EFFECT OF SMART BALANCE EXERGAME ON ATTENTION AND INHIBITORY CONTROL IN HEALTHY YOUNG ADULTS USING EYE-TRACKING METHOD

LEE JA NICE

UNIVERSITI SAINS MALAYSIA

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by

LEE JA NICE

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LIST OF SYMBOLS

cm	Centimeter
F	F-statistics
f	Effect size
ms	Millisecond
p	P-value
r	Correlation coefficient
t	T-statistics/ T-value
W	W-statistics
n^2	Partial Eta Squared

LIST OF ABBREVIATIONS

ADHD	Attention Deficit Hyperactivity Disorder
AOI	Area of Interest
ASD	Autism Spectrum Disorder
AST	Antisaccade Task
BDNF	Brain-Derived Neurotrophic Factor
BESS	Balance Error Scoring System
BMI	Body Mass Index
FIBOD	Smart Fitness Balance Board
fMRI	Functional Magnetic Resonance Imaging
ICC	Interclass Correlation Coefficient
MUET	Malaysia University English Test
NHMS	National Health and Morbidity Survey
PAR-Q	Physical Activity Readiness Questionnaire
SEBT	Star Excursion Balance Test
SD	Standard Deviation
USM	Universiti Sains Malaysia
VST	Visual Search Task
YBT	Y Balance Test

LIST OF APPENDICES

KESAN EXERGAME PINTAR BERDASARKAN LATIHAN IMBANGAN TERHADAP PERHATIAN DAN KAWALAN PERENCATAN DI KALANGAN DEWASA MUDA DENGAN MENGGUNAKAN KAEDAH PENJEJAKAN MATA

ABSTRAK

Pengenalan: Kebergantungan masyarakat moden kini terhadap pegunaan teknologi telah menyumbang kepada gaya hidup yang tidak memerlukan banyak pergerakandan ini sacra tidak langsung merosotkan keupayaan motor dan keupayaan kognitif. Langkah pencegahan yang efektif perlu dilaksanakan, terutamanya dalam kalangan dewasa muda yang sihat untuk mencegah kesan buruk ini. Kebelakangan ini, “exergame”, iaitu sebuah intervensi yang menggabungkan latihan motor dan latihan kognitif telah dicadangkan sebagai intervensi yang inovatif dalam meningkatkan keupayaan motor dan keupayaan kognitif.

Objektif: Penyelidikan ini bertujuan untuk mengkaji kesan exergame pintar yang berdasarkan latihan imbangan (FIBOD) terhadap keupayaan keseimbangan statik, keseimbangan dinamik, perhatian selektif, dan kawalan perencatan dalam kalangan dewasa muda.

Metodologi: Tiga puluh dua orang dewasa muda dari USM Kampus Kesihatan, Kelantan telah direkrut dan dibahagikan secara rawak ke dalam kumpulan intervensi (n=16) atau kumpulan kawalan (n-=16). Kedua-dua kumpulan ini telah menjalankan penilaian pra intervensi dalam keseimbangan statik, keseimbangan dinamik, perhatian selefktif dan kawalan perencatan. Selepas itu, peserta dalam kumpulan intervensi telah menjalani intervensi (latihan exergame FIBOD) selama 4 minggu (3 sesi seminggu, 15 minit setiap sesi) sementara peserta dalam kumpulan kawalan tetap menjalankan kehidupan biasa selama 4 minggu. Selepas 4 minggu, penilaian pasca intervensi (langkah yang sama dengan penilaian pra intervensi) telah dilakukan untuk kedua-dua kumpulan.

Hasil Kajian: Berbanding dengan peserta dalam kumpulan kawalan, peserta dalam kumpulan intervensi telah menunjukkan peningkatan prestasi yang signifikan dalam skor keseimbangan statik, skor keseimbangan dinamik, masa tindak balas dalam perhatian selektif, dan masa tindak balas dalam kawalan perencatan selepas menjalani intervensi exergame. Tetapi, peserta tidak menunjukkan peningkatan prestasi yang signifikan dalam skor ketepatan bagi kawalan perencatan.

Kesimpulan: Intervensi exergame adalah berkesan dalam meningkatkan kemampuan keseimbangan statik, keseimbangan dinamik, perhatian selektif dan kawalan perencatan. Oleh itu, adalah dicadangkan bahawa exergame boleh digunakan sebagai intervensi pencegahan yang inovatif bagi mencegahkan kesan buruk yang disebabkan oleh gaya hidup yang menetap.

EFFECT OF SMART BALANCE EXERGAME ON ATTENTION AND INHIBITORY CONTROL IN HEALTHY YOUNG ADULTS USING EYE-TRACKING METHOD

ABSTRACT

Introduction: The over-reliance of technology of the modern society had lead to sedentary lifestyle, resulting in declination of motor and cognitive ability. Effective prevention measure need to be implemented, especially among healthy young adults to prevent these consequences. Recently, it was suggested that exergame, a technology that combined motor training and cognitive training interactively, could be an effective intervention to improve motor and cognitive function.

