EFFECT OF EXERGAME-BASED BALANCE TRAINING ON SELECTIVE ATTENTION AND INHIBITORY CONTROL MEASURED VIA EYE TRACKING AMONG HEALTHY YOUNG ADULTS

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by

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LIST OF ABBREVIATIONS

ADHD	Attention Deficit Hyperactivity Disorder
AOI	Area of Interest
AST	Antisaccade Task
AVG	Action Video Games
DLPFC	Dorsolateral Prefrontal Cortex
EEG	Electroencephalogy
FEF	Frontal Eye Field
FOV	Functional Visual Field
FIBOD	Fitness Balance Board
NAVG	Non Action Video Games
ROI	Region of Interest
TMS	Transcranial Magnetic Stimulation
VST	Visual Search Task

LIST OF APPENDICES

KESAN LATIHAN KESEIMBANGAN EXERGAME KE ATAS PERHATIAN SELEKTIF (SELECTIVE ATTENTION) DAN KAWALAN PERENCATAN (INHIBITORY CONTROL) YANG DIUKUR MENGGUNAKAN PENJEJAK MATA (EYE-TRACKING) DALAM KALANGAN ORANG DEWASA MUDA YANG SIHAT.

ABSTRAK

Pengenalan: "Exergames" atau permainan video aktif telah muncul sebagai alat yang menjanjikan yang dapat memberi kesan tambahan dari latihan fizikal dan permainan dalam pendekatan teknologi interaktif. Kajian-kajian lepas menunjukkan bahawa terdapat penambah baikan dari segi kognitif berkaitan dengan exergame. Walau bagaimanapun, kesan exergames ke atas kemahiran imbangan telah banyak dikaji untuk mengurangkan kejatuhan dan memperbaiki postur tubuh. Justeru, terdapat keperluan untuk mengkaji samada latihan keseimbangan dalam aspek exergame dapat menghasilkan peningkatan fungsi kognitif.

Objektif: Untuk menentukan sama ada intervensi menggunakan peralatan berasaskan papan imbangan yang disebut "Fitness Balance Board" (FIBOD), dapat meningkatkan perhatian selektif dan kawalan perencatan di kalangan orang dewasa muda yang sihat (18-35 tahun).

Metodologi: Seramai 30 pelajar sarjana dari Universiti Sains Malaysia telah mengambil bahagian dalam kajian ini, dan reka bentuk kawalan rawak dengan rawak berstrata telah dilaksanakan, dengan 15 peserta ditugaskan untuk kumpulan kawalan pasif dan 15 peserta ditugaskan untuk kumpulan exergaming selama 4 minggu. Kajian ini menggunakan penjejak mata (Eye tracking) dalam paradigma "tugas pencarian visual" (VST) dan "tugas antisaccade" (AST) sebagai ukuran perhatian selektif dan kawalan perencatan.

Hasil: "2x2 mixed ANOVA" menguji empat objektif kajian ini. Seperti yang dihipotesiskan, dibandingkan dengan ujian pra dengan ujian pasca, exergamers lebih tepat (Perbezaan Min = 2.8, *p* = .008), membuat lebih sedikit fiksasi (Perbezaan Min = .45, *p* <.001), dan mempunyai penetapan waktu hingga pertama fiksasi (TTFF) lebih cepat (Perbezaan min = 132.5, *p* <.001) dalam VST dan masa tindak balas antisaccade yang lebih cepat (Perbezaan min = 51.9, *p* <.001). Exergamers juga menjadikan fiksasi yang kurang dan mempunyai TTFF yang lebih pantas dalam pencarian menggunakan jumlah item yang paling banyak (20 item) (Min jumlah fiksasi: 4.6, *SD* = 1.04; TTFF: 689.8ms , *SD* = 136.9) berbanding dengan pencarian sejumlah 15 item (Min jumlah fiksasi: 4.7, *SD* = 1.29; TTFF :738.6ms, *SD* = 189.8) di ujian pasca. Berbeza dengan hipotesis, tidak ada penambahbaikan pada ketepatan “antisaccade” pasca intervensi.

Kesimpulan: Kajian ini memberikan bukti bahawa latihan keseimbangan menggunakan FIBOD adalah layak untuk meningkatkan perhatian selektif dan kawalan perencatan orang dewasa muda yang sihat. Untuk saranan kajian masa hadapan diharapkan dapat meneroka lebih jauh perubahan dalam corak carian yang berkait rapat dengan permainan exergame. Hal ini demikian untuk mewujudkan pemahaman yang lebih mendalam tentang bagaimana exergames berkait rapat dengan peningkatan kognitif.

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ABSTRACT

Introduction: "Exergames" or active video games have emerged as promising tools that provide additive benefits of both physical exercise and gaming in an interactive technology-based approach. Previous studies demonstrated exergaming induced cognitive improvements, however, exergames focusing on balance mostly studied its effect on reducing falls and improving posture. Hence, there exists a need to assess whether exergame-based balance training can generate cognitive enhancement.

