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# Cognitive fatigue: Exploring the relationship between the fatigue effect and action video-game experience

James Brooks
*Edith Cowan University*

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# USE OF THESIS

# Cognitive Fatigue: Exploring the relationship between the fatigue effect and action video-game experience

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**Abstract**

A number of occupations involve performing sustained and divided attention tasks. These tasks are often susceptible to the effects of cognitive fatigue, resulting in poorer performance and increasing the likelihood of human error. Previous research indicates that those who regularly play action video games have superior performance on cognitive tests that are related to sustained attention and divided attention. However, few studies have investigated how performance on these tasks change as a result of increasing time-on-task and cognitive fatigue. This thesis reports three studies that were designed to investigate this issue.

Study 1 (Chapter 3) compared the divided attention performance of video game players (VGPs) and non-video game players (NVGPs) on the NASA Multi-Attribute Task Battery (version 2; MATB-II) before and after completing a 60-minute sustained attention task. Study 2 (Chapter 4) investigated whether divided attention and sustained attention could be improved from action video-game training. In Study 2, NVGPs from Study 1 were provided with 10 hours of either variable-priority training or fixed-emphasis training on an action video-game over four weeks. Participants completed a post-test using the cognitive tasks from Study 1, and returned for a three-month follow-up. Study 3 (Chapter 5) explored whether the cognitive benefits from action video game playing demonstrated in previous studies could be observed in real-world scenarios, such as driving. In Study 3, VGPs and NVGPs spent two hours in a driving simulator whilst their driving performance and eye-movements were recorded.

The main findings of this thesis reveal that VGPs experience similar levels of cognitive fatigue as NVGPs. In Study 1, the sustained attention performance of both VGPs and NVGPs declined by similar amounts, and in Study 3, when driving in a simulator, both VGPs and NVGPs made significantly more traffic violations as they became fatigued. Combined, these results demonstrate that both VGPs and NVGPs are equally susceptible to

the effects of cognitive fatigue. Despite this, there remain advantages to regularly playing action video games. In Study 1, VGPs were significantly better at multitasking on the MATB-II compared to the NVGPs. Further, VGPs also demonstrated superior multitasking when driving, as they made significantly fewer traffic violations compared to NVGPs when not fatigued. VGPs demonstrated eye-movements similar to those of expert drivers; however, this did not result in any difference in performance between the two groups. There was also some evidence of a positive effect of video game training, although there was no advantage of one training technique over the other. In Study 2, participants experienced the effects of cognitive fatigue to a lesser extent after video game training than compared to before training. Further, there was a significant improvement in multitasking performance after video game training, though as participants continued improving even at the three-month follow up test, it is unknown whether this was due to the video game training or due to practice effects on the MATB-II.

Overall, despite improvements in sustained and divided attention performance from regular action video game playing or training, VGPs and trained-NVGPs are just as susceptible to the effects of cognitive fatigue as NVGPs.

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## Introduction

Living and working in today's technology-driven world often requires individuals to perform multiple tasks simultaneously, of increasing complexity, and for long durations (Gartenberg, Breslow, McCurry, & Trafton, 2013; Gaspar et al., 2013; Hambrick, Oswald, Darowski, Rench, & Brou, 2010; Hubal, Mitroff, Cain, Scott, & DeWitt, 2010; Rosenberg, Noonan, DeGutis, & Esterman, 2013). Sustained and divided attention is a critical part of human performance in a range of occupations, including, but not limited to, pilots, air traffic controllers, power plant operators, long-distance drivers, security surveillance operators, military commanders, unmanned aircraft vehicle operators, and electronic warfare tacticians (Chiappe, Conger, Liao, Caldwell, & Vu, 2013; Durso & Sethumadhavan, 2008; Feltman, 2014; Finomore, Matthews, Shaw, & Warm, 2009; Gartenberg et al., 2013; Hubal et al., 2010; Warm, Matthews, & Finomore, 2008; Warm, Parasuraman, & Matthews, 2008).

Performing any task, whether it be mental or physical, for an extended period of time, can lead to fatigue, resulting in an increase in the difficulty of maintaining an adequate level of performance, and will eventually result in decreased performance and an increased likelihood of human error (Ackerman, 2011; Guastello et al., 2013; Lal & Craig, 2001; Van Dongen, Belenky, & Krueger, 2011). Further, when individuals are cognitively fatigued, they find it difficult to assess their current level of performance and to predict how their performance is going to be affected as their level of fatigue increases (Lorist & Faber, 2011). From the above list of occupations, it is easy to imagine the serious consequences that could, and do, occur should an individual become fatigued and not perform at an adequate level (Finomore, Shaw, Warm, Matthews, & Boles, 2013; Gunzelmann, Moore, Gluck, Van Dongen, & Dinges, 2011; Lim et al., 2012; Pattyn, Neyt, Henderickx, & Soetens, 2008; Van Dongen et al., 2011). Therefore, it is important to understand the factors involved in attaining optimum human performance and to implement procedures (for example, personnel

screening, assessment, or training interventions) to ensure that individuals are able to resist the effects of cognitive fatigue in order to maintain an adequately high level task performance for the required period of time.

Previous research has found that those who regularly play (or those who are trained on) action video games, and in particular first-person shooter (FPS) video games, demonstrate improved performance in a range of cognitive areas, including those areas that are most often used when performing sustained attention (Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Castel, Pratt, & Drummond, 2005; Dye, Green, & Bavelier, 2009b; C. S. Green & Bavelier, 2003, 2006b, 2007; Hubert-Wallander, Green, Sugarman, & Bavelier, 2011; T. N. Schmidt, Teo, Szalma, Hancock, & Hancock, 2012), and divided attention tasks (Chiappe et al., 2013; Dye, Green, & Bavelier, 2009a; Gaspar et al., 2013; Hambrick et al., 2010; Kearney, 2005). Action video games contain features that relate closely to well-known training principles (Chiappe et al., 2013); for example, instant feedback of performance, variability of training (Healy, Schneider, & Bourne Jr, 2012), motivated and focused learning, and increasing levels of difficulty (C. S. Green, Li, & Bavelier, 2009). Together, these features provide a possible medium through which to improve people's divided and sustained attention performance (Pavlas, Rosen, Fiore, & Salas, 2008). However, whilst there is a theoretical basis for the hypothesis that playing action video games can improve sustained attention and divided attention performance, there is currently little research on the topic, and none that explicitly focuses on cognitive fatigue.

The present thesis has three primary research aims; firstly, to determine whether regular action video game players (VGPs) demonstrate superior sustained attention and divided attention performance and experience less cognitive fatigue compared to non-video game players (NVGPs); secondly, to determine a causal relationship between playing action video games, improvements in sustained attention and divided attention performance, and

reduced cognitive fatigue, and thirdly; to determine whether VGPs also outperform NVGPs on, and experience reduced levels of cognitive fatigue during, real-world tasks requiring sustained and divided attention, such as driving.

# Chapter 1: Fatigue

For such a common phenomenon, fatigue is difficult to define (van der Linden, 2011). Outside of the scientific community, fatigue can be described as being synonymous with feeling tired, exhausted, weary, and sleepy. It is often considered to be due to prolonged periods of mental or physical work, or sickness (Ackerman, 2011; Manning, Rash, LeDuc, Noback, & McKeon, 2004; van der Linden, 2011), and is widely considered to play the main role in declining task performance (Earle, Hockey, Earle, & Clough, 2015).

However, fatigue is a complex state involving changes in behaviour (cognitive and physical), can be affected by a number of external factors (task difficulty and time performing a task) as well as internal factors (motivation and emotion), and does not always result in performance decrements, thus making it difficult to define in scientific terms (Matthews, 2011; van der Linden, 2011). In fact, many researchers simply state that “fatigue is a complex phenomenon that is difficult to define precisely” (Brown, 1994, p. 298) or instead create custom definitions for their own studies (Phillips, 2015). Thus, the term fatigue, and the different types of fatigue, have been loosely and inconsistently used for many years, lack concrete definitions, as well as a singularly accepted theory of fatigue’s origins and functions (Hockey, 2011, 2013; Lal & Craig, 2001; van der Linden, 2011).

Fatigue is commonly considered to be the transitory state between being awake and being asleep (Lal & Craig, 2001), and the prevailing view is that it is caused by a lack of energy (Hockey, 2013). However, Balkin and Wesensten (2011) suggested that the best definition was given by Fischler (1999), who stated that “fatigue is the decline in performance that occurs in any prolonged or repeated task” (p. 131), and this is in fact identical to one of the original views of fatigue (Bartlett, 1953; Gawron, French, & Funke, 2001). However, this definition is actually that of the fatigue effect or time-on-task effect (van der Hulst, Meijman, & Rothengatter, 2001), and is not actually a definition of the state

of fatigue itself.

More recently, Phillips (2015) conducted a review of the existing definitions of fatigue and found that these definitions ranged from broad overviews, encompassing experimental, physiological and performance aspects to narrow descriptions focusing specifically on one or two of these areas. The benefits and shortcomings of these different approaches were evaluated, and integrated into a new "whole definition" of fatigue:

> Fatigue is a suboptimal psychophysiological condition caused by exertion. The degree and dimensional character of the condition depends on the form, dynamics and context of exertion. The context of exertion is described by the value and meaning of performance to the individual; rest and sleep history; circadian effects; psychosocial factors spanning work and home life; individual traits; diet; health, fitness and other individual states; and environmental conditions. The fatigue condition results in changes in strategies or resource use such that original levels of mental processing or physical activity are maintained or reduced. (p. 53)

Here, exertion is defined as "mental processing or physical performance requiring directed effort" (p. 53), and the forms of exertion refers to either the mental processing or physical performance required to complete a task or tasks in different contexts, for example in simple or complex tasks, or active or passive tasks, that are performed over a long or short time (Phillips, 2015). This description of exertion in terms of mental processing matches closely to that of mental workload, "the degree of information processing capacity that is expended during task performance", which is often studied in conjunction with cognitive fatigue and in particular sustained attention (Warm, Parasuraman, et al., 2008, p. 433).

The varying definitions of fatigue are understandable as there are different categories of fatigue, and researchers have given different weights to these different aspects in their own interpretations (Hockey, 2013). However, it is accepted that fatigue can be categorised as either acute or chronic (van der Linden, 2011); active or passive (Desmond & Hancock, 2001); objective or subjective (Kanfer, 2011); and cognitive or physical (Atchley, Chan, & Gregersen, 2014). Whilst the focus of this thesis is primarily on acute, active, objective,

cognitive fatigue, there will be a brief discussion of the other categories in the following sections as it is important to understand fatigue as a “whole”.

**1.1 Cognitive Fatigue**

Cognitive fatigue is an unfamiliar term in psychology, and is a relatively new field of study (Matthews, 2011). In the psychological literature cognitive fatigue can also be referred to as mental fatigue, whilst in the medical literature it is often referred to as central fatigue (Gawron et al., 2001; van der Linden, 2011). Cognitive fatigue has many conceptual overlaps with other states such as motivation and boredom (Hockey, 2013; Lal & Craig, 2001). Thus, not only does this contribute to the difficulty in developing a unifying definition and theory of fatigue but it makes it difficult to identify fatigue as the principle variable in experimental situations (Hockey, 2013).

As previously mentioned, the prevailing view of cognitive fatigue is that it is a lack of energy or mental resources due to performing tasks with a high workload. However, this is known to be an oversimplification, as individuals may become aware of their level of fatigue and initiate strategies to overcome the associated performance decline (Brown, 2001; Saxby, Matthews, Warm, Hitchcock, & Neubauer, 2013). In addition, Hockey (2011, 2013) argued that this view was inaccurate and that the current understanding of cognitive fatigue has been hindered by two main assumptions; first, that fatigue is due to a loss of energy or resources, and second, that fatigue is a negative state and an unavoidable consequence of performing work. Whilst a resource view of fatigue may be a useful explanation of physical fatigue, as there are clear limits within human biology, for example limitations in the ability of the cardio-vascular system to transport oxygen and glucose to the muscles, for cognitive fatigue, the resource metaphor may not provide a completely appropriate explanation (Hockey, 2013; Matthews, 2000). Instead, Hockey proposed that cognitive fatigue is an adaptive state, with the function of controlling and managing motivation and behaviour. Thus, rather than

cognitive fatigue simply being a state of feeling tired due to depleted energy or cognitive resources, the feeling of fatigue is a state of awareness of the energy cost of the current task(s) being performed and of the potential need to focus on other neglected or alternate goals or activities. This perspective was initially proposed over one hundred years ago by Thorndike (1900), who stated that,

> Feelings of fatigue, such as they were, were not measures of mental inability ... We can feel mentally fatigued without being so, that the feelings described above serve as a sign to us to stop working long before our actual ability to work has suffered any important decrease. (p. 481)

This reinterpretation of cognitive fatigue has been reiterated by others (Bartley & Chute, 1947), but has since been somewhat neglected in the scientific literature (Hockey, 2013). However, this view of cognitive fatigue is beginning to receive more interest (for example Boksem & Tops, 2008; Kool, McGuire, Rosen, & Botvinick, 2010; Kurzban, Duckworth, Kable, & Myers, 2013). Cognitive fatigue is therefore believed not to be the "inability to do work but rather a *lack of desire*" (Hockey, 2013, p. 9) or resistance, to continue performing the current task (Earle et al., 2015). As such, it serves as a protective, self-regulating, adaptive function aimed at maintaining a balance between performing multiple tasks, by reappraising the mental resource costs and benefits of each, and allowing other behaviours to contend for motivational control (Bartley & Chute, 1947; Hockey, 2013; Kanfer, 2011). If an individual performs a task that has a high cost and low benefits, the function of fatigue will decide whether to compensate for the reduced mental resources by applying more effort to the task, or will alter performance goals to use fewer mental resources, or a combination of both (Balkin & Wesensten, 2011; Hockey, 1997; Smith, 2011). If the individual is unable to switch to a different task that has lower costs and higher benefits, they will become increasingly fatigued. This often occurs when tasks are driven by external rather than internal motivation, for example when at work, as a higher level of effort is required to perform an unenjoyable task when faced with more desirable alternative tasks, such as play (Hockey,

2011, 2013). In addition, if the individual is unable to switch tasks, they may re-evaluate the costs and benefits of the task's subcomponents and may adjust their performance strategy in order to conserve resources, for example, by focussing on speed instead of accuracy (Lorist & Faber, 2011; Matthews, 2000; van der Hulst et al., 2001; van der Linden, 2011).

### 1.1.1 Acute and Chronic fatigue.

Cognitive fatigue can be divided into two types, acute or chronic (van der Linden, 2011). The focus of this paper is on acute cognitive fatigue, which is categorised as being a temporary state, which is relatively easy to recover from. Cognitive fatigue can often be induced by performing cognitively complex tasks for extended periods of time, and can be relieved by stopping the current task and resting, or switching to a different task. Human factors research focusses on acute cognitive fatigue as it is often related to poor performance and safety concerns. Chronic cognitive fatigue however, is characterised by lacking in quick recovery and is thus longer lasting than acute fatigue. It is a symptom of psychological and somatic disorders, including chronic fatigue syndrome and depression, rather than a symptom of mental exertion (van der Linden, 2011).

### 1.1.2 Active and Passive fatigue.

Fatigue that is associated with high cognitive workload or demands is referred to as active fatigue, while passive fatigue is the result of performing tasks requiring low cognitive workload or that are monotonous (Desmond & Hancock, 2001). Both may induce similar subjective responses related to fatigue, for example, tiredness and reduced task engagement (Philip et al., 2005), however, differences in subjective responses occur when assessed at a multidimensional level (Matthews, Szalma, Panganiban, Neubauer, & Warm, 2013).