Objective: This study aimed to evaluate the effect of a balance-based exergame on static balance, dynamic balance, selective attention, and inhibitory control of young adults.

Methodology: Thirty-two young adults from USM Health Campus, Kelantan were recruited and randomized into either intervention group (n=16) or control group (n=16). Both groups underwent baseline measurement of static balance, dynamic balance, selective attention, and inhibitory control. Then, participants in the intervention group underwent 4 weeks of intervention (FIBOD exergame training) while the control group remained passive for 4 weeks. After 4 weeks, post-intervention measures (similar procedure as baseline measures) were conducted on both groups.

Results: Compared to participants in the control group, participants in the intervention significantly improved in static balance test score, dynamic balance test score, reaction time for selective attention task, and reaction time for inhibitory control task after the exergame intervention. However, there was no significant improvement in the accuracy score for inhibitory control task.

Conclusion: Exergame intervention is effective in improving static balance, dynamic balance, selective attention, and inhibitory control ability and hence, could be used as an innovative preventive measure to address the consequences caused by sedentary lifestyle.

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Technology is an inseparable part of human life as it improves productivity, lifestyle, and leisure. While advances in technology have provided many benefits to the society, the recent digital and information explosion have also brought unforeseen consequences to human life in terms of sedentary lifestyle (Woessner et al., 2021). Ultimately, our over-reliance on internet and mobile devices has transformed what originally meant to be helpful tools into enjoyment that promotes sedentary lifestyle, which subsequently bring harm to our physical health and cognitive ability.

1.1.1 Physical Health: Balance and Coordination Problem

The issue of sedentary lifestyle due to over-reliance of technology can be viewed in two aspects: (1) a great reduce in physical activeness that led to physical health problem, and (2) over-reliance on digital technology which appears to be negatively associated with cognitive performance. Technology greatly reduced physical needs in everyday tasks (e.g., cleaning using robotic vacuum cleaner) and promoted leisure time inactivity (e.g., sit on couch and browse the web), leading to severe physical inactivity. Physical inactivity is negatively associated with physical health. For instance, past studies have reported that physical inactivity is correlated with poorer fine motor precision, balance, and strength (Wang et al., 2016). A study by Gustafsson (2016) also indicated that physical inactiveness, specifically due to mobile phones usage could lead to balance issue and musculoskeletal disorders (e.g., neck pain).

1.1.2 Cognitive Ability: Selective Attention and Inhibitory Control

Additionally, sedentary lifestyle due to over-reliance on digital devices is also negatively associated with cognitive functioning. Emerging scientific evidence indicated that frequent digital technology use has a significant negative impact on brain function (Small, 2020). For instance, multiple studies have drawn link between computer use or extensive screen time (e.g., watching television, playing videogames) and attention problems in all age group (Small, 2020). Although the reason for the link between technology use and attention problem is uncertain, many researchers have attributed the reason to repetitive attentional shifts and multitasking, which impair the ability to stay focus for a long time (reduce attention span). To highlight that, a study by Moisala and colleague (2016) have found that participants who used digital devices more frequently are less able to filter environmental distractions (weaker selective attention). Additionally, it was also found that these participants who used digital devices frequently were less able to suppress stimuli that are no longer relevant to the task performance (inability to inhibit response – weaker inhibitory control) (Moisala et al., 2016).

1.2 Introduction

However, digital technology is not all that bad. Previous studies have found that adequate usage of digital technology may benefit physical and brain health (Small, 2020). For instance, adequate amount of video gameplay was found to be effective in improving visual attention and task switching abilities (Small, 2020). A systematic review by Stephenson and colleagues (2017) also revealed that technology-based intervention such as sport tracker can be effective in reducing sedentary lifestyle to promote physical health. These positive findings have inbred the idea of using innovative technology to encourage physical activity to further prevent physical health and cognitive consequences.

One of such innovative technology is exergame. Exergame, or interactive fitness is a form of physical activity which combines physical exercise with video games (Benzing and Schmidt, 2018). Exergame exhibits advantages in practical application because it is a rather convenient and fun substitution of physical activity (Benzing and Schmidt, 2018; Fang et al., 2019). Compared to conventional physical exercise, exergaming system are designed to be used in relatively confined spaces (e.g., home or school), which make it more convenient and easier to be used. Several studies have found that school-based exergaming is an easy-to-apply and effective intervention in increasing students' physical activity and reducing sedentary behaviour (Fang et al., 2019; Ye et al., 2019). In addition, exergame is also more fun to adhere to because it reduces the boredom of repeated physical movements through increasing enjoyment with the video game component (Fang et al., 2019). These characteristics of exergame implicates that it can be an effective intervention to prevent physical health and cognitive consequences that are caused by sedentary lifestyle and over-reliance on technology.