Objective: To determine whether an intervention using an exergaming equipment called "Fitness Balance Board" (FIBOD) can improve the cognitive functions of selective attention and inhibitory control among healthy young adults (18-35 years).

Methodology: A randomised control trial design with stratified randomisation was implemented. Thirty healthy undergraduate students (Mean Age: 22.3, *SD* = 1.4) from Universiti Sains Malaysia were recruited and completed the study, with fifteen participants assigned to a 4-weeks exergaming group, and fifteen participants assigned to a passive control group. The study implemented eye-tracking in a "Visual Search Task" (VST) and "Antisaccade Task" (AST) paradigm as measures of selective attention and inhibitory control respectively.

Results: Separate 2x2 mixed ANOVAs tested four hypotheses of this study. As hypothesised, compared to pre-test, at post-test, exergamers were significantly more accurate (Adjusted Mean Difference = 2.8%, p = .008), made less number of fixations

(Adjusted Mean Difference = .45 , $p < .001$), and had faster time to first fixation (TTFF) on target (Adjusted Mean difference = 132.5ms, $p < .001$) in VST. Exergamers also made less fixations and had faster TTFF at search with most number of items (20 items) at post-test (Mean number of fixations: 4.6, $SD = 1.04$; TTFF: 689.8ms , $SD = 136.9$) compared to search with lesser number of items (15 items) (Mean number of fixations: 4.7, $SD = 1.29$; TTFF :738.6ms, $SD = 189.8$). In AST, as hypothesised, exergamers had faster antisaccade reaction times at post-test compared to pre-test (Adjusted Mean difference = 51.9ms, $p < .001$). Contrary to hypothesis, exergamers did not reduce antisaccade errors. In comparison, control group did not significantly improve in any outcome measures from pre to post-test.

Conclusion: Exergame-based balance training using FIBOD was feasible to improve selective attention and inhibitory control of healthy young adults. Future research can further explore changes in search patterns related to exergame play to establish an understanding of exergame related cognitive improvements.

CHAPTER 1

INTRODUCTION

1.1 Study Background

1.1.1 Exergames

Exergames, or exercise-based video games or active video games have emerged as effective tools in increasing physical activity, balance, as well cognitive functions (Sween et al., 2014; Fang et al., 2020; Stanmore et al., 2017). Exergames are designed with motion-sensing technology that integrates player's body movements with visual stimuli allowing players to simultaneously perform physical activity and video games (Jin and Park, 2009). Exergaming can contribute to enjoyment among users that may be due to identification with their virtual avatars (Li and Lwin, 2016), or due to the extent to which player's body interacts with the game (Kim et al., 2014). Such enjoyment can subsequently lead to increased motivation to continue the gameplay (Li and Lwin, 2016; Kim et al., 2014).

From a neuroscientific perspective, exergames have been discussed to amplify the cognitive benefits of physical exercise by guiding neuroplastic changes via additional cognitive task (Monteiro-Junior et al., 2016; Stojan and Voelcker-Rehage, 2019). Playing exergames have also been linked to an increase in activation of brain regions involved in cognitive motor dual-task training, since exergaming consist of performing two tasks simultaneously (exercise and gaming) (Li et al., 2018). In typical cognitive motor dual task designs, a motor task such as balance or walking is performed with a concurrent cognitive task (such as mental arithmetic), and attention needs to be divided between both tasks resulting in performance decline in one or both task. This performance decline is called the "dual task cost", and increase in prefrontal cortex activity is observed during dual task performance, with greater Dorsolateral Prefrontal cortex (DLPFC) activity associated with reduction of dual-task costs (Li et al., 2018). Due to the involvement of prefrontal cortex in executive functions, with DLPFC activation especially crucial for visuospatial attention, selective attention, working memory and response inhibition, dual task training has been evidenced as a mean to improve executive functioning among healthy as well as clinical populations (Falbo et al., 2016; Norouzi et al., 2019; Pereira Oliva et al., 2020).

The extent of cognitive improvement resulting from dual tasks is explained in literature using the concept of "transfer effects". Transfer effect can be defined as the ability to apply skills learned from a trained task to an untrained task and it is suggested that the degree of transferability depends on the amount of neural overlap between the trained task and untrained task (Li et al., 2018). This means that, if the brain regions activated during training are the same regions necessary to perform executive functions, it is possible that the training can improve the corresponding executive function (Li et al., 2018). In this vein, exergames are able to improve cognitive abilities, with evidence suggesting greater cognitive improvement related to combined physical and cognitive training interventions compared to single-domain physical or cognitive training interventions (Lauenroth et al., 2016).