### 1.1.3 Subjective fatigue.

Not everybody experiences and reports fatigue in the same way, nor do people experience the same level of fatigue (if any) under the same circumstances (Guastello et al.,

2013). It has been proposed that this unobservable experience of subjective fatigue consists of two stages (Hockey, 2013). First, an awareness of the increasing cognitive cost of performing a certain task experienced as a mild cognitive discomfort, and second, either the change in behaviour needed to maintain an adequate level of performance, or increasing cognitive effort if the behaviour cannot be changed (Balkin & Wesensten, 2011; Hockey, 2013; Kanfer, 2011; Thorndike, 1900). Subjective feelings of fatigue, such as statements of aversion to performing a task, inability to concentrate, physical complaints (Ackerman, 2011), and frustration and discomfort (Hockey, 2013), often occur prior to any observable changes in objective measures of fatigue, such as increased reactions times and decreased performance accuracy. Thus, it is often the case that performance decrements due to fatiguing conditions are not always observed. This is because individuals may become aware of their fatigue and as a result implement compensatory strategies in balancing the costs and benefits of performing the task, allowing them to avoid any actual performance decrement before they occur (Bartley & Chute, 1947; Hockey, 1997; van der Linden, 2011). In addition, there are different strategies that individuals can use which would mask any effect of fatigue when group data is analysed. For example, half of a group may favour speed over accuracy, while the other half favour accuracy of speed. The overall result of the group would therefore not reveal any effect of fatigue on performance (van der Linden, 2011).

The experience of fatigue for an individual is not always consistent even whilst performing the same task, as attention can fluctuate over time, either due to fatigue, boredom, distraction (Rosenberg et al., 2013) or differing types or levels of motivation (van der Hulst et al., 2001). Often, these subjective differences are overlooked due to the tendency to only examine mean effects, rather than inter-individual variability and individual patterns of performance over time (Ackerman, 2011). It is generally agreed however, that as time increases, so too do subjective levels of fatigue (Hockey, 2013; Kanfer, 2011).

#### 1.1.4 Objective fatigue.

There are a number of objective measures that can be used to assess performance decrements due to fatigue (Ackerman, 2011). The typical finding is that cognitive fatigue results in increased reaction times, increased response variability, and decreased response accuracy (Ackerman, 2011; Guastello et al., 2013; Hockey, 2013), and these will be the measures used in the following studies. Other measures, which fall beyond the scope of this thesis, include measuring physiological symptoms of cognitive fatigue such as declines in brain functioning as measured by event-related brain potentials (Kato, Endo, Kobayakawa, Kato, & Kitazaki, 2011), and increased blood pressure and stress hormones (van der Linden, 2011).

### 1.2 Related Factors

Identifying fatigue as the principle variable in experimental situations is difficult to do as it has many causes and many symptoms (Hockey, 2013). Cognitive fatigue is related to physical fatigue, boredom, motivation, inherent personality traits, task difficulty, and time spent performing the task. However, the relationship between fatigue and these factors is not always clear, and individuals do not all respond the same to the effects of fatigue. Some people may experience a performance decrement over time, whilst others may experience improvements in performance, analogous to physical exercise and "getting warmed up" (Guastello et al., 2013, p. 4). In addition, increased time-on-task can result in improved, rather than declining performance, due to practice and learning (Ackerman, Calderwood, & Conklin, 2012). Further, switching tasks can alleviate fatigue, but only when the switch is intrinsically motivated. If the individual is forced to switch tasks, this can tax working memory and cognitive resources (Guastello et al., 2012; Rubinstein, Meyer, & Evans, 2001), resulting in increased levels of fatigue. The following section will highlight some of the overlapping factors associated with cognitive fatigue.

### 1.2.1 Physical fatigue.

Whilst physical fatigue and cognitive fatigue are often discussed separately, they are by no means unrelated. As the name suggest, physical fatigue occurs within the body and results in impaired co-ordination, feelings of physical discomfort, and a reduced ability to produce force or power (Barker & Nussbaum, 2011; Lal & Craig, 2001). The resource theory metaphor can be used to explain physical fatigue as there are clear limits within human biology, for example limitations in the ability of the cardio-vascular system to transport oxygen and glucose to the muscles (Hockey, 2013; Matthews, 2000). Thus, when these physical limitations are reached, and resources are depleted, physical fatigue occurs. Physical fatigue consists of two components, peripheral and central. Peripheral fatigue refers to metabolic changes in the muscles, eventually leading to a decreased capacity of the muscles to exert force. Central fatigue refers to changes in the neuronal control of motor behaviour, which can be affected by work demands and motivation (Barker & Nussbaum, 2011; Zijdewind, van Duinen, Zielman, & Lorist, 2006). Thus, changes in cognitive fatigue can impact physical fatigue and vice versa (Barker & Nussbaum, 2011).

### 1.2.2 Motivation.

Motivation is often used in the definition of cognitive fatigue (van der Linden, 2011), and is heavily related to cognitive fatigue in two key ways. Firstly, the level of fatigue experienced differs depending on whether the task being performed is intrinsically or extrinsically motivating (van der Hulst et al., 2001). It has long been known that when tasks are intrinsically motivating, performing them requires little effort and are therefore not fatiguing (Hockey, 2011; Thorndike, 1900). Secondly, declined motivation is a symptom of fatigue and is experienced as an unwillingness to continue performing the task (van der Linden, 2011). However, motivation is differentiated from fatigue in that it is not influenced solely by previous levels of activity or rest (Soames-Job & Dalziel, 2001). In addition, it is

possible to be motivated to perform a task, but be either physically or cognitive unable to, due to fatigue (van der Linden, 2011), or vice versa whereby the individual stops performing a task because they are not motivated despite not being fatigued (Soames-Job & Dalziel, 2001).

**1.2.3 Boredom.**

Boredom occurs due to under-stimulation and from tasks requiring low levels of cognitive demands (Bartley & Chute, 1947) such as performing tasks that are simple and highly repetitive (Hockey, 2013). Whilst fatigue and boredom often occur together and can have similar effects on performance (Hockey, 2013), fatigue is not a necessary and sufficient prerequisite of boredom. For example, it is possible to be well rested but still experience boredom whilst performing a repetitive task (Cummings, Mastracchio, Thornburg, & Mkrtchyan, 2013). To further complicate the matter, the terms boredom and passive fatigue are often used interchangeably depending on the particular field of study. Passive fatigue is used in human factors/ergonomics fields whilst boredom is used in education and organisational settings. However, regardless of the field of study, the underlying feature of these areas of research is that under stimulation or low levels of cognitive workload leads to deterioration in task performance (Jackson, Kleitman, & Aidman, 2014).

**1.2.4 Personality.**

Cognitive fatigue is associated with many factors including stable personality traits and how individuals manage task demands and workload (Matthews, 2011). It is believed that cognitive fatigue and its self-regulatory processes can be affected by differences in personality and motivational traits (Kanfer, 2011). Some stable traits may be associated with fatigue proneness, or a vulnerability to the effects of fatigue (Matthews, 2011). Of the five personality traits, conscientiousness has been found to be the most related to fatigue, as it suggests that individuals who score highly, commit more energy to work-related activities (Matthews, 2011). However, reinforcement sensitivity theory suggests that fatigue is also

related to extraversion. This theory proposes that extraverts are more prone to positive affect, that is, more easily generate excited emotions, and thus they experience lower fatigue (Corr, 2009). Further, Ackerman and Kanfer (2009) have found that higher levels of subjective cognitive fatigue are reported by those who score highly on levels of neuroticism-related traits.

### 1.3 Cognitive Fatigue and Executive Control

Cognitive fatigue was initially thought to be the result of depleted cognitive resources. However, after a review of the literature, Hockey (2013) proposed that cognitive fatigue is rather an adaptive mechanism, with the function of controlling and managing motivation and behaviour, and is therefore connected to executive functions. Executive functions are regulatory processes that control human information processing and play a vital role when presented with novel situations, for example in problem solving (Lorist & Faber, 2011; Schmorrow et al., 2012). They are higher-order cognitive control processes that organise and control lower-level cognitive functions according to the individual's goals. They are used when goals need to be prioritised, when irrelevant stimuli need to be ignored, when automatic responses need to be overruled, and when information needs to remain active in memory for extended durations (van der Linden, 2011). When executive functions are adjusted to maintain cognitive resources, there is a decline in performance, for example as irrelevant stimuli are responded to and automatic responses are not withheld. However, performance decrements on tasks that tax executive control functions are not always observed (van der Linden, 2011). In order to prevent fatigue from affecting task performance, there are a number of different strategies (controlled by executive functions) that individuals may implement (Hockey, 1997). For example, individuals may choose to make speed-accuracy trade-offs; focus on the primary task and ignore/reduce attention to secondary tasks; or expend more effort and attempt to overrule the desire to stop performing the current task (van

der Linden, 2011). The regulatory processes controlled by executive functions require a high degree of mental effort, and over time, this amount of effort increases, resulting in a reduction in the efficiency of these functions, and an associated reduction in performance, known as the fatigue effect (Earle et al., 2015; Lorist & Faber, 2011; Lorist et al., 2000; van der Linden, 2011; van der Linden, Frese, & Meijman, 2003).

**1.4 The Fatigue / Time-on-task Effect**

As previously discussed, fatigue is difficult to define. To avoid this issue, it is often operationalised and expressed in terms of the fatigue effect or time-on-task effect (Stern, Boyer, & Schroeder, 1994). Put simply, the time-on-task effect is a reduction in task performance (typically increased reaction times and/or increased number of errors) as time spent performing the task increases. However, it has been suggested that changes in reaction time variability should also be analysed, as although the time-on-task effect is often seen in aggregate data it is not consistently seen in individual results (Van Dongen et al., 2011).

In addition, the time-on-task effect is often investigated in relation to the vigilance (or sustained attention) decrement (Davies & Parasuraman, 1982; Gunzelmann et al., 2011), which is considered to be the most robust effect of cognitive fatigue (Dinges, 1995). Similar to the time-on-task effect, the vigilance decrement is also characterised by increasing reaction times and decreasing detection accuracy (Davies & Parasuraman, 1982; Helton & Russel, 2011). More specifically however, the vigilance performance decrement is usually complete after 20 to 35 minutes performing the task (See, Howe, Warm, & Dember, 1995).

Whilst the terms ‘vigilance’ and ‘sustained attention’ are often used interchangeably (Finomore et al., 2013; Pattyn et al., 2008; Rosenberg et al., 2013), for the purpose of this thesis, ‘vigilance’ will be used when referring to the performance decrement as observed whilst performing vigilance tasks, whilst ‘sustained attention’ will be used to refer to the broader cognitive process of directing and maintaining attention on a task for an extended

period of time, regardless of the type and duration of task being performed.

**1.4.1 Sustained attention & vigilance.**

Sustained attention is the ability to maintain one's focus of attention and remain alert for long periods of time in order to accurately and quickly respond to stimulus changes (Larue, Rakotonirainy, & Pettit, 2010; Rosenberg et al., 2013; Scerbo, 1998; Warm, Parasuraman, et al., 2008). An increased ability to sustain attention protects the individual from performance declines due to fatigue or distraction (Clayton, Yeung, & Cohen, 2015). The main focus of sustained attention research has been on the vigilance decrement (Helton & Russell, 2012; Scerbo, 1998; Warm, Parasuraman, et al., 2008). A typical vigilance task measures the speed and accuracy of participants' responses to infrequent and unpredictable stimuli (Rosenberg et al., 2013). For example, participants must monitor a blank computer screen and respond as fast as possible when a target appears. The vigilance decrement typically takes 20 to 35 minutes to complete, with the majority of this loss occurring within 15 minutes of onset of the task (Rosenberg et al., 2013; See et al., 1995; Teichner, 1974), however, this may be reduced to as little as 5 minutes depending on the demand characteristics of the task (Caggiano & Parasuraman, 2004; Helton et al., 2007; See et al., 1995).

There are two main families of theories that attempt to explain the cause of the vigilance decrement (Dillard et al., 2014; Helton & Russell, 2012). Currently, the resource theory (Fisk & Scerbo, 1987; Fisk & Schneider, 1981; Kahneman, 1973; Parasuraman & Davies, 1977; C. D. Wickens, 1984) is the dominant model, and is based on the premise that there is a limited amount of cognitive resources available at any point in time (Dillard et al., 2014). It proposes that as vigilance tasks are difficult and mentally taxing, over time, cognitive resources are drained, resulting in poorer vigilance performance (Helton & Russell, 2012). In opposition are the theories that propose that the vigilance decrement is due to

under-stimulation and boredom, resulting in disengagement from the task and thus poorer performance, and consists of the under-load (Frankmann & Adams, 1962; Heilman, 1995; Loeb & Alluisi, 1977; Welford, 1968) and mind-wandering theories (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). However, based on a review of literature, it has been found that neither the resource theory, nor its opponents, can adequately account for all findings related to the vigilance decrement (Thomson, Besner, & Smilek, 2015).

Similarly to cognitive fatigue, it has been proposed that the vigilance decrement is due to reduced executive functioning, rather than a lack of cognitive resources (Thomson et al., 2015). Thomson et al. (2015) suggested that performing vigilance tasks taxes executive functions, as these functions control the ability to ignore irrelevant stimuli and inhibit automatic responses. Over time, as executive functions become taxed, insufficient amounts of attentional resources are allocated towards the task, resulting in deteriorating vigilance performance. As such, it is possible that individuals with greater executive control will be better able to direct the required attentional resources towards the vigilance task, resulting in better performance over a longer period of time (Thomson et al., 2015).

#### 1.4.2 Vigilance tasks.

A disadvantage of traditional vigilance tasks is that the occurrences of the target stimuli are infrequent, and therefore so too are participants' responses. It is thus not possible to accurately measure fluctuations in accuracy or reaction time on a moment-to-moment basis (Rosenberg et al., 2013). To account for the inability to measure moment-to-moment reaction times, there are sub-types of vigilance tasks, referred to as not-X Continuous Performance Tasks (not-X CPTs), as well as the Sustained Attention to Response Task (SART), that require participants to respond to frequent non-target stimuli, and to withhold responses to the rare target stimuli (Larue et al., 2010; Rosenberg et al., 2013). Thus, these tasks can measure a greater number of reactions as well as determine the pattern of reaction times that precede

and predict errors. However, not-X CPTs are not without limitations. For one, vigilance decrements are not consistently found with not-X CPTs in healthy adult populations (Rosenberg et al., 2013), and sometimes vigilance performance improves, rather than deteriorates, over the course of the task (Helton, Kern, & Walker, 2009). Thus, it has been argued that not-X CPTs may not accurately assess the vigilance decrement (Helton & Russell, 2011; Rosenberg et al., 2013). However, one possible explanation for these findings is that the abrupt visual onset of each stimulus captures participants' attention, and thus cues the participant to respond to the stimuli, resulting in more consistent performance over time (Esterman, Noonan, Rosenberg, & DeGutis, 2012; Rosenberg et al., 2013). Therefore, to account for the abrupt onset of stimuli, Esterman et al. (2012) developed a gradual-onset Continuous Performance Task (gradCPT) in which stimuli are presented in gradual transitions rather than with abrupt onsets, and found that this task was able to successfully tax participants' ability to sustain attention.

In addition to the above types, vigilance tasks can also be classified as being successive or simultaneous (Davies & Parasuraman, 1982; Finomore et al., 2009). In simultaneous vigilance tasks, all of the information needed to make a decision is presented, and thus a comparative judgement must be made. In successive vigilance tasks, absolute judgements must be made, comparing the currently presented stimuli with a target retained in their memory (Davies & Parasuraman, 1982; Finomore et al., 2009). Therefore, successive judgement vigilance tasks place a greater demand on attentional resources and working memory than simultaneous judgement tasks (Finomore et al., 2009; Shaw et al., 2010).