Apart from that, the design of exergame could be advantageous for improving cognitive and motor behaviour through physical exercise. Exergame require players to physically move (light to moderate, or even vigorous level) in response to game demands and/ or an on-screen character (Harris et al., 2015), and hence, create an interaction between physical and cognitive demands. This interaction element could be important for effective cognitive and motor improvements: while players are moving, jumping or running, their physiological arousal and motor control skills increase, subsequently enlarging attentional pool; at the same time, players need to memorize the game rules as well as the movements in the exercise, which involves higher-order cognition – this allow them to be more focus in the game and is more effective in improving both motor skill and cognition compared to traditional physical exercise which are less demanding (Herold et al., 2018; Huang, 2020).

Nevertheless, previous studies on exergame have demonstrated its effectiveness in improving motor skills and multiple cognitive domains, including physical fitness, balance, executive functions, processing speed, visuospatial skill, memory, and verbal fluency in children and older adults (Benzing and Schmidt, 2018; Eggenberger et al., 2016; Fang et al., 2019; Huang, 2020). Exergame has been widely recognized as effective therapeutic intervention for elderly population to improve balance and coordination (Pacheco et al., 2020). For instance, a pilot study on healthy elderly women shown that an exergaming intervention as short as four weeks could significantly improve in static and functional balance (Brachman et al., 2021). Studies on adults and elderly have also linked exergame with improvement of several component of executive function, such as inhibitory control and selective attention (Benzing et al., 2016; Stojan and Voelcker-Rehage, 2019). Specifically, it is found that participants who engage in exergaming resulted in significantly better selective attention performance compared to those who only engage in physical exercise (Benzing et al., 2016). These findings demonstrated the effectiveness of exergame in improving cognition and motor behaviour as compared to conventional physical activity.

In contrast, it is also important to note that the improvement in motor and cognitive functioning through exergame may be very specific to the exercise elements and video games elements used in the exergame. Findings from previous study have indicated the importance of choosing exergame which have exercise and video games elements that are closely related to the goal of training. For instance, a preliminary study by Adcock and colleagues have found that participants who undergo a dancing exergame training (where music is the major element) show significant improvement in reaction time for auditory stimuli but not visual stimuli (Adcock, Sonder, et al., 2020). This is because auditory attention but not visual attention is more important in the game. Hence, choice of exergame must be suitable to the goal of training.

However, although studies on exergame generally show positive effect on cognition, some researchers found no overt effect or only short-term effect of exergaming on cognitive function (Ordnung et al., 2017; Staiano et al., 2012). Specifically, Ordnung and colleague found that although exergaming improved game performance, it is not sensitive enough to improve sensorimotor and cognitive function (Ordnung et al., 2017). Staiano and colleague in the other hand discussed that executive function skills may be just a short-term effects of a long-term exergame-based training intervention (Staiano et al., 2012). These “insignificant” findings could be due to the vast different in load characteristics of exergame study such as type of exergame, intervention duration and participants’ developmental stages. Current study set sights on addressing these issues:

1.3 Problem Statement

Firstly, there are plenty of different exergame in the market, which composed of different exercise and video games elements. Some exergame even mixed a few elements in the same training (e.g., yoga and dancing in the same game). This make it extremely difficult to identify which element of exergame are beneficial for improvement in which type of skill. For instance, if an exergame involved both yoga and dancing improve balance skill, it would be difficult to determine whether the improvement was due to yoga practice or dancing practice in the game.

Secondly, although there are many studies about exergame in the literature, there are no clear conclusion on the appropriate load characteristic of exergame for different population. For instance, when looking at intervention period and intensity of exergame training, the recommendation given by researchers were drastically different, ranging from immediate pre-post design (Benzing et al., 2016) to as long as 12 weeks training (Wu et al., 2019). This create a gap by which it is unsure what intervention period or intensity of training would exert the most benefits.

Just as importantly, most past studies on exergame focus only on elderly, children and clinical population and there is a lack of research in young adults, especially for healthy young adults. Among that, more than half of the studies are done on elderly, probably because the invention of exergame was first meant to reduce fall risk and delay neurodegeneration in elderly. The focus on children and clinical population are also due to the same reason: childhood is an important period for cognitive development while clinical population needed innovative intervention that could control their symptoms and improve their cognitive abilities. The lack of research on the effect of exergame on motor and cognitive function of healthy young adults, who are the biggest user of digital device and commercialized exergame is a gap that need to be filled crucially.

1.4 Study Rationale

Current study intended to address these problems by investigating the effect of a balanced-based exergame on static balance, dynamic balance, visual selective attention and inhibitory control in healthy young adults.