When the individual components of exergaming is considered, studies have demonstrated that both exercise and video games separately contribute to enhanced performances in various cognitive domains. Effectiveness of different types of exercise can be observed in areas such as sustained attention, inhibitory control, cognitive flexibility and working memory (Radel et al., 2018; Ludyga et al., 2016). Moreover, exercise has been associated with neuroplasticity of the brain (Mandolesi et al., 2018) such as increased grey matter volume in the hippocampus, cerebellum, basal ganglia, cingulate, frontal, parietal, temporal, and insular cortices in both young and older adults (El-Sayes et al., 2019). For the videogaming component, while some gaming studies, most which categorised individuals as gamers based on self-reports, has attributed negative effects such as impulsivity to videogame playing, studies that implemented game based training advocates for the efficacy of it (Jeong et al., 2020). For instance, videogaming has been linked to enhanced brain functions, especially in the regions involved in the attentional network of the brain, with expert video game players exhibiting higher integration between attentional and sensorimotor processing (Palaus et al., 2017). Based on the beneficial effects of both video gaming and physical exercise, integration of these components through a man-videogame interface allows the processing of somatosensory information that requires cognitive abilities such as attention, perception, and executive functions (Diarra et al., 2019).

In literature, effects of exergaming has been studied mainly as a part of intervention, using tools with sensors embedded to detect the movement made by players. These tools are connected to a software so that the games can be projected on a screen and players can make movements depending on the demands of the game, making these games interactive (Oliveira et al., 2019). Commonly used exergaming tools include gaming consoles such as Nintendo Switch, Microsoft Kinet and also Nintendo Wii Balance board, a sensor based balance board where individuals have to perform movements on the board itself (Oliveria et al, 2019; Clark et al., 2018). Despite the equipment being used, what is common in exergaming tools is that all tools are designed with interactive elements which links physical activity of players to a virtual environment. Past intervention studies using these exergaming tools have demonstrated that both exercise and gaming induced cognitive improvements can also be observed after an exergaming intervention mainly among elderly, clinical populations such as those with Parkinson's disease or those who suffered a stroke. These cognitive improvements are observed in domains such as divided attention, focused attention, attentional span, and inhibition (Ou et al., 2020; Benzing and Schmidt, 2019; Diarra et al., 2019; Adcock et al., 2020; Eggenberger et al., 2016; Schättin et al., 2016; Huang, 2020; Schaeffer et al., 2019; Jirayucharoensak et al., 2019; Kannan et al., 2019; Werner et al., 2018; Hutchinson et al., 2016).

1.1.2 Balance-based exergames

Control of balance in healthy individuals is the consequence of integration of multisensory inputs originating from different spatial frames; the allocentric (vision), egocentric (somatosensory), and geocentric (vestibular) spatial frames (Lacour et al., 2018). Frontoparietal networks in the brain involved in visuospatial attention are activated during the execution of a planned movement (Bigelow et al., 2015). Balance training also contributes to increase in precentral cortical thickness and reduced volume in the putamen, suggesting that balance training can lead to neuroplasticity in areas related to visual and vestibular self-motion perception (Rogge et al., 2018).

Balance training has been linked to improvement in aspects of attention since such training can increase grey matter in frontoparietal areas, with greater activation of these areas with more demanding balance conditions (Slobounov et al., 2005; Slobounov et al., 2009; Hülsdünker et al., 2015; Mierau et al., 2015; Thorben Hülsdünker et al., 2016; Edwards et al., 2018; Varghese et al., 2019). More challenging balance conditions such as balancing on an unstable platform were found to be more effective in improving cognitive functions compared to stable platforms or even aerobic exercise (Rogge et al., 2018; Eckardt et al., 2020). When balance as the physical activity component of exergaming is considered, beneficial effects of balance training via exergaming has been shown to be effective in improving posture but there exists a scarcity of studies focusing on cognitive functions since most balance exergame studies have been conducted on elderly and clinical populations. Additionally, majority of these studies have also been conducted using Nintendo Wii Balance Board and other tools that uses a stable platform for balance training.

Among the different exergaming tools, the Fitness Balance Board or FIBOD is a new exergaming tool developed in Malaysia that facilitates the possibility of exploring the benefits of wobble-board balance training in an exergame context. This board was developed to reduce falls in the elderly with a component especially designed for balance training, and another component consisting of games that require attentive and balancing skills (Khor et al., 2018). To date, a pilot study has been conducted using FIBOD on elderly individuals, and found that balance training component of FIBOD was effective in reduce falls and improve balance (Khor et al., 2018). However, it is yet to be explored whether the gaming components are effective, and also to test whether FIBOD is feasible to generate cognitive benefits such as improvement of executive functions as demonstrated by previous exergaming research.

1.1.3 Eye tracking and exergaming

An important aspect of the design of games in exergaming is their potential to influence our attentional skills, as gaming requires players to attend to the demand of the games. Depending on the type of game, players might need to be quick in shifting attention and eye tracking is a useful tool to detect such changes in attention since eye movements are an indicator of visual attention (Wollenberg et al., 2020). Eye tracking studies give an indirect measure of brain activity that is relatively cost-effective compared to neuroimaging modalities and can be carried out in natural, less space restricted settings (Eckstein et al., 2017). Additionally, eye tracking measures have a high temporal resolution enabling measurement of response to task demands on a moment-by-moment basis (Eckstein et al., 2017).