Accuracy of responses on a vigilance task can be influenced by either perceptual sensitivity or the individual's decision criterion (Davies & Parasuraman, 1982). Signal detection theory is therefore used assess vigilance performance accuracy as it takes these factors into consideration. Sensitivity ($d'$) measures how well the signal (target) can be

detected from the noise (non-targets). When *d'* is close to zero, targets are difficult to detect and when it is large they are easy to detect. Typically, participants have little to no control over signal detectability as it is mostly influenced by the way the stimuli are created in the experimental design (e.g. size of stimulus). Signal detectability is also influenced by the physiology involved in the detection process (T. D. Wickens, 2001). The response criterion (*c*, also referred to as $\lambda_{centred}$) represents the amount of evidence needed by the observer in order to classify a stimulus as a target. When the evidence is greater than the response criterion level, the observer classifies the stimulus as a target, and when it is below, it is classified as noise. Criterion levels however, are controlled by the individual, as this is a representation of their response strategy/bias. The response criterion is a representation of the amount of evidence needed by the participant for them to determine whether a stimulus is a signal (target) or noise (non-target); if the evidence is above the response criterion level, the stimulus is classified as a signal. Thus, decreasing criterion levels indicate an increased propensity to respond to a stimulus (less evidence is needed), resulting in more correct responses but also more false alarm errors (T. D. Wickens, 2001).

**1.4.3 Reducing the effects of fatigue.**

A number of solutions have been proposed to reduce the performance decrements produced by fatigue-inducing tasks in varying domains. The simplest and most effective solution is to increase the number of personnel, resulting in shorter work schedules (Miller, Matsangas, & Shattuck, 2008) and allowing individuals to stop when they become fatigued (Atchley et al., 2014). However, this solution is not always possible, for example long-distance flying or driving, where the number of personnel is limited. Other methods include screening personnel to identify those likely to perform well on sustained attention tasks, providing training to personnel to assist in reducing the cognitive demands of the required task, and designing tasks in such a way as to reduce the cognitive demands (Miller et al.,

2008). For example, in human-computer interaction systems it has been found that providing knowledge of results is beneficial in providing a buffer against the effects of cognitive fatigue (Ackerman, 2011; T. N. Schmidt et al., 2012).

In addition, individuals often employ their own methods in an attempt to relieve their sense of fatigue. For example, whilst driving they may turn on the radio or roll down the window (Atchley et al., 2014). Other more novel interventions have also been used as a counter-measure to performance deficits caused by cognitive fatigue. For example, researchers have found that intermittently presenting pleasant odours to participants resulted in significantly faster reaction times compared to those in the control condition (Kato et al., 2011).

Vigilance training has also been used in an attempt to improve sustained attention performance. In a study by Parasuraman and Giambra (1991), participants completed twenty 30-minute vigilance tasks over a period of two to three weeks. It was found that overall, practice reduced the vigilance decrement, however, training did not eliminate it. In addition, Ariga and Lleras (2011) were able to reduce the vigilance decrement in participants by providing brief and rare mental breaks. However, Helton and Russell (2012) were unable to replicate these results. It has also been found that motivation may affect vigilance performance. In a study by Szalma and Hancock (2006), participants were provided with the illusion that they were able to choose between a supposedly easy or hard vigilance task. Participants who were offered their choice showed improved performance in target detection compared to those who were given the opposite of their choice.

One solution for reducing the effects of cognitive fatigue that has been largely ignored is that of assessing the cognitive abilities of personnel. Researchers have generally ignored individual differences in sustained attention, as vigilance tasks lack intellectual content and are therefore not affected by variations in cognitive ability (Shaw et al., 2010). However, it is

believed that the primary source of cognitive fatigue is the demand placed on executive functions by cognitively demanding tasks (Guastello et al., 2013; Logie, 2011). Further, there is evidence that the vigilance decrement is also related to executive functions (Thomson et al., 2015). Therefore, this would suggest that individuals who have superior executive functions would not be as susceptible to the effects of cognitive fatigue, as they would be better able sustain their attention whilst performing complex tasks for extended periods of time. Accordingly, it should follow that individuals who perform well on tests of executive functioning (for example, tests of divided attention and multitasking) should also be resilient to the effects of cognitive fatigue.

Previous research has found that those who regularly play (or those who are trained on) action video games, and in particular FPS video games, demonstrate improved performance in a range of cognitive areas, including those areas that are most often used when performing sustained attention (Boot et al., 2008; Castel et al., 2005; Dye et al., 2009b; C. S. Green & Bavelier, 2003, 2006b, 2007; Hubert-Wallander, Green, Sugarman, et al., 2011; T. N. Schmidt et al., 2012), and divided attention tasks (Chiappe et al., 2013; Dye et al., 2009a; Gaspar et al., 2013; Hambrick et al., 2010; Kearney, 2005). Action video games contain features that relate closely to well-known training principles (Chiappe et al., 2013); for example, instant feedback of performance, variability of training (Healy et al., 2012), motivated and focused learning, and increasing levels of difficulty (C. S. Green et al., 2009). Together, these features provide a possible medium through which to improve people’s divided and sustained attention performance (Pavlas et al., 2008). However, whilst there is a theoretical basis for the hypothesis that playing action video games can improve sustained attention and divided attention performance, there is currently little research on the topic, and none that explicitly focuses on cognitive fatigue.

## Chapter 2: Video Games

Over the past four decades, video games have become increasingly popular, replacing more traditional forms of leisure activities (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012), and this is set to continue as new games, platforms, and technologies are released (Colzato, van der Wildenberg, Zmigrod, & Hommel, 2013; Connolly et al., 2012). This growth in the video game industry has led to increasing interest in the effects of playing video games on individuals, and in particular the influence of violent games on aggressive behaviour (Colzato, van Leeuwen, van der Wildenberg, & Hommel, 2010; Ferguson, 2007). Accordingly, a debate has arisen in the research literature concerning the impact of playing violent video games on individuals’ behaviour. However, a discussion of this issue is beyond the scope of this proposal, and the reader is referred to Ferguson (2010) for an in-depth discussion of the moral panic, public debate, and sociological and historical context surrounding violent video games.

Just as interest in the negative behavioural impacts of video games has grown, so too has research into the positive cognitive effects of playing video games (Colzato et al., 2013; Dye et al., 2009b; Ferguson, 2007; Karle, Watter, & Shedden, 2010). Although research into the cognitive effects of video game playing began over three decades ago (Lowery & Knirk, 1982; Spence & Feng, 2010), there has been a recent increase in research in the last decade (Dye et al., 2009b; Karle et al., 2010), particularly focussing on first-person shooter games (a sub-type of action video games), since the seminal paper by C. S. Green and Bavelier (2003) .

In their study, C. S. Green and Bavelier (2003) compared the performance of VGPs and NVGPs in areas of selective attention, capacity of attention, and attention in time. A training experiment was also conducted in which NVGPs played either an FPS game *Medal of Honor*, or a non-FPS game *Tetris*, for one hour, for 10 consecutive days. It was found that VGPs performed better in all of the areas of attention compared to NVGPs, and the NVGPs

trained on the FPS game performed better than the NVGPs trained on the non-FPS game. These results suggest that FPS game playing and training increases attentional capacity, improves the spatial distribution of attention, and enhances attentional flexibility.

Video games have developed from simple tasks of basic skill and ability, to being completely immersive experiences. In particular, FPS games require the player to develop an adaptive mindset in order to successfully complete complex, and demanding tasks (Colzato et al., 2013; C. S. Green & Bavelier, 2006a; Murphy & Spencer, 2009). A typical FPS game involves controlling the movements of the player’s character, aiming and firing at other players whilst avoiding being hit oneself, and monitoring health status and ammunition supplies, all simultaneously and in a time pressure situation (Kearney, 2005). These tasks thus require rapid responses to visual and auditory events, discriminating between relevant and irrelevant stimuli, tracking multiple objects, and continuous switching between numerous subtasks (Castel et al., 2005; Colzato et al., 2010; C. S. Green & Bavelier, 2006b, 2006c; Hubert-Wallander, Green, Sugarman, et al., 2011; Oei & Patterson, 2015). In addition to this, video games are goal directed and players receive instantaneous feedback (Greenfield, 1994), for example, through receiving rewards for accurately and quickly processing and responding to the relevant information, or consequences for allowing irrelevant information to interfere with their task or failing to respond to stimuli (Dye et al., 2009b; C. S. Green & Bavelier, 2006b).

Subsequent studies have replicated and extended upon the findings of C. S. Green and Bavelier (2003), demonstrating that regular players of FPS video games display superior performance in a range of visual and cognitive skills compared to non-players (Barlett, Anderson, & Swing, 2009; Bavelier, Green, Pouget, & Schrater, 2012; Castel et al., 2005; Clark, Fleck, & Mitroff, 2011; Connolly et al., 2012; Dye et al., 2009b; Ferguson, 2007; Hubert-Wallander, Green, & Bavelier, 2011).

## 2.1 Cognitive Improvements

Playing FPS video games has been shown to improve individuals' visuospatial cognitive abilities in selective attention, allocation of attention, and attention in time (Boot et al., 2008; Hubert-Wallander, Green, & Bavelier, 2011), as well as sustained attention (Dye et al., 2009b) and divided attention (Chiappe et al., 2013).

### 2.1.1 Selective attention.

Selective attention is the ability to direct attentional resources to certain areas within the visual field in order to detect target stimuli, often whilst ignoring irrelevant stimuli.

#### *2.1.1.1 Useful (Functional) field of view.*

A common task for assessing selective attention is the Useful Field of View task, developed by Ball and colleagues (Ball, Beard, Roenker, Miller, & Griggs, 1988; Ball & Owsley, 1993). In this task, a small target stimulus is briefly presented at a random location on a screen followed by a mask to remove after-images, and participants must then identify where the target stimulus appeared. The task measures an individual's ability to direct their attention towards an area of space. (Myers, Ball, Kalina, Roth, & Goode, 2000).

Video game players often outperform NVGPs in the Useful Field of View task (Feng, Spence, & Pratt, 2007; C. S. Green & Bavelier, 2006b), and this benefit is also generalised to areas of the visual field that extend beyond those of normal video game play (C. S. Green & Bavelier, 2003). Further, NVGPs who have been trained on an action video game for 10 hours (Feng et al., 2007; C. S. Green & Bavelier, 2003) and 30 hours (C. S. Green & Bavelier, 2006b) showed significant improvements in performance. This improvement was also maintained at a follow-up approximately 5 months later (Feng et al., 2007).

#### *2.1.1.2 Swimmer task.*

The "swimmer task" also measures an individual's ability to spatially allocate attentional resources. In this task, developed by West, Stevens, Pun, and Pratt (2008)**,**

participants must search for a non-moving target amongst a large group of oscillating targets or ‘swimmers’. West et al. (2008) found that VGPs outperformed NVGPs, in that VGPs were more accurate (higher detections and lower miss rates) across a range of visual fields, under both high and low workloads.

Taken together, the results from the Useful Field of View task and the Swimmer task suggest that action video game playing improves visuospatial attention. However, not all studies examining the visuospatial attention of VGPs and NVGPs have found significant differences between the two groups (Boot et al., 2008; Murphy & Spencer, 2009).

Boot et al. (2008) compared VGPs and NVGPs on a number of cognitive tasks, including the Useful Field of View task, that assessed visual and attentional ability, spatial processing and memory, and executive control. It was found that although VGPs performed better at the task than NVGPs, the difference was not significant. Further, NVGPs who received training on an FPS game did not show a significant improvement compared to those who received training on Tetris, or who received no video game training. It should be noted that the study contained small sample sizes when comparing VGPs (n = 11) and NVGPs (n = 10), however, when comparing different video game training conditions sample sizes were larger and ranged from 19 to 23 participants. Interestingly though, C. S. Green and Bavelier (2003) were able to find significant differences between 8 VGPs and 8 NVGPs. Boot et al. (2008) attempted to replicate the study and results of C. S. Green and Bavelier (2003) and therefore used the same FPS game. Therefore, one possibility for the disparity between findings may be due to the video game player recruiting criteria (Hubert-Wallander, Green, & Bavelier, 2011). Boot et al. (2008) required participants to have played any type of video game for seven or more hours per week for the past two years to be classified as VGPs, whilst other studies have required participants to have played specifically action video games, for at least 4 to 5 hours per week (C. S. Green & Bavelier, 2003; Hubert-Wallander, Green, &

Bavelier, 2011).

### 2.1.2 Capacity of attention.

Capacity of attention refers to the number of objects in the visual field that one can direct their attention towards.

#### *2.1.2.1 Enumeration.*

In the enumeration task (Trick & Pylyshyn, 1993, 1994), multiple identical objects are briefly flashed on a screen and participants must report the number of objects presented as accurately and quickly as possible. When one to four objects are presented, participants are able to report the number of objects without counting, and their responses are quick, accurate, and predominantly automatic. The process responsible for these responses is termed subitising. As the number of objects increases beyond this range, accuracy decreases and reaction times increase, and this slower process is termed enumeration (Hubert-Wallander, Green, & Bavelier, 2011). C. S. Green and Bavelier (2003; 2006c) found that VGPs' enumeration performance was significantly greater than NVGPs, in that VGPs were able to identify the number of objects more accurately and faster for an increasing number of objects compared to NVGPs. Both groups displayed equal subitising reaction times, however, VGPs' subitising accuracy was higher than NVGPs', suggesting that VGPs have enhanced visual short-term memory. Both studies included a training paradigm in which participants completed 10 hours of an FPS game (C. S. Green & Bavelier, 2006c, experiment two) and found that action video game training significantly improved participants' attention capacity. However, Boot et al. (2008) was unable to replicate these results. It was found that video game players performed faster and more accurately than NVGPs, however the difference did not reach significance, and there was no difference between the video game training conditions.

#### *2.1.2.2 Multiple object tracking.*

The capacity of attention can also be measured through the use of a multiple object tracking task (Pylyshyn & Storm, 1988). In this task, a number of motionless target and non-target objects are presented. The objects begin to move randomly about the screen, and it is the participant's task to track the target objects. After a certain period of time the objects become motionless and all objects are made to look identical. The participant must indicate whether a selected object was a target or non-target (Hubert-Wallander, Green, & Bavelier, 2011).

C. S. Green and Bavelier (2006c, experiment four) found that VGPs outperformed NVGPs in accurately detecting whether objects were targets or non-targets. Further, after 30 hours of video game training (C. S. Green & Bavelier, 2006c, experiment five), those who played the FPS video game showed a significant improvement in multiple object tracking performance, whilst those who received the control (*Tetris*) did not. Boot et al. (2008) also found that VGPs outperformed NVGPs in a multiple object tracking task. Video game players were able to track and identify with 100% accuracy, three target objects moving at significantly higher speeds compared to NVGPs. However, there were no significant improvements in NVGPs who received 21.5 hours of video game training.

Video game players' superior enumeration and multiple object tracking performance suggests that playing FPS games enhances the speed at which individuals can update visual working memory, thus increasing the number of objects that can be viewed and tracked (C. S. Green & Bavelier, 2006c).

### 2.1.3 Attention in time.

Attention in time refers to how attention is allocated within a period of time in order to accurately and quickly process consecutive stimuli.

#### ***2.1.3.1 Attentional blink.***

The attentional blink task (Raymond, Shapiro, & Arnell, 1992) measures an individual’s ability to direct their attention in time. In this task, a primary target is presented, followed by a secondary target a few hundredths of a second later. Participants often fail to report seeing the secondary target, due to an attentional ‘blink’ (Hubert-Wallander, Green, & Bavelier, 2011). C. S. Green and Bavelier (2003) found that VGPs performed better at detecting the second target than NVGPs, thus demonstrating a shorter attentional blink. Due to the design of the task, the authors also determined that VGPs had superior task-switching abilities. These results suggest that VGPs have an enhanced ability to process information over time, however it is unclear whether this was due to faster processing, or the ability to maintain multiple attentional windows simultaneously. Boot et al. (2008) were unable to replicate the findings of C. S. Green and Bavelier (2003), however this may have been due to differences in the design of the task in the two studies, thus reducing the ability to observe any group differences.