The exergame used in current study is the smart fitness balance board (FIBOD), a video game balance training program with visual feedback on smart device (Khor et al., 2018). Understood the importance of choosing the correct training element that matches the goal of training, current study chose a balance-based exergme after considering the benefit of balance training in improving both motor functioning (specifically balance skill) and executive function (specifically selective attention and inhibitory control). Balance training has been always linked to the improvement of balance skill and executive function (Eggenberger et al., 2016). Past studies have shown the potential of balance training in improving balance, attention and inhibition (Abuin-Porras et al., 2018; Eggenberger et al., 2016; Rogge et al., 2017, 2018). Specifically, magnetic resonance imaging (MRI) study have found that balance training (Rogge et al., 2018) increases cortical thickness in visual and vestibular cortical region, which enhance the connection between the vestibular nuclei and cerebellum, hippocampus and prefrontal cortex, resulting in improvement of attention, memory and executive function such as inhibitory control (Rogge et al., 2017). Nevertheless, the games included in FIBOD exergame are also challenging and have elements of visual attention and inhibitory control. Hence, the FIBOD exergame with balance element was chosen for current study.

In terms of intervention period, current study adopted a 4 weeks training (3 session per week) with a training intensity of 15 minutes per session. This intervention period and training intensity was based on past findings from physical training and exergame. Studies on physical exercise have shown that a short one month physical exercise training is enough for effective improvement in cognition (Kramer and Colcombe, 2018). Several exergames studies have recommended that 3 intervention sessions per week would be sufficient for improvement in motor and cognitive skills

(Benzing and Schmidt, 2019; Wall et al., 2018; Wu et al., 2019)Past studies also suggested that a moderate training intensity (11-20 minutes) exert the most benefits on cognition (Chang et al., 2015; Wang et al., 2016). In addition to that, another study that used FIBOD, the same exergame as current study, also recommended a 15 minutes training intensity (Khor et al., 2018). Hence, the intervention period and training intensity in current study were incorporated from all these past findings.

Current study also focused on healthy young adults, as it is the population that was least studied in past study. Neverthelss, healthy young adults are the biggest group of digital device and commercialized exergame user and hence, it is important to understand the effect of a balanced-based exergame on their balance ability, selective attention and inhibition skills. To the best of the researcher's knowledge, not much study on the effect of exergame on young adults, especially those who investigate on both motor and cognitive ability together have been published. Investigating on this population would contribute to the literature by adding understanding of the effect of exergame on cognitive function of healthy young adults and demonstrate whether exergame could act as an innovative technology that prevent consequences cause by over-reliance of technology in human life.

As a summary, the purpose of this study is to investigate the effect of a balance-based exergame on motor ability, specifically static balance and dynamic balance, and executive function, specifically visual selective attention, and inhibitory control in healthy young adults.

1.5 Research Question

Does balance-based exergame intervention improve static balance, dynamic balance, visual selective attention, and inhibitory control in healthy young adults?

1.6 Objectives of Study

1.6.1 General Objective

To investigate if balance-based exergame intervention could improve static balance, dynamic balance, visual selective attention and inhibitory control in healthy young adults.

1.6.2 Specific Objective 1

To compare static balance performance between control group and intervention group within pre- and post-intervention.

1.6.3 Specific Objective 2

To compare dynamic balance performance between control group and intervention group within pre- and post-intervention.

1.6.4 Specific Objective 3

To compare visual selective attention performance between control group and intervention group within pre- and post-intervention.

1.6.5 Specific Objective 4

To compare inhibitory control performance (latency of first target fixation and accuracy) between control group and intervention group within pre- and post-intervention.

1.7 Hypothesis

1.7.1 Hypothesis 1

Compared to the control group, the intervention group would show significant improvement in static balance performance after the balance-based exergame intervention.

1.7.2 Hypothesis 2

Compared to the control group, the intervention group would show significant improvement in dynamic balance performance after the balance-based exergame intervention.

1.7.3 Hypothesis 3

Compared to the control group, the intervention group would show significant improvement in visual selective attention performance after the balance-based exergame intervention.

1.7.4 Hypothesis 4

Compared to the control group, the intervention group would show significant improvement in inhibitory control performance (latency of first target fixation and accuracy) after the balance-based exergame intervention.

1.8 Operational Definition

1.8.1 Static Balance

Static balance was operationally defined as the number of errors made by participants in the Balance Error Socring System (BESS) test, where a lower number of errors indicated better static balance performance.

1.8.2 Dynamic Balance

Dynamic balance was operationally defined as the composite reach distance of particiapants in the Y-Balance Test (YBT) for left and right leg, respectively. A higher composite reach distance indicates better dynamic balance performance.

1.8.3 Visual Selective Attention

Visual selective attention was operationally defined as the latency to first target fixation (time from stimuli onset to first fixation on target) of participants in the Visual Search Task, where a lower latency score indicates higher visual selective attention performance.

1.8.4 Inhibitory Control

In the current study, inhibitory control was measured in two parameters: (1) lantency to first target fixation and (2) accuracy.