Eye tracking allows identification of the precise location that the person is focusing on, known as a fixation, as well as identifying eye movements between fixations (known as saccades) (Bueno et al., 2019). A fixation can be defined as eye movements that stabilize the retina over a stationary object of interest. Saccades are rapid eye movements used in repositioning the fovea of the eye to a new location in the visual environment (Duchowski, 2017). Controlling of saccades are supported by widespread cortical and subcortical regions, including occipital cortex, posterior parietal cortex, frontal and supplementary eye fields, superior colliculus, thalamus, striatum/basal ganglia, and cerebellum (Klein and Ettinger, 2019). Analysis based on fixations and saccades have been used as an indirect measure of brain activity that can provide insight on the association between brain and behaviour (Bueno et al., 2019; Eckstein et al., 2017). Commonly used tasks in eye tracking such as visual search tasks (VST) measure goal directed selective attention, or the ability to attend to one or fewer sensory stimuli while ignoring or suppressing all other irrelevant sensory inputs (Bater and Jordan, 2019), while tasks such as the "antisaccade task" (AST) can measure goal-driven attention in terms of higher order executive functioning such as inhibitory control or the ability to voluntarily suppress our reflexes (Schmitt et al., 2016). Antisaccade accuracy of those who underwent exergame intervention was linked to increased grey matter in the frontal eye fields, an area which plays a crucial role in the execution of voluntary saccades (Diarra et al., 2019).

While there are not much exergaming studies conducted using eye tracking, it is an important tool to assess cognitive improvement related to gaming studies because eye tracking allows the study of transfer effects (Brunyé, Drew, Weaver & Elmore, 2019) in a gaming context. This is due to the overlapping neural mechanisms behind controlling of eye movements and frontoparietal networks of attention that are also activated during videogame play. Therefore, choosing a cognitive task that may represent neural overlap with game play is important to address whether cognitive elements trained during the gameplay is transferred to untrained cognitive tasks (Li et al., 2018).

1.2 Problem Statement, Rationale and Significance

1.2.1 Problem Statement

Even though previous studies have demonstrated that balance training alone can improve balance and cognitive abilities, traditional balance training methods can be repetitive and demotivating (Barry et al., 2016). Compared to traditional balance, exergame based balance has been found to be an alternative method of balance training, that increases motivation and adherence to training due to its interactive nature (Willaert et al., 2020). However, balance training in an exergame context has mostly been conducted to portray its benefits in improving balance and reducing falls, but there exists a scarcity of research that studies its cognitive benefits. Hence, there is a need to assess whether cognitive improvements evidenced from traditional balance studies are also observed in exergame based balance training. Additionally, based on studies conducted on dual-task balance training, it is evident that combined cognitive and motor training can be more beneficial than traditional balance training to improve executive functions (Li et al., 2018). For these reasons, the current study introduced the FIBOD as an exergame tool in order to assess whether balance training using FIBOD can improve executive functions.

In addition to the above, research on balance have demonstrated the close relationship of eye movements to the control of balance, since neuroscientific evidence reveal an integrated network of vision and vestibular system (Lacour et al., 2018). Studies have been conducted to show that eye movement training can improve balance, however, there is a lack of studies that implement eye movement tasks to understand the effect of balance training (Aguiar et al., 2015; Bae, 2016; Thomas et al., 2016; Rodrigues et al., 2015). Eye movement tasks can potentially be a good way to measure cognitive functions trained from exergames, since, aside from balance, the gaming component is also highly dependent on accurate gaze to ensure success in the games. Furthermore, frontoparietal networks of attention used during gameplay is also necessary to control saccades (Palaus et al., 2017; Klein and Ettinger, 2019), hence establishing a neural overlap between saccade mechanisms and gaming. Such an overlap is important in the study of transfer effects, since concept of transfer effect posits that degree of transferability of skills learned during training to an untrained cognitive task depends on the extent of neural overlap. For these reasons, this study also utilised an eye tracking paradigm to study effects of exergaming on executive functions. Specifically, commonly used tasks in eye tracking such as VST and AST could measure executive functions of selective attention and inhibitory control, therefore, the current study adopted these eye tracking tasks in order to measure cognitive benefits of exergame based balance training using FIBOD.

1.2.2 Study Rationale

Technology based lifestyle such as usage of computers, smart phones and videogame playing has become common part of our lives. Because of this, there has been reported an increased level of physical inactiveness among young generations due to increase in screen time (Barnett et al., 2018). Sedentary lifestyle can ultimately lead to cognitive decline, and engaging in an active lifestyle during youth and young adulthood is important for healthy cognitive development (Choudhary et al., 2021; Wheeler et al., 2017). Therefore, exergames are attractive tools since exergames offer a way to integrate technology into an active lifestyle that can also generate cognitive improvements. Specifically, exergame offers a path to improve executive functions that has been shown to be improved due to dual task training, such as selective attention and inhibitory control (Li et al., 2018). Therefore, the current study was conducted to determine whether exergame based balance training could improve selective attention and inhibitory control among a young adult population.