## 2.2 Video games and Executive Control

The assessment of visual and attentional cognitive abilities often involves the completion of repetitive computer tasks involving simple stimuli. These tasks are quite dissimilar to FPS games, which are visually complex and require fast responses to novel stimuli, thus highlighting the fact that skills learned from video game playing have far transferability to other skills (Bavelier et al., 2012). Recently, it has been suggested that playing FPS games does not develop the specific skills that have been previously measured in laboratory settings, but rather that they develop the ability to quickly learn how to perform new tasks (Bavelier et al., 2012; C. S. Green, Pouget, & Bavelier, 2010).

The prevailing view is that action video game playing improves the skill referred to as ‘learning to learn’ (Bavelier et al., 2012; Dobrowolski, Hanusz, Sobczyk, Skorko, &

Wiatrow, 2015). The primary mechanism of learning is the improvement of the probability of making a correct decision based on the limited amount of data/information provided (Bavelier et al., 2012). This notion, referred to as probabilistic inference or ‘learning to learn’ (Harlow, 1949), is argued to be the unitary mechanism that accounts for video game players’ improvements in the wide range of cognitive abilities (Bavelier et al., 2012; Bisoglio, Michaels, Mervis, & Ashinoff, 2014; C. S. Green et al., 2010), as all the studies in which VGPs outperform NVGPs use tasks that require participants to “make a decision based on a limited amount of noisy data” (Bavelier et al., 2012, p. 399). Thus, it is argued that playing video games improves the general mechanisms involved in learning and the ability to control top-down attentional processes, which leads to improvements in unrelated cognitive tests (Appelbaum, Cain, Darling, & Mitroff, 2013; Bavelier et al., 2012; Dobrowolski et al., 2015). In addition, executive functions play a crucial role in learning to learn (Bisoglio et al., 2014), as they control the processes involved in changing one’s behaviour (making a decision) when the situation demands it (new information is provided) (Andrews & Murphy, 2006).

Due to mixed findings in the video game literature, whether or not action video game enhance an underlying cognitive mechanism remains debateable (Strobach, Frensch, & Schubert, 2012). Oei and Patterson (2014) have critiqued the ‘learning to learn’ hypothesis and have highlighted a number of limitations of this view. Firstly, it is unknown whether the ability of learning to learn is an improvement specific to action video games or whether it can be improved from other video game genres (Oei & Patterson, 2014), as many genres share similar gameplay mechanics (Dobrowolski et al., 2015). Secondly, it is not clear which tasks can and cannot be improved through action video game playing, and thirdly, whilst there is evidence that probabilistic inference can account for improvements in a visual perceptual task, there is a lack of evidence that it can account for the other types of tasks on which VGPs show improvements (Oei & Patterson, 2014).

Despite these limitations, evidence continues to emerge supporting the hypothesis that action video game playing improves executive control skills (Appelbaum et al., 2013; Strobach et al., 2012). As previously discussed in Section 1.4.1, executive control can be assessed through analysing performance on sustained attention tasks (Thomson et al., 2015). However, executive control is typically assessed using tasks that require divided attention, for example in dual-task (Strobach et al., 2012) multitasking paradigms (Boot et al., 2008; Cain, Landau, & Shimamura, 2012; Hambrick et al., 2010).

**2.2.1 Sustained Attention.**

Executive control plays a crucial role when performing vigilance tasks as these functions control processes involved in ignoring irrelevant stimuli and overruling automatic responses (Lorist & Faber, 2011). Dye et al. (2009b) compared sustained attention (vigilance) performance of VGPs and NVGPs, using the Test of Variables of Attention. The test is 21.6 minutes long and requires participants to respond to shapes when they appear in target locations and withhold responses to shapes appearing in other locations. It includes two test conditions, one where targets are infrequent (test of sustained attention), and one where targets are more frequent that non-targets (test of impulsivity). The authors classified VGPs as people who played action video games 5 hours or more per week in the previous year. They found that, for both segments of the test, VGPs were significantly faster than NVGPs, and that there was no significant difference in accuracy between the two groups, indicating that VGPs did not make a speed/accuracy trade-off. This provides further evidence that VGPs may be more resistant to the effects of cognitive fatigue than NVGPs. However, performance over time was not analysed (Dye et al., 2009b), and the test is too short to induce fatigue or a vigilance decrement, thus the difference in the effect of reduced executive control and increased cognitive fatigue on sustained attention performance between VGPs and NVGPs remains unexplored.

**2.2.2 Divided Attention.**

Executive control skills are important in multitasking situations as these skills allow the processing of complex situations, for example, when needing to perform differing tasks simultaneously, or rapidly switching between multiple tasks (Strobach et al., 2012). Individuals with FPS game experience have been shown to be able to multitask better than those without such experience (Chiappe et al., 2013). In a study by Kearney (2005), NVGPs completed 2 hours of training on either the FPS game *Counter-Strike*, or the puzzle game *Tetris*. Participants also completed 5 minutes of *SynWin* before and after training. *SynWin* is a PC-based multiple-task battery that includes a simple memory task, an arithmetic computation task, a visual monitoring task, and an auditory monitoring task, all presented simultaneously. Results indicated that participants trained with the FPS game for 2 hours showed a significantly greater improvement in multitasking ability compared to those who received non-FPS training (Kearney, 2005).

In another study using *SynWin*, it was found that video game experience was positively correlated with effective multitasking strategies (Hambrick et al., 2010). Effective multitasking strategies were calculated by correlating the total *SynWin* score with the response probabilities (individuals' tendency to stay on one task or switch to another). Thus, video game experience was a significant predictor of effective multitasking strategies that allowed for superior multitasking performance (Hambrick et al., 2010).

Multitasking has also been assessed using the Multi-Attribute Task Battery (MATB) (Chiappe et al., 2013; Hambrick et al., 2010). The MATB was originally developed by researchers at the National Aeronautics and Space Administration (NASA, Comstock & Arnegard, 1992) to test human performance and human/automation interaction. It consists of two primary tasks (Tracking and Resource Management) that require constant monitoring, and two secondary tasks (System Monitoring and Communications) that are performed

intermittently.

In one study that utilised the MATB to examine the effect of action video game training on divided attention performance (Chiappe et al., 2013), one group of NVGPs played a range of action video games for a minimum of 5 hours per week for 10 weeks, whilst the control group did not play any video games. It was found that those that completed more video games showed the greatest improvements. However, action video game training only resulted in improved performance (faster responses and fewer errors) on the secondary tasks, with no reduction in performance on the primary tasks. Overall, there were no differences between the groups in performance on the primary tasks. These results suggest that video game playing increases both visual and auditory attention capacity, and it is this increased capacity that allowed the video game players to perform better at the secondary tasks without affecting performance on the primary tasks (Chiappe et al., 2013).

Currently, whether or not there is an underlying cognitive mechanism that transfers improved video game performance to other tasks is uncertain (Boot et al., 2008; Strobach et al., 2012). This is not surprising as not all studies find transfer effects between FPS video game playing and single (Murphy & Spencer, 2009; van Ravenzwaaij, Boekel, Forstmann, Ratcliff, & Wagenmakers, 2014) or dual-task cognitive tests (Donohue, James, Eslick, & Mitroff, 2012). It has been highlighted in the previous sections that there are some inconsistent findings within video game research. Further, it has been noted by others (see Boot, Blakely, & Simons, 2011; Kristjánsson, 2013) that methodological shortcomings limit the conclusions of the literature. These issues are discussed in the following section.

**2.3 Methodological Limitations of Video Game Research**

Research investigating the effects of video game playing on cognitive abilities must be interpreted with caution, as not all studies find significant differences in cognitive abilities between VGPs and NVGPs (Unsworth et al., 2015). Video game studies, particularly those

with training paradigms, are limited by potential methodological flaws that can occur in all research with clinical trials and experiments that focus on expertise (Boot et al., 2011). These issues include, but are not limited to, recruitment methods, comparable control conditions, and recruitment criteria (Boot et al., 2011; Dobrowolski et al., 2015; C. S. Green, Strobach, & Schubert, 2013; Unsworth et al., 2015).

#### 2.3.1 Recruitment.

Nearly all studies comparing VGPs and NVGPs specifically recruit for either group, or fail to report how recruitment occurred (Boot et al., 2011). The belief that one should perform well in a task can positively influence ones performance on that task (Langer, Djikic, Pirson, Madenci, & Donohue, 2010). Thus, if a VGP is aware that they have been recruited because of their experience with video games, and then the experiment requires the completion of a video game, or video-game-like task, they will be more motivated to perform well, compared to NVGPs who would have no reason to be as motivated (Boot et al., 2011). Therefore, it will be more likely that VGPs will perform even better than expected, increasing the likelihood of finding a significant difference between the two groups. Although this methodological limitation does not account for differences between novices and experts, and may be negligible on its own, it is possible that when combined with other methodological limitations, or when effects are small, that the potential of finding a significant difference is increased.

Further, simply comparing VGPs and NVGPs is not enough to conclude that playing video games is the cause of any differences. It is possible that VGPs possessed specific cognitive abilities that allowed them to perform well at video games, and because they were good at these games they continued to play them (Adams & Mayer, 2012). Therefore, to account for this possibility, training studies are used (Bavelier et al., 2012), however, this raises the potential issue of implementing an effective control condition.

### 2.3.2 Control condition.

In clinical trials it is important to have a comparable control or placebo group, and the same is necessary in training studies (Boot et al., 2011). However, if a video game training condition was compared to a non-active control condition, then any improvement in the video game conditions could be the result of a placebo effect or any number of other non-experimental effects such as the Hawthorne effect (participants' performance increases due to receiving attention from the experimenter) (C. S. Green et al., 2009). Fortunately, many video game training studies have used an active control condition, for example an FPS game compared with a non-FPS game (Boot et al., 2011). However, choosing an appropriate control condition is a complex issue. There is no standard accepted taxonomy of video game genres (Connolly et al., 2012), and games often differ within each genre (Spence & Feng, 2010). Unfortunately, the majority of game training studies assume that providing, for example, a slower-paced puzzle game like *Tetris* is an adequate control video game when comparing to a fast-paced action FPS game. Boot et al. (2011) suggest that participants' perceptions vary as to the benefits of different games in improving different cognitive abilities. Therefore, the experiment remains subject to a placebo effect whereby participants have no reason to believe that training in a control condition would improve their performance on the experimental measure.

### 2.3.3 Definition of action video game players.

As previously mentioned, there is no standard definition for each video game genre (Connolly et al., 2012), and games vary widely within each genre (Spence & Feng, 2010). As such, what is considered to be an 'action' video game is debatable (Oei & Patterson, 2015). Within this genre exist a wide range of types, requiring differing levels of perceptual and cognitive skills (Latham, Patston, & Tippett, 2013a; Oei & Patterson, 2015), and it has been suggested that this lack of concrete categorisation is a contributing factor to the inconsistent

results in the video game literature (Bisoglio et al., 2014). In addition, although the focus of research has typically been on FPS video games, VGPs rarely only play one sub-genre of video game (Dobrowolski et al., 2015), thus complicating the interpretation of results.

In addition to there being no standard definition of an action video game, there is no standard definition of what constitutes a video game player. The criteria for a participant to be classed as a VGP has ranged from playing video games 2 hours per week for the previous 6 months (Donohue, Woldorff, & Mitroff, 2010) to playing more than 7 hours per week for the previous 2 years (Boot et al., 2008). However, some studies have attempted covert recruitment as suggested by Boot et al. (2011), and thus defined VGPs and NVGPs after receiving responses to video game history questionnaires (Bailey, 2009), resulting in further inconsistencies.

A further limitation concerning the definition of video game players is the use of the term *expert*. Studies often refer to VGPs as experts, rather than as those with more video game experience (Andrews & Murphy, 2006; Boot et al., 2008; Karle et al., 2010; Zhang, Shen, Luo, Su, & Wang, 2009). Although the process of becoming an expert may require many hours of practice (VanDeventer & White, 2002), it is not sufficient criteria for being considered an expert. Most psychologists agree that experts display superior performance than novices, as measured by speed, accuracy and/or efficiency (Speelman, 1998). Thus, expertise is based on the results of performance, not the amount of time spent performing. Therefore, as the majority of research studies use self-report questionnaire to determine group classification, VGPs should not be referred to as experts (Latham, Patston, & Tippett, 2013).

In addition, the use of self-report measures fails to take into consideration differences between VGPs (Unsworth et al., 2015). There is likely to be a larger range of video game experience in the VGP group, whilst most NVGPs will be similar in the experience. For example, a participant who has recently purchased a new console and/or game and has been

playing regularly for the past six months will be considered equal to a participant who has been playing regularly for the past 10 years (Latham et al., 2013a; Unsworth et al., 2015).

## Chapter 3: Study 1 - Video Game Experience and Resistance to Cognitive Fatigue

Sustained attention, the ability to maintain attentional focus and remain alert for long periods of time, and divided attention, the ability to perform two or more tasks simultaneously (Matthews, 2000), play crucial roles in human performance in a range of occupations (e.g. pilots, unmanned vehicle operators, air traffic controllers, power plant operators, long-distance drivers, and security surveillance operators) (Chiappe et al., 2013; Durso & Sethumadhavan, 2008; Finomore et al., 2009; Gartenberg et al., 2013; Hubal et al., 2010; Warm, Matthews, et al., 2008; Warm, Parasuraman, et al., 2008). Performing such complex cognitive tasks for long periods of time can result in cognitive/mental fatigue, which can lead to reduced task performance and an increased likelihood of error (Ackerman, 2011; Guastello et al., 2013; Lal & Craig, 2001; Van Dongen et al., 2011). This decline in task performance over time is known as the fatigue effect or the time-on-task effect (Van Dongen et al., 2011).

It has previously been shown that those who regularly play (or those who are trained on) first-person shooter (FPS) action video games demonstrate improved performance in a range of cognitive areas, including those used when performing sustained attention (Boot et al., 2008; Castel et al., 2005; Dye et al., 2009b; C. S. Green & Bavelier, 2003, 2006b, 2007; Hubert-Wallander, Green, Sugarman, et al., 2011; T. N. Schmidt et al., 2012), and divided attention tasks (Chiappe et al., 2013; Dye et al., 2009a; Gaspar et al., 2013; Hambrick et al., 2010; Kearney, 2005). Action video games include features such as instant feedback of performance, variability of training (Healy et al., 2012), motivated and focused learning, and increasing levels of difficulty (C. S. Green et al., 2009), which all relate closely to well-known training principles (Chiappe et al., 2013). Thus, it is possible that these features provide a medium through which to improve people’s divided and sustained attention performance (Pavlas et al., 2008). However, although the hypothesis that playing action video

games can improve sustained attention and divided attention performance is supported in theory, there is currently little research on the topic, and none that explicitly focuses on cognitive fatigue. Thus, the purpose of this research study was to investigate whether action video game players (VGPs) were more resilient to the effects of cognitive fatigue compared to non-video game players (NVGPs), as measured by sustained attention and divided attention task performance.

Initially, cognitive fatigue was considered to be the outcome of depleted cognitive resources. However, after reviewing the literature, Hockey (2013) proposed that cognitive fatigue is instead an adaptive mechanism, with the function of controlling and managing motivation and behaviour, and is therefore connected to executive functions. As previously discussion in Section 1.3, executive functions are higher-order cognitive control processes that organise and control lower-level cognitive functions according to the individual's goals (van der Linden, 2011). They are used when irrelevant stimuli need to be ignored, when automatic responses need to be overruled, and when information needs to remain active in memory for extended durations (van der Linden, 2011). Over time, the amount of mental effort required in using executive control to perform these tasks increases, resulting in a reduction in the efficiency of these functions, and thus the occurrence of the fatigue effect (Earle et al., 2015; Lorist & Faber, 2011; Lorist et al., 2000; van der Linden, 2011; van der Linden et al., 2003).