(1) Inhibitory control was operationally defined as the latency to first target fixation (time from stimuli onset to the first fixation on target) of participants in the antisaccade trial of the Antisaccade Task. A lower latency score indicated higher inhibitory control.

(2) Inhibitory control was operationally defined as the accuracy of participants in the Antisaccade Task, where a lower number of error indicated better inhibitory control.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Current study aimed to investigate the effect of a balance-based exergame on visual selective attention and inhibitory control in young adults. This chapter provides an overview of previous findings on exergame and its relationship with balance, selective attention, and inhibitory control. This literature review starts by discussing the concept of motor-cognitive training and the theory of mind-body interaction, followed by how exergame works based on these concepts. The subsequent part review the past studies on the effect of exergame on balance, selective attention, and inhibitory control.

2.2 Mind-Body Interaction Thory: The Bidirectional Relationship of the Cognitive and Motor System

Cognition and motion are crucial aspects of human living, so does the interaction of the cognitive and motor system. This is known as the mind-body interaction in the literature. The interaction between the cognitive system and the motor system has been crucial for adaptation and survival of human since ancient past. Our ancestors needed to use cognitive and sensorimotor resources simultaneously in activity such as hunting, fishing, and tool making to fight through environmental constraints. For instance, when hunting, the interaction of both cognitive process (e.g., visual attention to detect a deer in the landscape) and motor actions (e.g., throwing a weapon to the deer) were needed to ensure successful capture of prey (Herold et al., 2018). Although evolution and industrialization of the society has vastly minimized the energy required to adapt to these environment constrains, nevertheless, majority of human daily life activities in modern time still require the simultaneous interaction between the mind and the body.

For instance, even with the help of digital map on smartphone, an individual will still need to integrate both cognitive (e.g., understanding the map) and sensorimotor resources (e.g., walking and looking at sign board) to be able to get to a destination.

From a biological perspective, human life is inseparable from the mind-body interaction – the central nervous system control muscle and movements, and the feedback received from sensory organs influence brain activity (Adcock, Fankhauser, et al., 2020; Herold et al., 2018). Cognitive process is required for the control of movements, while motor behavior could influence cognition and its underlying processes (both functionality and structure). Hence, any deficits on one of these two systems may directly or indirectly affects the functionality of the other one. For instance, sedentary lifestyle is linked to altered brain structure (e.g., reduction of brain size), which could have adverse effect on cognition. Subsequently, the degraded motor performance caused by sedentary lifestyle may further decline cognitive performance because more cognitive resources were allocated to the sensorimotor system to compensate for the degraded motor performance (Wang et al., 2016). Contrariwise, training and intervention on one of the two systems could be beneficial to the other one and ask as a preventive measure to protect these two systems.

2.2.1 Motor Training

Past findings on motor training have demonstrated that it is effective for improving motor and cognitive functioning in all age classes (Elkana et al., 2020; Kalbe et al., 2018; Smith-Ray et al., 2015). A few mechanisms may be involved in mediating the association between motor training and improvement of cognition. For instance, past findings have demonstrated that motor training may improve cognition by inducing arousal effects and enlarging attention capacity. Motor training such as physical activity and exercising is linked with increase in neural activation and elevated functional connectivity of brain networks (Elkana et al., 2020; Schmidt et al., 2020) These exercise-induced arousal increases the attentional pool capacity, allowing more attentional resources to be available in subsequent cognitively effortful tasks, and hence, improve cognitive functioning (Schmidt et al., 2020).

It has also been posited that motor training can induce production of catecholamines and neurotrophic factors such as the BDNF. These catecholamines and neurotrophic factors facilitate synaptic transmission in the neural networks, leading to increase intracortical and corticospinal activation in the sensorimotor cortex. This in turn induce plasticity in the brain, which may be associated with improvement in general executive function and memory (Elkana et al., 2020).

2.2.2 Cognitive Training

Cognitive training has also found to be effective in improving both cognition and motor ability (Fraser et al., 2017; Kao et al., 2018; Schmidt et al., 2020). Past findings indicated that cognition related training can promote motor ability such as gait stability and fitness by improving visuospatial working memory, speed of processing and inhibitory control (Kao et al., 2018). It is explained that cognitive training is able to improve executive function and the attentional resources needed to perform these executive functions, thereby allocating more free attentional resources that can be directed to motor skill such as maintaining balance. For instance, a study on older adults has demonstrated the transfer effect of cognitive training to daily motor ability (Fraser et al., 2017). They found that older adults who received a computerized training (seated at a computer, no physical activity involved) significantly improve in balance as compared to the passive control group, indicating that skill transfer from cognitive training to motor ability is possible.

2.3 Integrating Motor Training and Cognitive Training

Past findings on motor and cognition demonstrated the bidirectional nature of cognition and motor ability while past findings on motor training and cognitive training reveals that they are effective in improving both motor and cognitive domain. Considering these positive findings, many researchers have hypothesized that an integration of motor training and cognitive training may add value to the positive effect of training in improving motor and cognitive ability alone.