1.2.3 Significance of the study

The findings of this study will be beneficial to the understanding of how exergame based balance training can improve cognitive functions among a population of young adults. Significant findings will pave a way for young adults to boost their cognitive skills with simultaneous engagement in an active lifestyle using a technology friendly approach. Additionally, knowledge from transfer effects helps to establish a link between exergaming and cognition, assisting the understanding of their neural bases (Palaus et al., 2017). This knowledge can help to perhaps create exergames, or upgrade the design of existing tools to make exergaming more effective for both rehabilitation as well as cognitive training purposes.

1.3 Objectives, Research Questions and Hypotheses

1.3.1 General Objective

To examine the effect of exergame based balance training using FIBOD on selective attention and inhibitory control of healthy adults (between 18-35 years)

1.3.2 Specific objectives

1. To compare changes in selective attention performance as measured by VST accuracy from pre to post intervention between a FIBOD training group and a passive control group.
2. To compare changes in selective attention performance as measured by "fixation count" and time to first fixation (TTFF) on a target in VST from

pre to post intervention between a FIBOD training group and a passive control group.

3. To compare changes in inhibitory control performance as measured by AST accuracy from pre to post intervention between a FIBOD training group and passive control group.
4. To compare changes in inhibitory control performance as measured by AST reaction time from pre to post intervention between a FIBOD training group and passive control group.

1.3.3 Research Questions

1. Is there a difference between selective attention performance as measured by VST accuracy from pre to post intervention between a FIBOD training group and control group?
2. Is there a difference between selective attention performance as measured by “fixation count” and time to first fixation (TTFF) on a target in VST from pre to post intervention between a FIBOD training group and a passive control group?
3. Is there a difference between inhibitory control performance as measured by AST accuracy from pre to post intervention between a FIBOD training group and passive control group?
4. Is there a difference between inhibitory control performance as measured by AST reaction time from pre to post intervention between a FIBOD training group and passive control group?

Based on the findings that indicated the effectiveness of video gaming on improving performance of selective attention (Palaus et al., 2017; Qui et al., 2018; Föcker et al., 2018; Mack and Ilg, 2014; West et al., 2013; Hubert-Wallander et al., 2011; Wu and Spence, 2013), and the possibility of near and far transfer effects due to exergaming, the following hypotheses are derived.

1.3.4 Hypotheses

1. FIBOD training group will improve selective attention by increasing VST accuracy from pre to post intervention and will demonstrate a higher accuracy compared to a control group at post intervention.
2. FIBOD training group will improve selective attention by reducing Fixation count and TTFF from pre to post intervention and will demonstrate greater reduction compared to a control group at post intervention.
3. FIBOD training group will improve inhibitory control by increasing antisaccade task accuracy from pre to post intervention and will demonstrate higher accuracy compared to a control group at post intervention.
4. FIBOD training group will improve inhibitory control by reducing antisaccade task reaction time from pre to post intervention and will demonstrate greater reduction compared to a control group at post intervention.

CHAPTER 2

LITERATURE REVIEW

2.1 Exergaming and Selective attention

Previous studies indicate that exergaming involves activation of several brain areas, some of which are related to attentional processing. In an EEG study which was the first to demonstrate that brain activity could be measured while exergaming, Anders et al. (2018) reported that frontal theta wave activity increased during exergaming, indicating that attentional processes were being used while exergaming. Additionally, post-exergaming, higher grey matter volume in right hippocampus, right DLPFC and the right cerebellum was also observed (West et al., 2017). Out of these areas, the right DLPFC plays a key role in integrating sensory information with goal directed behaviour, working memory, attention and future planning (Kühn et al., 2014). Integration of sensory information with goal directed behaviour is a key component of selective attention (Siu and Woollacott, 2007).

2.1.1 Videogaming and selective attention

When the gaming component of exergaming is considered, video game training has been targeted as a method of cognitive behaviour training in healthy and patient populations (Green and Seitz, 2015). Past studies indicate that the genre of video game also has an effect on the performance of cognitive tasks. Even though videogaming concept is extremely heterogenous and difficult in comparing genres, Choi and colleagues (2020) in their review identified that commercially available video games which are built for the purpose of entertainment can be divided into mainly five genres:

1. Traditional games such as puzzle games,
2. Simulation games (sports and racing games),
3. Strategy video games (games that require focusing on visual information use of strategies such as planning and decision making),
4. Action video games (categorised by the presence of a static locator linking the gaze of players and their actions in the gaming environment),
5. Fantasy games (relatively slow paced games where players need to explore the game environment to solve problems.