Executive control is typically assessed using tasks that require attention to be switched between two or more different tasks (Boot et al., 2008; Cain et al., 2012; Hambrick et al., 2010). Previous research has examined divided attention performance using multitasking paradigms (Chiappe et al., 2013; Hambrick et al., 2010), for example the Multi-Attribute Task Battery (MATB). The MATB was originally developed by researchers at the National Aeronautics and Space Administration (NASA, Comstock & Arnegard, 1992) to test

human performance and human/automation interaction. It consists of two primary tasks (Tracking and Resource Management) that require constant monitoring, and two secondary tasks (System Monitoring and Communications) that are performed intermittently.

Chiappe et al. (2013) used the MATB to examine the effect of action video game training on divided attention performance. In their study, one group of NVGPs played a range of action video games for a minimum of 5 hours per week for 10 weeks, whilst the control group did not play any video games. It was found that action video game training resulted in improved performance (faster responses and fewer errors) on the secondary tasks, with no reduction in performance on the primary tasks. Although participants spent 90 minutes on the MATB, only the last 30 minutes were used in the analysis, and thus any effect of cognitive fatigue on divided attention performance could not be examined. However, this study does add to the existing evidence (Bavelier et al., 2012; Cain et al., 2012; Hambrick et al., 2010; Kearney, 2005) that video game playing can lead to improved multitasking abilities and thus superior executive functioning, compared to NVGPs.

The fatigue effect can also be measured through the vigilance decrement, which is characterised by increasing reaction times and/or decreasing detection accuracy on a vigilance task that typically occurs after 20 to 35 minutes performing the task (Buck, 1966; Hancock, 2013; Helton & Russell, 2012; Mackworth, 1948; See et al., 1995). Currently, the resource theory (Fisk & Scerbo, 1987; Fisk & Schneider, 1981; Kahneman, 1973; Parasuraman & Davies, 1977; C. D. Wickens, 1984) is the dominant model used to explain the vigilance decrement (Helton & Russell, 2012). However, neither the resource theory view of vigilance, nor its opponents, the under-load (Frankmann & Adams, 1962; Heilman, 1995; Loeb & Alluisi, 1977; Welford, 1968) and mind-wandering theories (Robertson et al., 1997), can adequately account for all findings related to the vigilance decrement. Instead, similar to cognitive fatigue, it has been proposed that the vigilance decrement is due to reduced

executive functioning, rather than a lack of cognitive resources (Thomson et al., 2015).

Thomson et al. (2015) proposed that performing vigilance tasks taxes executive functions, as these functions control the ability to ignore irrelevant stimuli and inhibit automatic responses Over time, as executive functions become taxed, an insufficient amount of attentional resources are allocated towards the task, resulting in deteriorating vigilance performance. It is therefore possible that individuals with greater executive control will be better able to direct the required attentional resources towards the vigilance task, resulting in improved performance over a longer period of time (Thomson et al., 2015).

Dye et al. (2009b) compared sustained attention (vigilance) performance of VGPs and NVGPs, using the Test of Variables of Attention. The test is 21.6 minutes long and requires participants to respond to shapes when they appear in target locations and withhold responses to shapes appearing in other locations. It includes two test conditions, one where targets are infrequent (test of sustained attention), and one where targets are more frequent that non-targets (test of impulsivity). The authors classified VGPs as people who played action video games 5 hours or more per week in the previous year. They found that, for both segments of the test, VGPs were significantly faster than NVGPs, and that there was no significant difference in accuracy between the two groups, indicating that VGPs did not make a speed/accuracy trade-off. This provides further evidence that VGPs may be more resistant to the effects of cognitive fatigue than NVGPs. However, performance over time was not analysed (Dye et al., 2009b), and the test is too short to induce fatigue or a vigilance decrement, thus the difference in the effect of cognitive fatigue on sustained attention performance between VGPs and NVGPs remains unexplored.

### 3.1 The present study

In the present study, the effects of cognitive fatigue on VGPs and NVGPs were compared. Cognitive fatigue was induced by time-on-task, with participants completing a

gradual-onset Continuous Performance Task (gradCPT) for 60 minutes. Time-on-task is a common method of inducing fatigue (Lorist et al., 2000), and often involves completing continuous vigilance tasks (Xiao et al., 2015).

The continuous-performance design was chosen because it measures moment-to-moment fluctuations in reaction times and accuracy, requiring participants to respond to frequent non-target stimuli and to withhold responses to the rare target stimuli (Esterman et al., 2012; Larue et al., 2010; Rosenberg et al., 2013). Although the vigilance decrement has not been consistently found using this design (Helton et al., 2009; Rosenberg et al., 2013), Esterman et al. (2012) found that using gradual-onset stimuli in a continuous performance task, rather than abrupt-onset stimuli, successfully taxes the ability to sustain attention. In the present study, stimuli gradually transitioned from the inter-stimulus mask (‘X’) into the stimulus (a random number between 1 and 9) and back into the inter-stimulus mask.

Performance accuracy on the gradCPT was measured according to signal detection theory using sensitivity (*d'*) and response criterion (*c*, also referred to as $\lambda_{centred}$) (T. D. Wickens, 2001). Sensitivity measures how well the signal (target) can be detected from the noise (non-targets). When *d'* is close to zero, targets are difficult to detect and when it is large they are easy to detect. Typically, participants have little to no control over signal detectability as it is mostly influenced by the way the stimuli are created in the experimental design (e.g. size of stimulus). Signal detectability is also influenced by the physiology involved in the detection process (T. D. Wickens, 2001). In the current experiment the presentation of the stimuli remained consistent throughout the experiment, thus any reduction in sensitivity levels is a result of cognitive fatigue. The response criterion (*c*) represents the amount of evidence needed by the observer in order to classify a stimulus as a target. When the evidence is greater than the response criterion level, the observer classifies the stimulus as a target, and when it is below, it is classified as noise. Response criterion levels however, are

controlled by the individual, as this is a representation of their response strategy/bias. The response criterion is a representation of the amount of evidence needed by the participant for them to determine whether a stimulus is a signal (target) or noise (non-target); if the evidence is above the response criterion level, the stimulus is classified as a signal. Thus, decreasing response criterion levels indicate an increased propensity to respond to a stimulus (less evidence is needed), resulting in more correct responses but also more false alarm errors (T. D. Wickens, 2001).

Participants also completed a 20-minute version of the updated MATB (MATB-II) prior to, and after the gradCPT task. Comparing task performance when rested and fatigued is a common method of assessing the effects of fatigue (Chaiken et al., 2011). Performance on the first MATB-II session provided an initial measure of executive function for VGPs and NVGPs and any decline in MATB-II performance between the first and second MATB-II sessions is therefore attributed to cognitive fatigue.

At the end of the second MATB-II session, participants played the FPS video game *Unreal Tournament 2004* by Atari, on a computer. Previous research has classified participants as ‘video game experts’ based purely on self-report measures of how often they play (Latham, Patston, & Tippett, 2013b) and although the process of becoming an expert may require many hours of practice (VanDeventer & White, 2002), it is not sufficient criteria for being considered an expert. Experts are individuals who display superior performance compared to novices, as measured by speed, accuracy and/or efficiency (Speelman, 1998). Although it has been previously suggested (Latham et al., 2013b; Towne, Ericsson, & Sumner, 2014; Wang, Richard, & Schmular, 2014), there is a lack of research that uses objective measures to classify participants as either VGPs or NVGPs, and many authors often use the argument that doing so is impractical (Gobet et al., 2014). To maintain consistency with previous research, a self-report questionnaire was also used to classify participants as

VGPs or NVGPs in conjunction with participants' video game performance.

## 3.2 Hypotheses

Previous research has shown that VGPs outperform NVGPs on short vigilance tests (Dye et al., 2009b), and that they demonstrate superior performance on tasks related to sustained attention (Boot et al., 2008; Castel et al., 2005; C. S. Green & Bavelier, 2003, 2006b, 2007; Hubert-Wallander, Green, Sugarman, et al., 2011; T. N. Schmidt et al., 2012). Therefore it was predicted that VGPs would perform better than NVGPs on all measures of the gradCPT. Due to the vigilance decrement, it was expected that performance for both groups would decline as time-on-task increases. However, it was hypothesised that the decline would be greater for NVGPs than VGPs.

Video game experience has been shown to improve divided attention performance (Chiappe et al., 2013). Therefore, it was hypothesised that VGPs would perform better than NVGPs on both the first and second sessions of the MATB-II. Due to the time-on-task effect and being fatigued from the gradCPT, it was expected that MATB-II performance for both groups would decline from session 1 to session 2. However, it was predicted that VGPs would experience a smaller reduction compared to NVGPs. The MATB-II also includes the Workload Rating Scale (WRS), a measure of subjective workload. It was predicted that as VGPs should perform better in the MATB-II, then they should also experience lower levels of subjective workload.

## 3.3 Method

This study received approval from the Edith Cowan University Human Research Ethics Committee.

### 3.3.1 Participants.

Forty-seven individuals were recruited from Edith Cowan University, Western Australia, through announcements in undergraduate classes, flyers, and word-of-mouth.

Three participants withdrew from the study and therefore their data was not used. All participants went into a draw to win one of two $50 gift cards. Two participants were over the age of 60 years and therefore their data was removed in order to avoid a potential age confound. In addition, one of these participants reported to be a VGP, however was considered to be a NVGP based on their video game performance. The removal of these participants resulted in data for 42 participants being used in the present study.

To maintain consistency with previous research, participants were classified as VGPs if they reported playing FPS games for 4 or more hours per week, for a minimum of 1 hour each time, over the previous 6 months. Participants were also asked to specify which video games (of any genre) they most commonly played as well as the video game genre and platform (see Appendix A). After completing the cognitive tests, participants practiced the video game for 2 minutes on ‘novice’ difficulty and then completed three 5-minute games on ‘expert’ difficulty. Performance was calculated by subtracting the number of deaths from the number of kills and averaging over the three games. Participants who were classified as VGPs based on their self-report measure all scored above 0, indicating that they killed the enemy target more times than they themselves were killed. In addition, there were seven participants who scored above 0 but did not meet the self-report VGP criteria. However, upon further investigation, it was found that these individuals did report to playing FPS games for less than 4 hours per week and/or reported to playing other action video games (e.g. racing, 3$^{rd}$ person shooter games) for 4 or more hours per week over the previous 6 months, and so they were also classified as VGPs. Thus, all participants who scored above 0 in *Unreal Tournament 2004* reported playing action video games for 4 or more hours per week over the previous 6 months, and all participants who scored below 0 reported playing no video games of any genre. To confirm group allocation, a between-groups t-test was conducted on *Unreal Tournament 2004* performance. There was a significant difference in *Unreal Tournament*

*2004* (UT2004 score) between those classified as VGPs and those classified as NVPGs, $t(40) = 13.86$, $p < .001$ (see Table 3.1).

Table 3.1

*Participants' demographic details and video game performance*

| | Sex | | Age (years) | | UT2004 score | |
|---|---|---|---|---|---|---|
| Group | Male | Female | Mean | SD | Mean | SD |
| VGP | 15 | 3 | 26.50 | 7.33 | 6.39 | 3.35 |
| NVGP | 5 | 19 | 37.92 | 11.28 | -8.40 | 3.48 |

### 3.3.2 Tasks.

#### *3.3.2.1 Sustained attention (gradCPT).*

The gradCPT was created using the E-Prime 2.0 software. In the gradCPT task, participants were required to respond (press the spacebar) to the numbers '1' through to '9', except for the number '4' (the target). There were a total of 2400 stimuli, with the target occurring 480 times (probability of occurrence of 0.2). The stimuli were presented individually, fading in and out at the centre of the computer monitor. The stimuli were separated by an inter-stimulus mask ('X') that also faded in and out. The duration of the transition from inter-stimulus mask to the next stimulus (and vice versa) was 500ms, and each stimulus was presented at 100% opacity for 500ms before beginning the transition back to the inter-stimulus mask. The stimuli were presented in size 72.5 Arial font, on a 20-inch computer monitor.

The gradCPT was divided into ten 6-minute periods, each consisting of 240 trials. Reaction times (RT) were collapsed to mean values that were used for the analysis. In addition, the standard deviations of RTs for each period were used to analyse the variability of the raw reaction times. Reaction times were measured from stimulus onset, that is, from

when the inter-stimulus mask ('X') began the gradual transition into the numbered stimulus. Thus, a reaction time between 150ms and 500ms indicated a response that occurred when the inter-stimulus symbol was transitioning into the stimulus, a reaction time between 500ms and 1000ms indicated a response that occurred when the stimulus was at 100% opacity, and a reaction time between 1000ms and 1500ms indicated a response that occurred when the stimulus was transitioning into the following inter-stimulus mask. Response times less than 150ms were considered anticipatory and were therefore labelled as errors.

***3.3.2.2 Divided attention (MATB-II).***

The tasks in the current version of the MATB, the revised MATB (MATB-II), are approximations of those in a flight-deck, consisting of two primary tasks; tracking and fuel management; and two secondary tasks, systems monitoring and a communication task (see Figure 3.1).

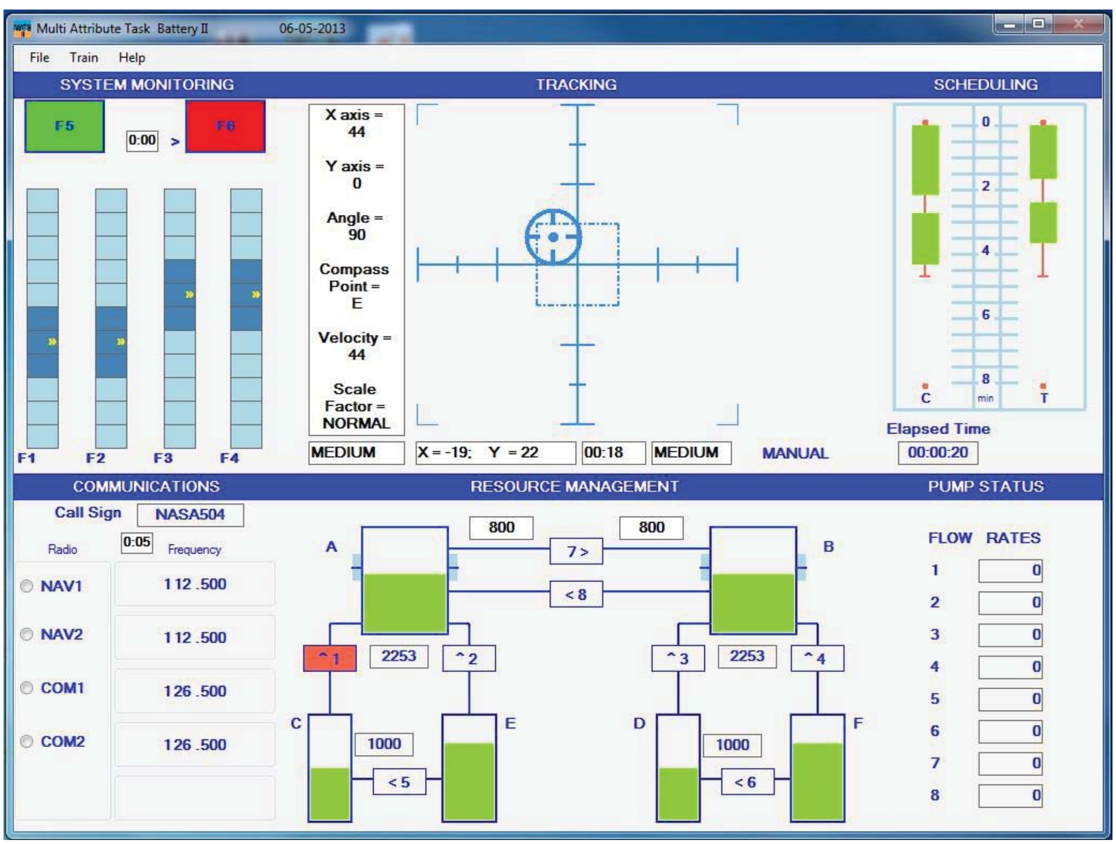


*Figure 3.1.* The on-screen display of the revised Multi-Attribute Task Battery (MATB-II).