There are several points to support this speculation. Firstly, compared to training motor or cognitive ability alone, an integration of motor and cognitive training highly resembles real-life demands, and therefore, yielded a higher chance of successful transfer effect than training in only one domain (Ordnung et al., 2017; Wall et al., 2018). If a computerized training was able to improve balance skill in older adult (Fraser et al., 2017), would not an integrated cognitive and motor training which resembles balancing in real life (e.g., reaching to different target objects while maintaining balance) be even more effective in improving balance and reducing fall risk? Secondly, an integration of motor training and cognitive training resembles the mind-body interaction (bidirectional relationship of cognition and motor ability). Knowing how much the cognitive system and motor system could affect one another, it was no surprise that a combined training would be able to target the interplay between cognitive system and motor system more efficiently.

Lastly, it is proposed that a integration of motor training and cognitive training may have a synergistic effect that is superior to the positive effects of only motor or cognitive training alone (Adcock, Fankhauser, et al., 2020; Herold et al., 2018). According to the guided plasticity facilitation framework, the “facilitation effects” of motor training and the “guidance effects” of cognitive training could be integrated to produce a super additive synergistic effect in improving motor and cognitive ability. Motor training provide "facilitation" by triggering neurophysiological mechanisms that promote neuroplasticity. Motor training such as exercising induce the release of neurotrophic factors such as BDNF, which is associated with synaptogenesis and neurogenesis – mechanisms that foster improved cognitive ability and promote neuroplasticity. While motor training induces the neurophysiological mechanisms related to neuroplasticity, cognitive training is assumed to "guide' these neuroplastic changes. Cognitive stimulation from cognitive training activates and stimulates these newly generated synapses or neurons and guide the new neuronal structures to functionally integrate with respective brain circuits and therefore, stabilizing the neuroplastic changes (Herold et al., 2018).

Remarkably, past studies on the effect of combining cognitive and motor training have demonstrated that integrating cognitive and motor training could evoke greater motor and cognitive enhancement than doing motor or cognitive training alone (Elkana et al., 2020; Fraser et al., 2017; Kalbe et al., 2018; Schmidt et al., 2020). For instance, a focused review on combining motor and cognitive training demonstrated that combined training appears to be superior to training cognitive or motor ability alone (Li et al., 2018). They highlighted a study on patients with Parkinson's disease – after a 6-weeks of training, the participants who received combined training shown superior improvement in motor and cognition, as compared to participants who received motor training alone (Mirelman et al., 2016). In the same study, fMRI scans showed that participants who received the combined training shown increased activation the in prefrontal cortex (not seen in motor training group), further supported the added value of integrating motor and cognitive training (Mirelman et al., 2016).

2.3.1 Type of Motor-Cognitive Training

However, there are different methods to combine motor training and cognitive training, and each method posits of different strength and weaknesses. From past studies, it can be concluded that there are 3 types of motor-cognitive training, which are: (1) sequential, (2) simultaneous, and (3) interactive.

2.3.1(a) Sequential Motor-Cognitive Training

Sequential motor-cognitive training involved training motor ability and cognitive ability in sequence: both the motor training and cognitive training are conducted in different time points (either on the same day or separate days). The sequence of training is flexible (motor training first, then cognitive training, or cognitive training first, then motor training).

2.3.1(b) Simultaneous Motor Cognitive Training

Simultaneous motor-cognitive training is also known as dual task training. This training involved performing both motor training and cognitive training at the same time. Simultaneous motor-cognitive training is similar to the typical dual-task training, where a secondary task is used as a distractor of the primary task. This means that both tasks are not interactive – the additional secondary task is not a prerequisite to successfully complete the first task. For example, walking on a treadmill (primary task – motor training) while solving a math questions (secondary task – cognitive training) – failure in solving the math question will not affect the primary task.

2.3.1(c) Interactive Motor-Cognitive Training

Interactive motor-cognitive training is similar to simultaneous motor-cognitive training, except that the cognitive training and motor training is incorporated together instead of just purely added together (Herold et al., 2018). In simpler terms, the motor training and cognitive training are interwoven such that performance in one domain will affects the others (Wall et al., 2018). For instance, walking to certain cones (motor training) in a predefined order (cognitive training) - failure to remember the predefined order will cause the motor task to fail too.

It is generally agreed in the literature that an interactive based motor-cognitive training is more beneficial in improving motor and cognitive ability. For instance, it was demonstrated that children who underwent an interactive motor-cognitive intervention improve in cognitive and motor ability more than their counterpart who underwent simultaneous motor cognitive training (Mavilidi et al., 2018). There are a few reasons why interactive motor-cognitive training poses more advantage than sequential and simultaneous motor-cognitive training. Firstly, interactive motor-cognitive training is designed to resembles daily life situation. For instance, while it is unusual that one will walk while solving a math question, it is common that one will need to walk through the supermarket while recalling the items he or she need to buy. The overlapping of characteristics in interactive motor-cognitive training and real-life skill could greatly enhance the transfer effect of training to real life.