Out of these genres, majority of evidence suggest that due to their complex visual representation, action video games contribute to more beneficial outcomes than other game types (Boot, 2015). Action video games (AVGs) are characterized by complicated three dimensional settings, with highly transient objects, strong in-game demands in terms of processing stimuli in the periphery, along with highly disseminated attention while engaging in quick actions (Green and Bavelier, 2015). Previous literature has demonstrated that AVGs contribute to improvement in cognitive abilities including domains of attention. For example, Palaus et al. (2017) reviewed 117 articles on video game playing to determine neural basis of videogaming and found that AVG players were better at improving selective attention compared to those who played role playing games (fantasy games), traditional games (puzzle games) and strategy games. This may be due to the extensive use of attentional system coupled with precise timing that these types of games require. An experiment by Qiu et al. (2018) compared the differences between expert verses non expert AVG players before and after a one hour AVG training. They found that prior to training, expert AVG players had higher response time in a task that measured visual selective attention and also a larger P2 amplitude in EEG study, which is indicative of improved selective attention and attentional control processes. However, after the training, there were no differences in response time or the P2 amplitude between experts and non-experts, implying that non expert's attentional level reached expert level after an hour of training.

It has also been evidenced that the improvement in attention among video game players was associated with accompanying plasticity in the frontoparietal network, which is a region involved in top-down attentional processing (Föcker et al., 2018). With increasing task difficulty and attentional demands, compared to non-action video game (NAVG) players, AVG players utilised frontoparietal network to a lesser extent indicating that AVG players use a more automatic allocation of attention (Bavelier et al., 2012). Similar to this, studies have also revealed that AVG players demonstrated greater neural suppression in task irrelevant information (Krishnan et al., 2013; Mishra et al., 2011). Moreover, the superior ability of AVG players over NAVG players were also linked with an increased attention-dependent parietal process rather than an increase in activity of lower extra striate visual pathway (Föcker et al., 2018).

There is a controversy in literature regarding whether skills learned in videogames can only be applied to tasks homologous with the games (near transfer effect), or whether the learned skills will help to improve performance in untrained cognitive tasks as well (far transfer effect) (Chan et al., 2019). Feng and Spence (2018) suggested a "common demand hypothesis" which assumed that training effects of video game playing are task specific and game based benefits can only be observed in tasks that share common elements or demands with the game used for training. This is to imply that game training will only contribute to near transfer effects, but not far transfer effects. Consistent with this, Azizi et al. (2017) found that after training on video game, visual attention measured by eye movement only improved in VST that contained game-related images, and improvement was not observed when natural scenes were used as images in visual search. Similarly, Oei and Patterson (2015) showed that improvements related to training were only observed in tasks that share common characteristics with the game that was played. On the other hand, Duyck and De Beeck (2019) demonstrated that videogaming can produce both near and far transfer effects where videogame intervention lead to improvement in executive functioning tasks.

2.1.2 Balance based training on selective attention

The association between balance and attention has been considered as an integral part of postural control (Lacour et al., 2018). Control of balance in healthy individuals is the consequence of integration of multisensory inputs originating from different spatial frames; the allocentric (vision), egocentric (somatosensory), and geocentric (vestibular) spatial frames (Lacour et al., 2018). Frontoparietal networks in the brain involved in visuospatial attention are activated during the execution of a planned movement (Bigelow and Agrawal, 2015). Balance training also contributes to increase in precentral cortical thickness and reduced volume in the putamen, suggesting that balance training can lead to neuroplasticity in areas related to visual and vestibular self-motion perception (Rogge et al., 2018).

Balance training has been linked to improvement of aspects of attention in both single and dual task conditions. In single task context, it has been demonstrated that just two sessions of whole-body balance training was sufficient to increase grey matter volume in frontal and parietal brain areas (Taubert et al., 2010). Data from neuroimaging studies have revealed that activation of frontoparietal networks increased as the postural stability tasks became more challenging (Slobounov et al., 2005; Slobounov et al., 2009; Hülsdünker et al., 2015; Mierau et al., 2015; Thorben Hülsdünker et al., 2016; Edwards et al., 2018; Varghese et al., 2019). Balance training in a dual task setting can lead to the activation in the DLPFC, which is an area involved in coordination of processing of simultaneous tasks (Li et al., 2018). Exergame-based balance can be considered as a dual task since it involves simultaneous focus on balance and gaming.

2.1.3 Intervention Studies on exergaming and attention

Recent intervention studies using exergaming has mainly focused on different clinical populations and elderly populations (Stanmore et al., 2017), and mostly used paper and pencil tests to measure attention. Among studies that used such paper and pencil tests, improved attention after exergaming intervention was found among children with ADHD in five domains of attention: focused, sustained, selective, alternating, and divided attention (Ou et al., 2020). Significant increase of cognitive performance in the tests of attention after the intervention was also found in patients with Parkinson's disease (Schaeffer et al., 2019). Exergame based balance training using Nintendo Wii Fit Plus balance board was associated with increased speed of processing and sustained attention among patients with multiple sclerosis (Prosperini et al., 2015). Additionally, cognitive motor exergame training also was found to improve both motor and attention among patients with chronic stroke while a conventional balance training among this population only improved motor but not attention (Kannan et al., 2019). One finding that is not consistent with majority of results is the finding from Adcock et al. (2020), that showed that only control group significantly improved in attention span while exergaming group did not. Researchers mentioned that it could be because the task used in the study was not reliable enough to measure attention.