The tracking task requires the participant to use a computer joystick to keep the reticule in the centre of the square of the cross-hairs. The fuel management task requires the participant to turn the eight pumps ‘on’ or ‘off’ in order to maintain them as closely as possible to a pre-determined level. Occasionally, a pump will ‘fail’ and become unusable for a set period of time. Thus, the participant must determine how to best re-direct the fuel. In the systems monitoring task, the participant must monitor two lights and four dials. For the lights task, participants are required to keep one light on, and another light off. For the dial task, participants must reset a dial if it is fluctuating outside of a specified range. The communications task requires participants to respond to the call-sign “NASA-504” and alter one button and one dial setting to match that of an audio message, and to ignore messages for other call-signs.

Each MATB-II session was designed to include the same number of events so as to maintain task difficulty between sessions. For the System Monitoring task, participants had to respond within a 10-second time limit, and for the Communications task there was a 30-second time limit. The Tracking task remained in the ‘manual’ setting for the entire duration.

While the MATB-II produces data on 21 measures, however, in keeping with methods used by Chiappe et al. (2013) only eight were used in the analysis, as these did not suffer from range restrictions, and are commonly reported in previous studies (Caldwell & Ramspott, 1998; Singh, Tiwari, & Singh, 2010). The Communications task consisted of two measures, mean reaction time (seconds) of correct responses and accuracy of correct responses. The Tracking task consisted of one measure, the root mean squared deviation (RMSD) of the distance (in pixels) of the reticule of the joystick to the centre of the target location. The Resource Management task consisted of one measure, the mean deviation of the fuel level in Tanks A and B, from the target level of 2500 units. The System Monitoring task was separated between the Light task and the Scale task. Each of these consisted of two

measures, mean reaction time (seconds) of correct responses and accuracy of correct responses. For the Tracking and Resource Management tasks, low values indicate better performance.

The MATB-II also includes a Workload Rating Scale (WRS) that is completed at the end of the session and was analysed separately to the eight MATB-II performance measures. The WRS is based on the NASA-TLX (Hart & Staveland, 1988) and consists of six subscales of workload: mental demand, physical demand, temporal demand, (subjective level of) performance, effort, and frustration. All subscales are measured on a 100-point scale, and each is measured from ‘low’ to ‘high’ except for the performance subscale which was reversed because a low rating of subjective performance is an indication of high workload.

**3.3.3 Procedure.**

After receiving an information letter (Appendix B) and signing the consent form (Appendix C), participants were instructed on how to perform the MATB-II. Participants were shown an image of the MATB-II and provided with verbal instructions on each of the four tasks. Participants then completed a 5-minute practice version of the task whilst the experimenter provided directions and assistance and answered any questions. Upon completion, the experimenter left the room and the participant completed the first 20-minute MATB-II session on their own.

The experimenter then provided instructions on how to complete the gradCPT, and informed the participants that they should respond as quickly and accurately as possible. Participants then completed a 1-minute practice version of the gradCPT while the experimenter ensured that they were attempting to respond correctly. The experimenter left the room whilst participants completed the 60-minute version of the task. Upon completion, the experimenter then initiated the second MATB-II session. No further practice was provided, however the experimenter answered any questions participants had about

performing the task.

At the completion of the second MATB-II session, participants were allowed to take a short break before returning and playing the FPS game *Unreal Tournament 2004*. Similar to the other tasks, participants were shown an image of the game and provided verbal instruction on the controls and how to play. They then practiced the game for 2 minutes, before completing three 5-minute games. All verbal instructions for all tasks, including the video game, were scripted to ensure the same instructions were provided to all participants regardless of video game experience.

## 3.4 Results

### 3.4.1 Sustained attention.

A doubly-multivariate profile analysis was initially conducted on the four measures of sustained attention performance (reaction time, reaction time variability, sensitivity, response criterion), with post hoc tests conducted as required.

Profile analysis is a multivariate alternative to the repeated-measures ANOVA. A popular extension of the profile analysis is the doubly-multivariate profile analysis, which is used when multiple dependent variables are measured at multiple time points (Tabachnick & Fidell, 2007). In profile analysis, parallelism is the multivariate alternative to the univariate test of interaction. When two or more profiles are parallel there is no interaction, that is, differences between the groups are constant across the levels of the dependent variable. The test for equality of levels (or equality of groups) is the multivariate alternative to the univariate between-subjects test. The flatness of profiles test (or test for equality of levels) is the multivariate alternative to the univariate within-subjects test (Tabachnick & Fidell, 2007).

#### ***3.4.1.1 Doubly-multivariate Profile Analysis.***

A 2 (group) x 10 (period) doubly-multivariate profile analysis was conducted on the sustained attention performance of VGPs and NVGPs using the four measures: reaction time,

reaction time variability, sensitivity (d'), and response criterion (c). The group by period interaction (deviation from parallelism) was not significant, $V = 0.81$, $F(36, 5) = 0.59$, $p = .839$, partial $\eta^2 = .81$. The equality of levels test was significant, indicating a difference in sustained attention performance between VGPs and NVGPs, $V = 0.27$, $F(4, 37) = 3.33$, $p = .020$, partial $\eta^2 = .27$. For the flatness test, there was no significant change in performance over time (difference between periods), $V = 0.92$, $F(36, 5) = 1.59$, $p = .321$, partial $\eta^2 = .92$.

Each of the four measures was analysed individually to determine on which measures the VGPs and NVGPs differed.

***3.4.1.2 Reaction time.***

The reaction time (RT) profiles of the VGPs and NVGPs , seen in Figure 3.1, did not deviate significantly from parallelism, $V = 0.26$, $F(9, 32) = 1.25$, $p = .301$, partial $\eta^2 = .26$.

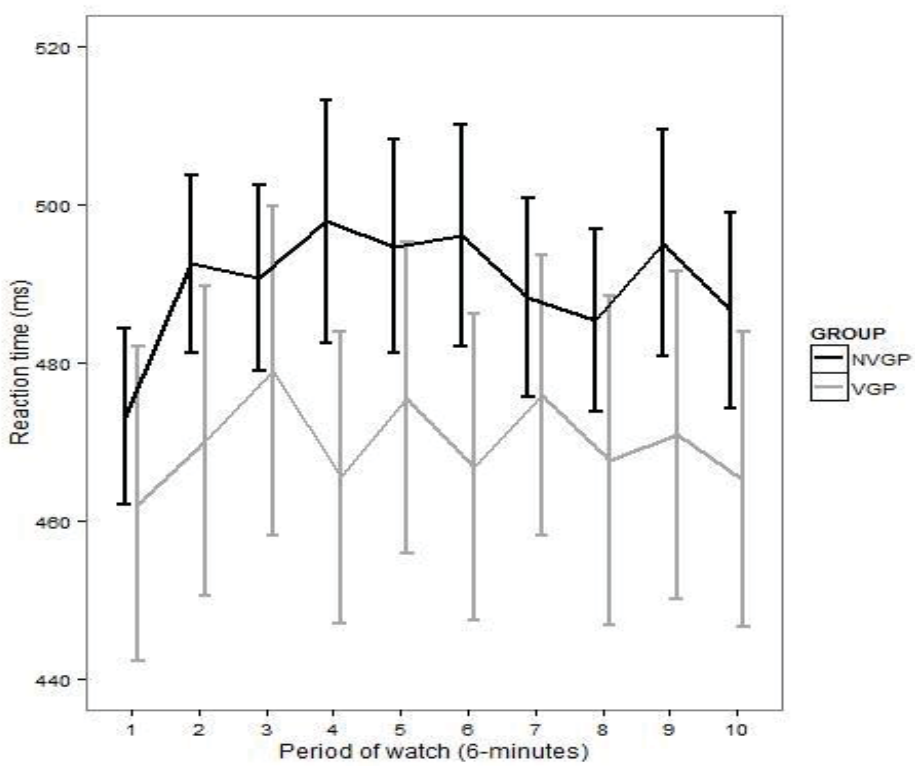


*Figure 3.2.* Mean reaction times (ms) of correct responses across periods. Error bars represent ±1 standard error.

For the equality of levels test, when reaction times were averaged over all periods,

there was no significant difference between VGP (*M* = 469.84ms, *SE* = 15.85) and NVGP (*M* = 490.06ms, *SE* = 13.73), $F(1, 40) = 0.93$, $p = .341$, partial $\eta^2 = .02$.

For the flatness test, when averaged over groups, there was no significant difference between periods, indicating no deviation from flatness, $V = 0.27$, $F(9, 32) = 1.28$, $p = .285$, partial $\eta^2 = .27$.

*3.4.1.2.1 VGP*.

Mauchly's test of sphericity was conducted on the RT of VGPs. The assumption of sphericity was violated, $\chi^2(44) = 82.68$, $p = .001$, therefore the degrees of freedom were corrected using the Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.495$). The results showed that there was no significant effect of period, $F(4.46, 75.75) = 7.43$, $p = .580$, partial $\eta^2 = .04$.

*3.4.1.2.2 NVGP*.

Mauchly's test of sphericity was conducted on the RT of NVGPs. The assumption of sphericity was violated, $\chi^2(44) = 104.39$, $p < .001$, therefore the degrees of freedom were corrected using the Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.442$). The results showed that there was no significant effect of period, $F(3.98, 91.47) = 1.47$, $p = .219$, partial $\eta^2 = .06$.

***3.4.1.3 Reaction time variability (Standard deviation).***

The profiles of reaction time variability for VGPs and NVGPs, seen in Figure 3.2, were parallel, $V = 0.13$, $F(9, 32) = 0.54$, $p = .836$, partial $\eta^2 = .13$.

For the equality of levels test, when variability of reaction times were combined over all periods, there was no significant difference between VGPs (*M* = 90.89, *SE* = 6.46) and NVGPs (*M* = 93.92, *SE* = 5.59), $F(1, 40) = 0.13$, $p = .725$, partial $\eta^2 = .003$.

For the flatness test, when combined over groups, there was a significant difference between periods, indicating a significant deviation from flatness, $V = 0.489$, $F(9, 32) = 3.41$,

$p$ = .005, partial $\eta^2$ = .49.

Post hoc tests were conducted to examine the differences between periods within each of the groups.

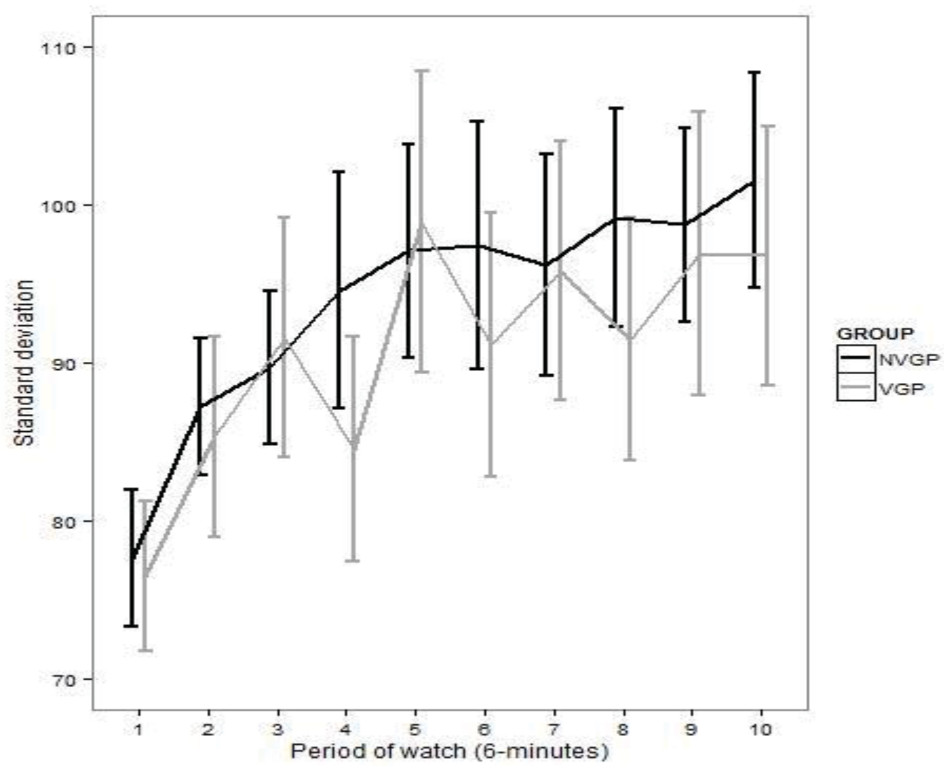


*Figure 3.3*. Variability of raw reaction times (standard deviation units) across periods. Error bars represent ±1 standard error.

*3.4.1.3.1 VGP*.

Mauchly's test of sphericity was conducted on the reaction time variability (SD) of VGPs. The assumption of sphericity was violated, $\chi^2(44)$ = 73.67, $p$ = .005, therefore the degrees of freedom were corrected using the Greenhouse-Geisser estimates of sphericity ($\varepsilon$ = 0.52). The results showed that there was a significant effect of period, $F(4.67, 79.35)$ = 3.03, $p$ = .017, partial $\eta^2$ = .15, and a significant linear trend, $F(1, 17)$ = 9.78, $p$ = .006, partial $\eta^2$ = .37.

*3.4.1.3.2 NVGP.*

Mauchly's test of sphericity was conducted on the reaction time variability (SD) of NVGPs. The assumption of sphericity was violated, $\chi^2(44) = 68.80$, $p = .012$, therefore the degrees of freedom were corrected using the Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.58$). The results showed that there was a significant effect of period, $F(5.24, 120.49) = 3.99$, $p = .002$, partial $\eta^2 = .15$, and a significant linear trend, $F(1, 23) = 17.57$, $p < .001$, partial $\eta^2 = .43$.

***3.4.1.4 Sensitivity.***

The profiles of sensitivity of VGPs and NVGPs, seen in Figure 3.3, were parallel, $V = 0.08$, $F(9, 32) = 0.37$, $p = .967$, partial $\eta^2 = .08$.

For the equality of levels test, when d' values were combined over all periods, there was no significant difference between VGPs ($M = 3.95$, $SE = 0.21$) and NVGPs ($M = 4.46$, $SE = 0.19$), $F(1, 40) = 3.27$, $p = .078$, partial $\eta^2 = .08$.

For the flatness test, when combined over groups, the difference in sensitivity between periods was significant, $V = 0.58$, $F(9, 32) = 4.85$, $p < .001$, partial $\eta^2 = .58$.

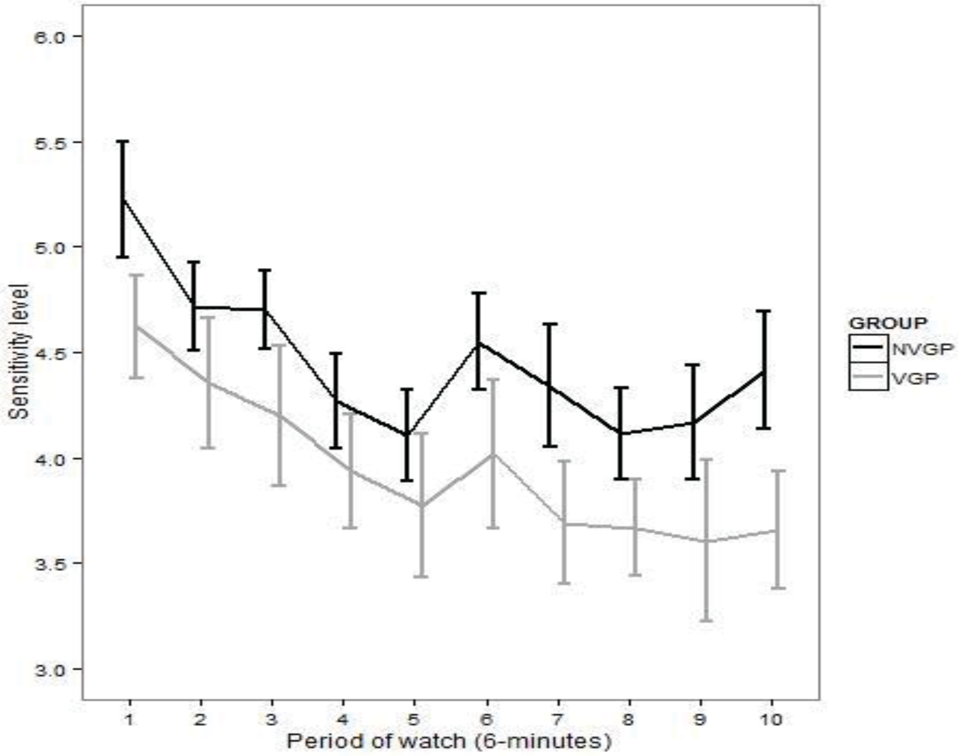


*Figure 3.4.* Sensitivity levels across periods. Error bars represent ±1 standard error.