In addition to that, interactive motor-cognitive training is also said to be more enjoyable to adhere to as compared to the other two types of training. This is because incorporated task is closer to real-life situation. Such combination is regarded as more meaningful (compared to doing two unrelated tasks) and hence are easier to adhere to. Furthermore, as compared to simultaneous motor-cognitive training, interactive motor-cognitive training does not posit any prioritization effects (prioritizing one domain because the two domains are fighting for the limited attentional capacity). Hence, participants could equally benefit from both type of training without having to ignore any domain due to limited attentional capacity. Although sequential motor-cognitive training also does not posit any prioritization effects (because the motor and cognitive training are done separately), but it is difficult to determine the appropriate load characteristic for this type of motor cognitive training. It remains unclear whether motor training should be performed prior to or after cognitive training, and how long should the duration between the two different training be. Hence, most motor-cognitive intervention nowadays, for example exergame, are interactive based.

2.4 Exergame as an Interactive Motor-Cognitive Training

Exergame, or interactive fitness is a form of interactive motor-cognitive training. Exergame involved interaction between two major mechanism: (1) physical exercise and (2) video games – players need to physically move in response to game demands and/ or an on-screen character (Benzing et al., 2018; Harris et al., 2015). Exergame sought to improve motor and cognitive ability by targeting the interplay between cognition and the motor system: while players are moving, jumping or running, their physiological arousal and motor control skills increase, subsequently enlarging attentional pool, at the same time, players need to memorize the game rules as well as the movements in the exercise, which involves higher-order cognition. In simpler terms, players can be more focus while facing high cognitive and physical demands, something that single domain training or non-interactive multi-domains training could not achieved.

Past studies on exergame have shown that it is an effective intervention in improving motor and cognitive ability across different population. These include reducing fall risk, improving physical fitness, executive functions, processing speed, visuospatial skill, memory and verbal fluency in children, young adults and older adults (Benzing and Schmidt, 2018, 2019; Huang, 2020; Verheijden Klompstra et al., 2014;

Y. Zhao et al., 2019). In contrast to traditional interactive motor-cognitive training, exergame is said to be more effective in improving motor and cognitive ability because it provides immediate visual feedback on participants' performance. For instance, failure in remembering game rules or performing a movement in specific time would lead to punishment (e.g., deduction of marks, the avatar loses one live, etc.) while good performance would lead to reinforcement (e.g., bonus after 10 combo) (Brachman et al., 2021; Pacheco et al., 2020). This immediate feedback could provide stimulation that aids the motor and cognitive learning processes. In addition, this also make exergame more enjoyable and easier to adhere to compare to traditional motor-cognitive training.

Apart from that, exergame also exhibit several advantages in practical application. Compared to conventional physical exercise and cognitive training, exergame is more appealing because it reduces the boredom of repeated physical movements through increasing enjoyment with the video game component (Fang et al., 2019). This could effectively increase players' motivation and adherence towards high levels of exercise. For instance, an exergame study done on older adults have achieved a high adherence rate of 90%, with participants showing positive emotion after training (Adcock, Sonder, et al., 2020). Moreover, exergame training can be applied in diverse settings (e.g., home or school) and even confined spaces, making it more convenient and easier to be used (Fang et al., 2019). Nevertheless, exergame is suitable for all age and have been gradually implemented in rehabilitation (e.g., fall risk prevention), education (e.g., obesity prevention) and as therapy for clinical population (e.g., cognitive training for ADHD and ASD) (Y. Zhao et al., 2019).

2.4.1 Exergame and Balance

Balance is defined as the ability of stabilizing one's center of gravity within any support based (Demir and Akin, 2020; Li et al., 2018). There are two main goals in achieving balance: (1) static balance - to maintain the center of gravity in support based under static condition, and (2) dynamic balance – maintain stability during straight-ahead walking (Li et al., 2018). Past findings reported improvement in both static balance and dynamic balance following exergame intervention in children and older adults.

Majority of studies on exergame and balance are based on healthy older adults, probably because this population is vulnerable to falling, which can be avoided through improved balance ability (Fang et al., 2020). A systematic review on the effectiveness of exergame in improving balance in older adults reported that exergame as an intervention (for 4-8 weeks of intervention) is effective in improving both static balance and dynamic balance of older adults as compared to their counterpart in control group (Pacheco et al., 2020). Another systematic review also demonstrated that exergame is a viable therapeutic tool to prevent fall and improves balance ability (Harris et al., 2015). Out of the 6 static balance studies that they reviewed, only one intervention shown insignificant result while all other 5 studies shown significant improvement in static balance assessment post exergame intervention. For dynamic balance, 5 out of 6 studies reviewed shown significant improvement in dynamic balance task completion time.