Aside from the above, fewer studies have used neuroimaging modalities. For example, one study used EEG to measure frontal theta activity while performing a psychological test of divided attention and found that prefrontal activity significantly decreased in favour of the exergame group (Schättin et al., 2016). Similarly, another study used performance on a task using the exergaming platform whereby a motor-cognitive dual-task performance to measure divided attention was assessed using a simultaneous walking and a working memory task performed on the exergaming platform (Werner et al., 2018). The time taken to complete the task was measured during pre and post intervention, along with 2 times between interventions. The authors found that greatest improvements in attention was found just after 3 weeks of intervention, with improvements comparatively less during the measurements taken afterwards. This may indicate that just 3 weeks of exergame training may be able to generate improvements in attention tasks. Hence, they concluded that the time course of improvements in exergame performances seemed to be asymptotic rather than linear, with the greatest part of the total training effects already apparent at early stage of intervention phase.

2.1.4 Eye tracking studies on exergaming and selective attention

2.1.4 (a) VST as a measure of selective attention

In terms of eye tracking studies, researchers have measured the extent to which video game players were able to ignore task irrelevant stimuli, by integrating eye tracking to the “visual search task” (VST) (Hollingworth and Bahle, 2020). This task can be either feature task (where target that needs to be searched differs from distractors just by only one feature- for example, a black item among blue items) or conjunction search (target consists of combination of two or more features with the distractors (Wolfe, 2021). For example, finding a yellow vertical bar among yellow horizontal and blue vertical bars). According to Wolfe, (2021)’s updated guided search theory, among these two types of VSTs, selective attention is needed to perform conjunction based visual searches, as such attention is required to bind the features so that attended item can be identified as the target. To be identified as targets and rejected as distractors, items are compared to templates of the target stored in working memory, and the selection of attention is guided by these templates. Since we have limited attentional capacity, individuals cannot do feature binding simultaneously for all items in the display and therefore, they become slower in searching for a target with increasing number of distractors (Reimer and Schubert, 2020).

It is argued that conjunction based visual searches are difficult compared to feature tasks because the distractors in conjunction search are fairly similar to the target (Wolfe and Horowitz, 2017). However, difficulty may also depend on the colour of distractors. For example, search might be easy if distractor colour is relatively different from the target colour, even though distractors might be in the same shape and orientation as the target (Wolfe and Horowitz, 2017). When considering the relationship between number of items in display (setsize) and the mean correct search response time, earliest theories suggested that items are searched serially in an item by item basis, and because of this, there is a linear increase in reaction time with increasing set size (Liesefeld et al., 2016). However, Hulleman and Olivers (2017) argued that search is not conducted in an item by item basis, instead, search depends on one's functional visual field and is based on number of fixations. The researchers defined functional visual field as the area of visual field around a fixation, from which information can be detected and extracted during a visual task. They also posited that rather than scanning item by item, individuals may even clump items together to make search more efficient (Hulleman and Olivers, 2017). Overall, the VST serves as an important measure of selective attention, and in eye tracking research, search behaviour can be understood in terms of matrices such as latency of fixations, fixation count, fixation distribution and durations.

2.1.4 (b) Eye tracking in videogaming and balance training studies

For videogaming, there is literature which provides evidence for videogaming related improvements in visual search tasks. For example, compared to non-video gamers, video gamers demonstrated faster saccade reaction times and less oculomotor capture, indicating a better performance in the VST (Mack and Ilg, 2014). Consistent with this, AVG players also had a higher saccadic control (West et al., 2013), increased visual search accuracy and shorter reaction times (Hubert-Wallander et al., 2011). A type of action game categorised as "first person shooter" game players demonstrated better performance in both feature and conjunction search tasks (Wu and Spence, 2013). Azizi and colleagues (2017) found that after an AVG intervention, individuals developed a narrower search strategy, with reduction of vertical distribution of fixations in a visual search task that contained photos similar to the game. Schmidt et al. (2018) found that in a VST where participants had to find a "T" shape between "L" shaped distractors, AVG players did not differ in terms of accuracy but had a faster overall reaction time compared to control group. Additionally, search time per display items were also shallower for AVG players indicating that less time was need to analyse the search items.

For balance, in terms of eye tracking studies, fewer studies have addressed the effect of balance training on eye movements, rather, more studies assessed the opposite effect, which is the effect of eye movements on postural balance. A study by Aguiar and colleagues found that body sway was reduced during saccadic eye movements in both young and older adults indicating that postural balance and saccadic eye movements were an integrated system (Aguiar et al., 2015). Another study found that interventions on both saccadic eye movements and smooth eye movements (visually tracking objects that are in motion) were effective in improving plantar sensation and postural balance in elderly, with greater improvements after saccadic eye movements (Bae, 2016). Smooth eye movements also led to increase in body sway, indicating that there is an association between vision and vestibular system (Thomas et al., 2016). Additionally, training in saccadic eye movements entailed greater posture stability implying that there is a functional integration of gaze control and posture (Thomas et al., 2016). Given that vision and vestibular system is highly integrated, it is surprising that a scarcity of literature exist on the effect posture control has on eye movements. In fact, only one study was found in literature which indicated that posture can be modulated to increase the accuracy of gaze behaviour (Rodrigues et al., 2015).