*3.4.1.4.1 VGP.*

Mauchly's test of sphericity was conducted on the sensitivity levels of VGPs. The assumption of sphericity was violated, $\chi^2(44) = 99.74$, $p < .001$, therefore the degrees of freedom were corrected using the Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.487$). The results showed that there was a significant effect of period, $F(4.39, 74.57) = 2.53$, $p = .042$, partial $\eta^2 = .13$, and a significant linear trend, $F(1, 17) = 8.65$, $p = .009$, partial $\eta^2 = .34$.

*3.4.1.4.2 NVGP.*

Mauchly's test of sphericity was conducted on the sensitivity levels of NVGPs. The assumption of sphericity was not violated, $\chi^2(44) = 48.34$, $p = .323$. The results showed that there was a significant effect of period, $F(9, 207) = 3.84$, $p < .001$, partial $\eta^2 = .14$, and a significant linear trend, $F(1, 23) = 10.42$, $p = .004$, partial $\eta^2 = .31$, as well as a significant quadratic trend, $F(1, 23) = 7.01$, $p = .014$, partial $\eta^2 = .23$.

***3.4.1.5 Response Criterion.***

The profiles of response criterion levels of VGPs and NVGPs, seen in Figure 3.4, were parallel, $V = 0.097$, $F(9, 32) = 0.38$, $p = .936$, partial $\eta^2 = .10$.

For the equality of levels test, when c values were combined over all periods, the difference between VGPs ($M = 1.05$, $SE = 0.08$) and NVGPs ($M = 0.96$, $SE = 0.07$) was not significant, $F(1, 40) = 0.734$, $p = .397$, partial $\eta^2 = .02$.

For the flatness test, when combined over groups, the difference in the response criterion between periods was significant, indicating a deviation from flatness, $V = 0.45$, $F(9, 32) = 2.89$, $p = .013$, partial $\eta^2 = .45$.

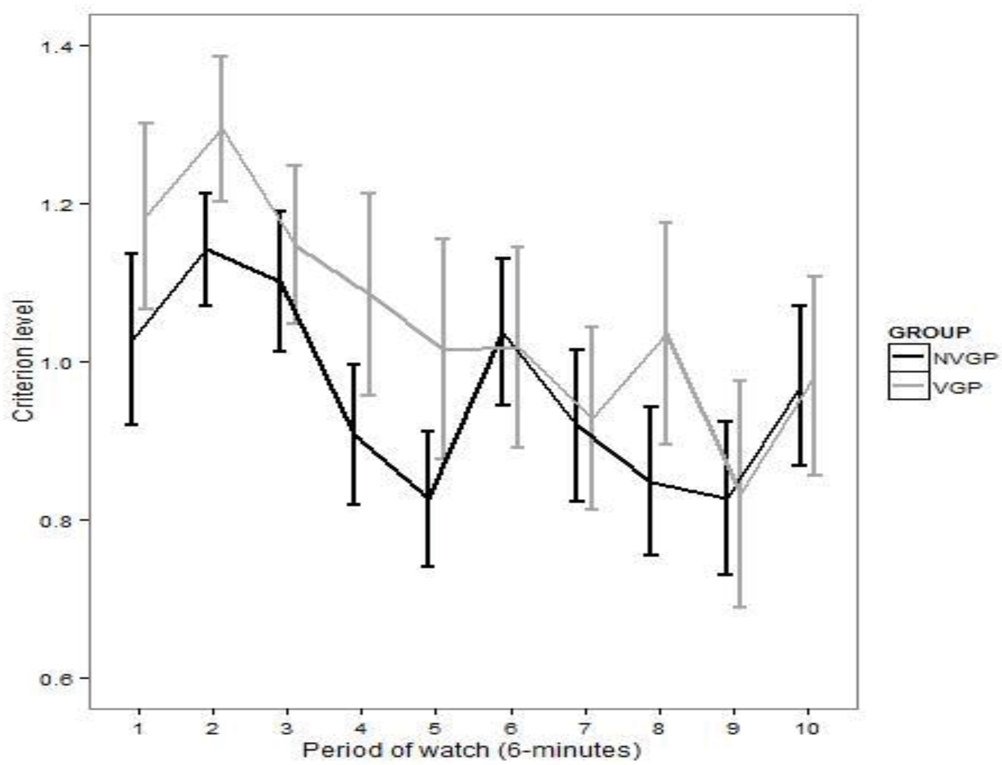


*Figure 3.5*. Criterion levels across periods. Error bars represent ±1 standard error.

*3.4.1.5.1 VGP*.

Mauchly's test of sphericity was conducted on the criterion levels of VGPs. The assumption of sphericity was violated, $\chi^2(44) = 74.298$, $p = .005$, therefore the degrees of freedom were corrected using the Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.578$).

The results showed that there was a significant effect of period, $F(5.21, 88.48) = 2.83$, $p = .019$, partial $\eta^2 = .14$, and a significant linear trend, $F(1, 17) = 9.29$, $p = .007$, partial $\eta^2 = .35$.

*3.4.1.5.2 NVGP.*

Mauchly's test of sphericity was conducted on the criterion levels of NVGPs. The assumption of sphericity was violated, $\chi^2(44) = 65.57$, $p = .023$, therefore the degrees of freedom were corrected using the Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.653$). The results showed that there was a significant effect of period, $F(5.87, 135.107) = 2.07$, $p = .04$, partial $\eta^2 = .08$, and a significant linear trend, $F(1, 23) = 5.78$, $p = .025$, partial $\eta^2 = .20$.

**3.4.2 Divided attention.**

In session 1, there were two missing cases (2 NVGPs) in Communications task RT, and two missing cases (1 NVGP; 1 VGP) in System monitoring Scales task RT. In session 2, there was one missing case (1 NVGP) in Communications task RT and one missing case (1 VGP) in System monitoring Scales task RT. Missing values in RT measures indicate that these participants did not respond to any of the events, or in the case of the communications task, they may have selected the radio and frequency but did not click on the 'Enter' button to record their answer. The missing values were replaced with the mean value of each participant's respective group.

A 2 (group) x 2 (session) doubly-multivariate profile analysis was conducted on the eight measures (see Table 2) of MATB-II performance. The group by session interaction (deviation from parallelism) was not significant, $V = 0.17$, $F(8, 33) = 0.85$, $p = .563$, partial $\eta^2 = .17$. The equality of levels test was significant, indicating a difference in divided attention performance between VGPs and NVGPs, $V = 0.36$, $F(8, 33) = 2.31$, $p = .044$, partial $\eta^2 = .36$. For the flatness test, there was a significant change in performance between sessions, $V = 0.63$, $F(8, 33) = 6.98$, $p < .001$, partial $\eta^2 = .63$.

To examine whether VGPs have superior executive functioning compared to NVGPs,

a MANOVA was conducted using performance on the first MATB-II session. Box's test of equality of covariances was significant, $F(36, 4520.03) = 1.84$, $p = .002$. The result of the MANOVA revealed no significant difference in performance between the two groups, $V = 0.31$, $F(8, 33) = 1.84$, $p = .104$, $\eta^2 = .31$. However, univariate results were analysed as it is possible that the different groups may have chosen to focus on particular sub-tasks at the expense of performance on the remaining tasks.

Levene's test of equality of variances was only significant for communication task accuracy and the tracking task (*p*s < .05). Video game players performed better on all measures compared to NVGPs. However, there was only a significant difference between the two groups on three of the eight MATB-II measures (see Table 3.2).

Table 3.2

*Session 1 MATB-II sub-task performance*

| Task | Measure | VGP (SD) | NVGP (SD) | ANOVA |
|---|---|---|---|---|
| Communications | RT | 3.40 (1.47) | 3.55 (1.38) | $F(1, 40) = 0.11$, $p = 0.739$ |
| | Accuracy | 0.97 (0.03) | 0.90 (0.14) | $F(1, 40) = 4.89$, $p = .033$ |
| Resource Management | Mean | 376.02 (387.33) | 558.74 (363.38) | $F(1, 40) = 2.46$, $p = .125$ |
| Tracking | RMSD | 34.43 (7.89) | 42.30 (14.74) | $F(1, 40) = 4.20$, $p = .047$ |
| System Monitoring - Lights | RT | 2.73 (0.66) | 3.25 (0.97) | $F(1, 40) = 3.89$, $p = .056$ |
| | Accuracy | 0.83 (0.15) | 0.76 (0.19) | $F(1, 40) = 1.86$, $p = .180$ |
| System Monitoring - Scales | RT | 4.01 (0.76) | 4.66 (0.70) | $F(1, 40) = 8.196$, $p = .007$ |
| | Accuracy | 0.66 (0.27) | 0.64 (0.19) | $F(1, 40) = .13$, $p = .724$ |

RT = Reaction time; RMSD = Root Mean Standard Deviation

An additional MANOVA was conducted using only data from session 2 of the MATB-II. Box's test of equality of covariances was not significant, $F(36, 4520.03) = 1.38$, $p = .067$. The result of the MANOVA revealed a significant difference in performance between the two groups, $V = 0.41$, $F(8, 33) = 2.80$, $p = .017$, $\eta^2 = .41$. Univariate results were analysed to determine which tasks the groups differed on.

Levene's test of equality of variances was non-significant for tasks ($p$s > .05). VGPs performed equal to or better than NVGPs on all tasks. However, there was only a significant difference between the two groups on three of the eight MATB-II measures (see Table 3.3).

Table 3.3

*Session 2 MATB-II sub-task performance*

| Task | Measure | VGP (SD) | NVGP (SD) | ANOVA |
|---|---|---|---|---|
| Communications | RT | 2.76 (1.51) | 3.29 (1.41) | $F(1, 40) = 2.88$, $p = .249$ |
| | Accuracy | 0.98 (0.30) | 0.96 (0.94) | $F(1, 40) = 0.003$, $p = .453$ |
| Resource Management | Mean | 259.11 (171.44) | 394.31 (237.78) | $F(1, 40) = 4.18$, $p = .048$ |
| Tracking | RMSD | 30.16 (5.51) | 36.16 (9.85) | $F(1, 40) = 6.41$, $p = .015$ |
| System Monitoring: Lights | RT | 2.50 (0.55) | 3.05 (0.60) | $F(1, 40) = 9.39$, $p = .004$ |
| | Accuracy | 0.89 (0.10) | 0.89 (0.10) | $F(1, 40) = 0.002$, $p = .960$ |
| System Monitoring: Scales | RT | 3.68 (0.92) | 4.16 (0.86) | $F(1, 40) = 2.96$, $p = .093$ |
| | Accuracy | 0.74 (0.23) | 0.78 (0.14) | $F(1, 40) = 0.65$, $p = .424$ |

RT = Reaction time; RMSD = Root-Mean-Square Deviation

**3.4.3 Workload Rating Scale (WRS).**

A doubly-multivariate profile analysis was conducted on the raw responses to the WRS. The group by session interaction (deviation from parallelism) was not significant, $V =$

0.09, $F(6, 35) = 0.54$, $p = .75$, partial $\eta^2 = .09$. The equality of levels test was not significant, indicating no difference in subjective workload between VGPs and NVGPs, $V = 0.27$, $F(6, 35) = 2.12$, $p = .075$, partial $\eta^2 = .27$. For the flatness test, there was a significant change in subjective workload between sessions, $V = 0.37$, $F(6, 35) = 3.38$, $p = .01$, partial $\eta^2 = .37$.

Inspection of the data revealed that both groups had lower scores on all measures in the second session compared to the first, matching the pattern of MATB-II performance. To determine whether there were any initial differences in workload a MANOVA was conducted using responses from the first MATB-II session. Box's test of equality of covariances was not significant, $F(21, 4926.67) = 1.17$, $p = .272$. The result of the MANOVA revealed a significant difference in workload rating between the two groups, $V = 0.33$, $F(6, 35) = 2.88$, $p = .022$, partial $\eta^2 = .31$. Univariate results were analysed to determine on which sub-scales the groups differed. Levene's test of equality of variances was non-significant for all of the sub-scales (*p*s > .05). There was a significant difference in subjective workload ratings between the VGPs and NVGPs on only one of the six sub-scales (see Table 3.4).

Table 3.4

*Session 1 WRS results*

| Sub-scale | VGP (SD) | NVGP (SD) | ANOVA |
|---|---|---|---|
| Mental | 70.61 (17.11) | 76.29 (17.61) | $F(1, 40) = 1.10$, $p = .301$ |
| Physical | 38.83 (19.45) | 32.92 (27.15) | $F(1, 40) = 0.62$, $p = .437$ |
| Temporal | 57.83 (21.72) | 61.38 (23.52) | $F(1, 40) = 0.25$, $p = .621$ |
| Performance | 32.22 (17.49) | 58.75 (23.98) | $F(1, 40) = 15.71$, $p < .001$ |
| Effort | 65.06 (17.91) | 70.29 (19.78) | $F(1, 40) = 0.78$, $p = .383$ |
| Frustration | 35.94 (18.86) | 48.71 (27.45) | $F(1, 40) = 2.87$, $p = .098$ |

A MANOVA was also conducted using only responses from the second MATB-II session. Box's test of equality of covariances was not significant, $F(21, 4926.67) = .081$, $p =$

.711. The result of the MANOVA revealed no significant difference in workload rating between the two groups, $V = 0.17$, $F(6, 35) = 1.21$, $p = .322$, partial $\eta^2 = .17$. Univariate results were analysed to determine if groups differed on any of the individual sub-scales. Levene's test of equality of variances was not significant for all of the sub-scales (*p*s > .05). The only significant difference between the groups was on the Performance sub-scale (see Table 3.5).

Table 3.5

*Session 2 WRS results*

| Sub-scale | VGP (SD) | NVGP (SD) | ANOVA |
|---|---|---|---|
| Mental | 63.36 (20.93) | 65.54 (19.18) | $F(1, 40) = 0.12$, $p = .731$ |
| Physical | 37.00 (18.72) | 31.83 (23.04) | $F(1, 40) = 0.61$, $p = .441$ |
| Temporal | 54.83 (20.26) | 56.29 (21.59) | $F(1, 40) = 0.049$, $p = .825$ |
| Performance | 26.44 (20.41) | 46.67 (28.19) | $F(1, 40) = 6.64$, $p = .014$ |
| Effort | 55.00 (23.50) | 60.79 (22.96) | $F(1, 40) = 0.64$, $p = .428$ |
| Frustration | 31.72 (21.09) | 34.96 (26.43) | $F(1, 40) = 0.18$, $p = .672$ |

## 3.5 Discussion

Overall, the results of the present study demonstrate that there is no difference in the levels of cognitive fatigue experienced between VGPs and NVGPs. The results of performance on the sustained attention task revealed that both groups experienced similar reductions in performance as time-on-task increased. In addition, from the results of the divided attention task it is not possible to determine whether participants experienced cognitive fatigue from session 1 to session 2 as the performance of both groups improved, possibly due to practice/learning effects.

