence of transferring improved performance in a specific function to a different domain of untrained function. Past studies have provided evidence to support the transfer effects of video game training and its ability to result in broad-based improvements in cognition (Laganà, 2018; Choi et al., 2020).

The balance training in the study was a 12-week home-based training using Wii balance board system (WBBS). In recent years, video game-based rehabilitation training was found to be effective in enhancing cognitive functions, for example, working memory and attention. Furthermore, video game-based training is advantageous as it is low-cost, fun, and motivating for patients to adhere to the training. These factors are able to increase patients' openness to the training as it combined physical activity and cognitively demanding task (Prosperini et al., 2015; Huang, 2020).

The primary outcome of the training was to improve static and dynamic balance, walking speed and quality of life of patients with multiple sclerosis. To examine the transfer effect of the training, the study also investigated the ability of sustained attention and speed of information processing using paced auditory serial addition test (PASAT). The findings showed that the training resulted in improvement in speed of information processing and sustained attention. The study hypothesised that video game-based training involved a complex training environment that may promote relearning capacity that will stimulate the plasticity of the brain networks that are responsible for motor and cognitive functions (Prosperini et al., 2015).

Other than people with ADHD and healthy adults, one study involved stroke patients where they experienced damage to the postural control mechanism and resulting them to lose the ability to maintain stable posture (Kim, Kim and Lee, 2016). Moreover, due to the damage to the postural control mechanism, they maintain postural stability consciously instead of unconsciously and automatically. Their postural stability is dependent on cerebrum which control attention. A study contributed to the relationship between balance and attention by taking into considerations both visual restriction and base conditions. 30 stroke patients in the study were divided into two groups. The first group is visual restriction and unstable base dual-task training (VUDT) and the second group is stable-base dual-task training (SDT). The VUDT group conducted two types of training, which are (1) standing on a stable surface with their eye closed to remove visual information and maintain their posture balance while performing recognition tasks, and (2) maintain balance on an unstable surface while conducting recognition tasks. The SDT group conducted two sets of training where they maintain posture balance on a stable surface and perform the same recognition tasks. The recognition tasks included speaking random numbers, remember objects and talking.

As a result, the VUDT group showed decreased in center of pressure moving distance which corresponded to decreased postural sway and increased stability. They also showed improvement in their balance ability and ability to perform daily life activities. In addition, the trail-making test and the Stroop test were administered to identify the visual attention performance of the participants. The tests results showed that the VUDT group showed a greater improvement as compared to the SDT group. This was because the VUDT group involved various balance conditions and divided attention for the patients with stroke who lost attention (Kim, Kim and Lee, 2016). Furthermore, visual restriction in the VUDT group also placed more challenges to stimulate the vestibular system of the patients to maintain balance as the visual system is being restricted in maintaining balance. Visual restriction enhances the awareness of body position images due to the reinforcement neural association that emerge from participation of cortical structure included in the locomotion imagination, foot positioning and dynamic postural control (El Shemy, 2018).

In a nutshell, the relationship between balance and attention has been focused on individuals with ADHD. They are found to have balance impairment at the same time as their attention deficits. Administration of balance training does not only improve their balance ability but also plays a role to improve their attention by regulating their core symptoms in

ADHD. In addition, when balance and attention are competing for our resources, our brain tends to prioritize the resources to maintain balance. Hence, an improvement in balance can result in more resources for attention, thus, improve attentional performance. This is supported by another study done among stroke patients. The study found that when there are challenging demands on the vestibular system, the awareness of body position will be enhanced. Again, more resources could be assigned to our cognitive processes. Another possible reason for the relationship between improved balance ability and improved attention comes from the transfer effect of video game training.

2.6 Balance and working memory

Balance occurs when the center of mass or gravity is in alignment with the base of support. There are two main types of balance, static balance, and dynamic balance. Static balance is the ability to maintain a fixed posture with the center of mass over the base of support. The balance is maintained when the body is at rest. Dynamic balance is the ability to maintain postural stability with adjustment to the center of mass over the base support. The balance is maintained when the body is in motion. It is more challenging than the static balance. Another type of balance is functional balance, it is the integration of the two mentioned balance (Wykle, 2013).

There are a few types of memory as shown in Figure 2.2. The three main types of memory are sensory memory, short-term memory and long-term memory. Working memory will be focused on in this study. It is the ability to maintain and manipulate information (Tang *et al.*, 2019). It is known as the sketchpad for temporary recall of information that is being processed. The information is readily available for a period of 10 to 15 seconds (Zhang, 2019).