2.2 Exergaming and inhibitory control

While selective attention aspect as measured by the VST share common characteristics with video games which focuses on attentive skills such as AVG playing, and can represent near transfer effects, there is evidence that the skills learned from video games can be transferred to cognitive aspects which are not directly trained by the game as well. Diarra and colleages (2019) demonstrated such far transfer effect by demonstrating that inhibitory control, which was a skill not used by the exergame that individuals played, improved after exergaming. A meta-analysis of randomized controlled trials on the effects of exergames on cognitive functions demonstrated the positive effects of exergames on inhibitory control across studies that used different intervention lengths (Stanmore et al., 2017). In addition to this, exergaming in cognitively and physically more challenging conditions improved reaction times of inhibitory control tasks among children with ADHD (Benzing and Schmidt, 2019). The following sections discusses the literature related to the effects of individual components of exergaming on inhibitory control.

2.2.1 Videogaming and inhibitory control

For the videogaming component, there seems to be a controversy of whether videogame training contributes to cognitive benefits, or problematic behaviour due to failure to control inhibition. The negative aspects of videogame playing has been investigated in relation to "dysfunctional", "harmful" or "addictive" video gaming, and the literature that supports negative effects of videogaming suggests relatively similar changes in brain regions associated with self-control in internet gaming disorders compared to other sorts of addictive disorders (Fauth-Bühler and Mann, 2017). Deleuze et al. (2017) claimed that these studies failed to take into account the different genres of videogaming. Additionally, Green and Seitz (2015) highlighted in their review that not all videogames are equal in terms of improvement in cognitive abilities, however, certain genres such as AVGs have shown to be more beneficial in improving executive functions. Similarly, Palaus et al. (2017) noted that although videogaming has been linked to negative consequences such as addiction, impulsivity and exposure to violence, majority of the recent literature supports for the cognitive benefits of it. Further supporting this claim, Jeong et al. (2020) stated that the negative effects of videogaming are reported mainly from the studies that used self-reports to measure cognition, and behavioural studies where participants need to do a task specialised for interested cognitive function reported mainly positive effects, thus weakening the view that videogame playing is linked to impulsivity and failure to control inhibition. Consistent with this proposition, Azizi and colleagues (2018) demonstrated that compared to non-gamers, gamers were found to be impulsive when measured using a self-report scale, but impulsivity was not observed when tested on behavioural measures.

Moving on to the cognitive effect of video gaming on inhibitory control, a study that used “hybrid stop task” which measures reaction time in two measures of inhibitory control demonstrated that AVG players (first person shooter gamers) had faster reaction time compared to strategy game players (Deleuze et al., 2017). This is because AVG playing requires fast game play, whereas strategy games are relatively slow paced, and require more decision making skills rather than attentive skills. The authors also noted that, despite faster reaction times, AVG players also made more errors compared to other genres, perhaps indicating that AVG players may be more impulsive and that such gamers might show improved reaction time, but still make errors when it came to response inhibition (Deleuze et al., 2017). Steenbergen et al. (2015) had young adults who were either AVGs (first person shooter game players) or NAVGs complete a task which shares similar characteristics as first person shooter games. They found that AVGs were more efficient in action cascading which consisted of cognitive control processes such as action selection and multitasking, however, AVGs were not more efficient in inhibitory control performance. This indicates that effects associated with gaming experience do not transfer to all cognitive tasks, and also the fact that AVGs were on par with NAVGs on inhibitory control performance gives support that AVG playing is not linked to failure to inhibit responses, rather, it just indicates that AVG playing was not necessarily sufficient to improve inhibitory control. Palaus et al. (2020) observed effects of a dual intervention based on videogame training followed by a transcranial magnetic simulation to the DLPFC that could enhance cognitive functioning in terms of near transfer effects and far transfer effects. The results demonstrated near transfer effects (tested with an alternate version of the trained video game), and this effect appeared because of the game training and was not mediated by the TMS. Moreover, far transfer effects (tested on executive performances) also were present after the training, with improvements in inhibitory control and working memory (Palaus et al., 2020). Similar to this, Hazarika et al. (2018) also revealed that compared to NAVG players, long term AVG players (those who played 15-20 hours a week) had greater neural interference suppression and stronger alpha activity indicating better inhibitory control. Consistently, Hilla et al. (2020) showed that alpha power representative of inhibitory control was higher in video game players compared to no video gamers, and among them, power was highest for AVG players. Overall, findings on videogaming and inhibitory control suggests that although some studies demonstrate a negative effect of videogaming on inhibitory control, these are mostly based on videogame addiction studies, and there exists substantial evidence of game related inhibitory control improvement, especially for AVG players.