However, there are also contradictory findings on the effect of exergame intervention on balance. For instance, a pilot study on the effect of exergaming intervention on balance in healthy elderly women shown that a four-week intervention using a commercially available exergame only improve certain aspects of balance (only improve dynamic balance but not static balance) (Brachman et al., 2021). It is deduced that this finding might be related to the design of the exergame – this study uses a balance platform in which more movement were involved (compared to staying static). Hence, it is possible that the training for static balance was not as sufficient as dynamic balance, leading to the insignificant result on static balance. Similarly, Phirom and colleague (2020) found that healthy older adults who underwent a 12-week exergame intervention program did not yield significant improvement in dynamic balance when compared with the passive control group. However, they found a significant improvement in dynamic balance in the intervention group when comparing pre- and post-intervention score. They deduced that this might be because the role of exergame intervention on balance in older adults is more on preserving balance skill (from further declining) rather than to drastically improve it. Thus, the participants in their study did improved, but the improvement was not significant enough for group comparison.

There are also several studies done on children and clinical population. For instance, Demir and Akin (2020) recruited pre-school children in Mexico and randomized them into either passive control group and intervention group. The children in the intervention group underwent exergame training for 8 weeks (3 days a week for only 40 seconds per session). It was found that the children in intervention group significantly improved in both static and dynamic balance. This study is highlighted that for younger population like children who are in rapid developmental stage, the intervention duration does not need to be high to reach favorable effect of training.

For clinical population, a study on older adults with knee osteoarthritis compare the effectiveness of 3 different type of intervention: (1) exergame, (2) tai chi, and (3) physical therapy (Manlapaz et al., 2020). It was found that all 3 types of intervention were able to improve dynamic balance in older adults with knee osteoarthritis, but exergame yielded the most effective improvement. Manlapaz and colleagues (2020) explained that this is probably because the exergame used in the study was designed to mimics the movements done in balance exercise commonly use in physical therapy and hence, when interactively combined this motor training with cognitive training, it produced a synergistic effect on balance improvement. It is also important to note that in this study, it was mentioned that participants were able to perform better if they enjoyed the activities in their respective groups. This indicated the importance of adherence in improving balance through exergaming.

As a conclusion, the literature shown that exergame intervention is generally effective for improving balance in children, older adults, and clinical population. However, there are certain aspects to consider when choosing the exergame to be used because different elements of exergame could have different training effects. Hence, it is better to use exergame that is tailored to the goal of the study. In addition to that, there are not much study on exergame and balance in young adult, probably because young adults were assumed to have optimal balance skill. Considering the sedentary lifestyle and excessive usage of mobile devices in young adults nowadays, it would be timely to investigate if exergame could improve balance skill in young adults and current study hopes to fill this gap.

2.4.2 Exergame and Selective Attention

Selective attention is one of the three components of executive function, which is sometimes refer as shifting or cognitive flexibility (Singh and Mutreja, 2020). It is defined as the ability to change perspectives of react and adapt to changing tasks and demands of environment (Schmidt et al., 2020). Past studies have demonstrated that exergame intervention is effective in improving selective attention in various population. For instance, Benzing and colleagues (2016) found that adolescents who underwent single-bout exergame intervention performed significantly better in selective attention task compare to adolescents who underwent single-bout physical exercise intervention.

Effect of exergame intervention on selective attention can also be found in older adults. A 3-months intervention study shown that older adults in the intervention group significantly improve performance in Stroop task after exergame intervention as compared to those in control group (Wu et al., 2019). Huang (2020) found a similar result in her study which involved only 4 weeks of exergame intervention in healthy older adults. In contrast, a 7 weeks exergame intervention study by Adcock and colleague (2020) revealed that healthy older adults in the intervention group only shown improvement in reaction time for auditory stimuli but not visual stimuli in the selective attention task. It is deduced that because the exergame used in this study involved more auditory component, especially for the dancing game and hence, visual selective attention was probably not trained enough. Their study highlighted that design of exergame could directly or indirectly affect its effectiveness in improving cognitive function.

Several studies also reveal the effectiveness of exergaming in improving selective attention in children. A study on pre-school children found that participants in both passive control group and exergame intervention group showed improved selective attention (probably because children are in a rapid learning stage, hence passive control group also shown improvement), but the children in intervention group shown significantly greater improvement than the control group (Gao et al., 2019). It is also observed that for children, exergame intervention could produce immediate gains in cognitive functions. This study highlights the importance of considering the developmental stage of participants when analyzing the effectiveness of exergame intervention on cognitive function (e.g., children learn faster while older adults focus on preserving skill but not improvement). Similarly, an exergame study involving ADHD children also found similar result – ADHD children in the intervention group