The doubly-multivariate profile analysis revealed that there was a significant difference between groups on the gradCPT, and that there was no significant change over

time. However, individual profile analyses were conducted on each of the four measures from the gradCPT and revealed no significant difference in performance between the groups on any of the measures. As the between-group difference only occurred at the multivariate level, this suggests that the difference in performance between VGPs and NVGPs is detectable only when a combination of the sustained attention performance measures are analysed together. In addition, both groups exhibited a significant decline in sustained attention performance over time on the reaction time variability, sensitivity, and response criterion measures. The non-significant effect of time in the doubly-multivariate profile analysis was likely due to the non-significant effect on reaction time masking the significant effect of time on the other three variables.

The similarity of sustained attention performance, when measured at the univariate level, between the VGPs and NVGPs is in contrast to previous research in this area. In particular, when Dye et al. (2009b) compared sustained attention performance, not only were VGPs significantly faster than NVGPs, their reaction times were so fast that their responses were initially considered to be anticipatory (less than 200ms). It was noted though that VGPs' responses were nearly always correct and thus these fast responses were considered to be 'real' responses. Thus, in the present study it is surprising that VGPs did not at least have significantly faster reaction times than NVGPs. However, there is increasing evidence that the effects of playing action video games on improving cognitive abilities may have been over estimated in the literature (Unsworth et al., 2015) and that research in this area suffers from a number of different methodological limitations (Boot et al., 2011; Gobet et al., 2014). Therefore the current univariate results add to the existing evidence (Irons, Remington, & McLean, 2011; Murphy & Spencer, 2009; van Ravenzwaaij et al., 2014) that action video games do not enhance cognitive abilities involved with performance in sustained attention tasks. However, as evidenced from the present study, it is important that measures of

cognitive performance are also analysed at a multivariate level to provide a more in-depth exploration of the phenomena.

The decline in sustained attention performance over time is consistent with results in the previous research. Both VGPs and NVGPs experienced significant reductions in performance on all measures except for reaction time. As time-on-task increased, reaction time variability increased, sensitivity levels decreased, and response criterion levels decreased. These results are all consistent with the previous research on the time-on-task effect and the effects of fatigue, however, the decline in performance did not stop after 30 minutes as has been demonstrated by previous research on the vigilance decrement (Buck, 1966; Hancock, 2013; Helton & Russell, 2012; Mackworth, 1948; See et al., 1995). Instead, there were significant linear trends for both groups in reaction time variability, sensitivity, and response criterion levels that persisted beyond 30 minutes on the task. It is suggested for future research that any investigation of sustained attention and the vigilance decrement should be at least 30 minutes in duration, and that sustained attention performance needs to be examined over the entire duration of the task.

Accuracy in sustained attention performance was assessed with signal detection theory, using d' (sensitivity) and c (response criterion) (T. D. Wickens, 2001). Decreasing sensitivity levels indicate a decreased ability to detect the signal (targets) from the noise (non-targets). Signal detectability is influenced by the way the stimuli are created in the experimental design and by the physiology involved in the detection process (T. D. Wickens, 2001). In the current experiment, as the presentation of the stimuli remained consistent throughout the experiment, any changes in sensitivity were a result of fatigued sustained attention processes.

Response criterion levels are controlled by the individual, as this is a representation of their response strategy/bias (T. D. Wickens, 2001). The response criterion is a representation

of the amount of evidence needed by the participant for them to determine whether a stimulus is a signal or noise; if the evidence is above the response criterion level, the stimulus is considered to be a signal. Decreasing response criterion levels therefore indicates an increased propensity to respond to stimuli (as less evidence is needed), resulting in more correct responses but also more false alarm errors (T. D. Wickens, 2001). Therefore, as time-on-task increased, participants compensated for this reduced ability to detect signals by lowering their response criterion and making more responses, inadvertently resulting in more false alarm responses. This adjustment in response behaviour, as a result of fatigue, supports the work of others (Hancock, 2013; Hockey, 2013; Thomson et al., 2015) who have proposed that being cognitively fatigued results in adaptive behaviour aimed at maintaining optimal task performance.

As discussed previously, sustained attention tasks are effective measures of executive control as these tasks require ignoring irrelevant stimuli and inhibiting automatic responses (Thomson et al., 2015). It was therefore hypothesised that those with greater executive control would be better at performing these tasks as they would be more efficient at controlling attention, allowing them to perform better for longer. Overall, VGPs exhibited better sustained attention compared to NVGPs at the multivariate level, suggesting that they have superior executive control. However despite this, from the non-significant interaction effect in the doubly-multivariate profile analysis, and the significant effect of time in the univariate tests, it can be concluded that both VGPs and NVGPs are equally susceptible to the time-on-task effect and cognitive fatigue.

With regards to divided attention performance, there was no evidence of participants experiencing cognitive fatigue over the two sessions of the MATB-II. In fact, both VGPs and NVGPs significantly improved in performance from session 1 to session 2. This can be attributed to a learning effect, and is a methodological issue rather than a theoretical one. This

is further supported by the doubly multivariate profile analysis on WRS scores that revealed a significant decline in subjective workload from session 1 to session 2. It is possible that the cognitive fatigue induced from the gradCPT task did impact MATB-II performance but that the practice effect was so large that it overcame any fatigue-related performance decline. However, this conclusion cannot be confirmed by the data available from the present study. Future studies investigating fatigue should use tasks on which optimal performance can be achieved in a short period of time in a practice trial, or to use tasks in which all participants are already proficient, as these will be more likely to show greater increases in fatigue (Ackerman, 2011).

Session 1 of the MATB-II was examined to assess differences in the two groups' initial level of executive functioning/control before they became fatigued. Multivariate analysis revealed that there was no significant difference between the groups, however univariate results were analysed as it was possible that groups may have varied in which sub-tasks they focussed on. VGPs performed better than NVGPs on all measures, but at the univariate level, differences on only three of the eight measures were significant. VGPs performed significantly better than NVGPs on the Tracking task, Communications accuracy, and System monitoring – Scale reaction time. VGPs' superior performance on the Tracking task is not surprising as this task required controlling a joystick, a device often used in computer-based video games. The other two measures, Communications accuracy, and System monitoring – Scale reaction time, are considered to be secondary tasks on the MATB-II, although it should be noted that no distinction was made to participants.

The fact that VGPs performed better on the secondary tasks is theoretically significant. This finding supports those of Chiappe et al. (2013), who found that video game training significantly improved performance on the secondary tasks without sacrificing performance on the primary tasks. One explanation for this is that VGPs required less

attentional resources to perform the primary tasks and were therefore able to focus on the secondary tasks. Although this is a significant point, it should be noted that one of the primary tasks was the Tracking task, and this is a potential confound for the current study. Thus, as VGPs were already familiar with controlling the joystick from playing video games, they were able to direct more cognitive resources to performing the secondary tasks. This is supported by the finding that VGPs performed significantly better than NVGPs on the Tracking task in both sessions of the MATB-II. All NVGPs reported that they were unfamiliar with using the joystick and it is likely that this required most of their attention whilst performing the task, especially as the joystick target was located in the centre of the screen, making it the primary visual focus. It is suggested that future research should use the option already available in MATB-II to turn off the Tracking task in order to remove any potential confounds.

Interestingly, the MANOVA of MATB-II performance in session 1 revealed no significant difference between the two groups, whilst in session 2 there was a significant difference. Although not related to fatigue, these results indicate that VGPs may be faster learners than NVGPs. Bavelier et al. (2012) proposed that the main advantage of regular action video game playing is an increased ability, referred to as ‘learning to learn’. Although both groups demonstrated significant improvements from session 1 to session 2, VGPs performed significantly better than NVGPs in session 2. However, these results from session 2 should be interpreted cautiously; the confound of the Tracking task remains; VGPs were only significantly better on three of the eight measures (including the Tracking task); and the group x session interaction of the doubly multivariate profile analysis was not significant, indicating that both groups experienced similar learning effects.

Most research in the video game field classifies VGP experts as individuals who have played approximately 4 hours of action video games per week over the previous 6 months. As

previously discussed, this is an inadequate criterion for classifying individuals as ‘experts’. In addition, there is no evidence that playing video games for this amount of time is sufficient to become an expert (Latham et al., 2013a). The present study used video game performance in conjunction with self-report measures to classify participants as either VGPs or NVGPs. Importantly, when participants were only grouped according to the amount of action video game experience they had, there was a significant difference in video game performance between the two groups. Thus, this is the first study to provide statistical evidence to support the use of self-report measures in classifying individuals as either VGPs or NVGPs. Whilst further investigation is needed into the specific requirements of becoming a video game expert, research that only uses self-report measures to classify participants should not be discounted, on the proviso that VGPs are referred to as having more ‘video game experience’, rather than as ‘video game experts’.

The present study is not without its limitations. As discussed above, it was difficult to recruit participants who solely played first-person shooter video games, thus the conclusions drawn here are in relation to the broader category of action video games. The lack of significant differences between VGPs and NVGPs may be due to the possibility that not all action video games induce the same cognitive benefits as FPS games. Investigation of this possibility however, is still in its early stages (Oei & Patterson, 2015). In addition, there were large differences between the groups with regards to age and sex, and so these variables are possible confounds to the between group differences, and thus the current results should be interpreted with caution.

In conclusion, action video game players experienced similar levels of cognitive fatigue compared to non-video game players. Although VGPs demonstrated superior sustained attention performance compared to non-video game players at the multivariate level, the performance of both groups significantly declined over time. In addition, VGPs

were significantly better at multitasking compared to NVGPs and appeared to be faster learners. Finally, the results of the present study reveal that although action video game experience improves sustained attention and divided attention performance, it does not assist with resisting the effects of cognitive fatigue.

# Chapter 4: Study 2 – Video Game Training and Cognitive Fatigue

The results from the previous study demonstrate that individuals with a greater amount of action video game experience perform better on sustained attention and divided attention tasks. However, whilst there may be an association between playing action video games and improved sustained and divided attention skills, a causal relationship cannot be established from the current results. For example, there remains the possibility that individuals who have superior sustained and divided attention skills are attracted to action video games and therefore perform well at them (Adams & Mayer, 2012). Therefore, to determine whether playing action video games is the cause of superior performance on sustained and divided attention tasks, as demonstrated by VGPs in the previous study, a training study was conducted.

A number of studies have trained NVGPs on action video games to determine the causal benefits (Boot et al., 2011; Oei & Patterson, 2014). For example, NVGPs trained on action video games showed improved cognitive and perceptual abilities compared to NVGPs trained on non-action video games (e.g. C. S. Green & Bavelier, 2003; Wu & Spence, 2013). Many of the cognitive benefits of playing action video games that have been found when comparing VGPs and NVGPs are also replicated in training studies comparing action and non-action video games (Oei & Patterson, 2015), including, multiple object tracking (C. S. Green & Bavelier, 2006c; Oei & Patterson, 2015), target detection (Feng et al., 2007; C. S. Green & Bavelier, 2003), and attentional switching (C. S. Green & Bavelier, 2003; Oei & Patterson, 2013). Despite this, results of action video game training studies have not always been consistent. For example, Green and Bavelier (2003) provided NVGPs with 10 hours of FPS video game training and found that performance on the UFOV task improved significantly more compared to non-action training. However, Boot et al. (2008) was unable to find similar results, even when 21.5 hours of training were provided. In addition, the

results found by C. S. Green and Bavelier (2006c, experiment two), that action video game training significantly improved attention capacity, could not be replicated (Boot et al., 2008). Similarly, van Ravenzwaaij et al. (2014) found no difference in the speed of information processing between individuals who received 20 hours of action video game training, cognitive training, or who received no training at all.

The following section outlines some of the limitations within the video game training literature that may account for these inconsistent results.

## 4.1 Methodological Limitations of Video Game Training Studies

Action video game training studies experience a number of limitations, some of which were discussed in Section 2.3. For example, just as action VGPs may expect to perform better than NVGPs due to the similarity between action video games and the cognitive tests used, so too can individuals who receive the action video game training when compared to those who receive the non-action video game training (Boot, 2015; C. S. Green & Bavelier, 2015). More specific to training studies though, is the inconsistent design of video game training methods themselves.

### 4.1.1 Duration.

Apart from often having incomparable control training groups (e.g. FPS games compared to non-FPS games such as Tetris and The Sims, see Section 2.3.2), training studies have varied widely in the number of training sessions, and the total duration of training provided (Boot et al., 2011). Training has ranged from 10 hours (five 2-hour sessions) to 50 hours (maximum 2-hours per day, maximum 10-hours per week, for no more than 12 weeks) (C. S. Green & Bavelier, 2012, 2015). Thus, due to these inconsistencies, it is not surprising that some studies have found differences in training conditions, whilst others have not. However, it may not simply be the varying duration of training lengths differentiating these findings. van Ravenzwaaij et al. (2014) found no difference in moving dot task performance,

and lexical decision task performance between participants trained on an FPS game and those trained on a non-FPS game for 10 hours. This conclusion was inconsistent with earlier studies that provided 10 hours of action video game training (Feng et al., 2007; C. S. Green & Bavelier, 2003). Thus, van Ravenzwaaij et al. (2014) conducted a replication experiment, and increased the total training duration to 20 hours, increased the number of participants, increased the number of trials, and a third condition was added in which participants completed no video game training. Despite these changes however, there continued to be no significant difference between training conditions on task performance (van Ravenzwaaij et al., 2014).

Although this study found no effect of action video game training, other studies using shorter durations have found such effects (Feng et al., 2007; C. S. Green & Bavelier, 2003), with improvements being maintained approximately five months later (Feng et al., 2007). When learning new tasks, the nature of practice or training is just as important as the amount (Voss et al., 2012). Therefore, it is possible that other aspects of training, for example, the difficulty of the training task, and the type of training provided, may be creating inconsistent results between studies.

#### 4.1.2 Difficulty.

A characteristic that is implicit in nearly every video game is the gradual increase in task difficulty that occurs as the player progresses through the game (C. S. Green & Bavelier, 2008). In video game training studies, this increase in task difficulty may be manipulated by the experimenters (C. S. Green & Bavelier, 2006b, 2006c, 2007; C. S. Green et al., 2010), controlled by the natural progression of the video game (Boot et al., 2008), or is not mentioned in the experimental procedure (e.g., C. S. Green & Bavelier, 2006c, experiment 2; C. S. Green, Sugarman, Medford, Klobusicky, & Bavelier, 2012). Further, whether difficulty level does or does not increase with player progression is a significant issue, as video game

performance is dependent on the relationship between the challenges of the game and the skill of the player (Jin, 2012). Participants may lose motivation and become bored when a task is too easy, resulting in a decline in performance. Conversely, if a task is too complex, it may induce anxiety and frustration, and thus the player will be unable to complete the task. It is important that the difficulty of the task matches the player's skills and continues to provide a challenge as the player's abilities develop (Jin, 2012). As this feature is inherent in most, but not all, video games, and the rate of difficulty-increase varies from game to game, this also further complicates the issue when comparing video game training studies, and when comparing training on action and non-action video games

#### 4.1.3 Training Strategies.

One variable that has yet to be explored in modern action video game training studies is the use of differing training strategies. Although practicing a task will surely improve performance at it, specific training strategies can be more effective at increasing learning, improving retention of newly learnt skills, and broadening the transfer of training (Gopher, Kramer, Wiegmann, & Kirlik, 2007; Lee, Boot, et al., 2012; R. A. Schmidt & Bjork, 1992), as they require different brain processes that are related to learning (Voss et al., 2012).

A common method of training, and the one that is invariably used in action video game training studies, is that of whole-task training. In whole-task training, the full task is performed, resulting in practicing all sub-tasks simultaneously. In comparison, part-task training involves practicing sub-tasks in isolation from the full task (Lee, Boot, et al., 2012). Each of these methods has its advantages and disadvantages. Whole-task training allows for participants to learn how sub-tasks work together in the context of the full task, however, complex tasks can be overwhelming whilst participants are beginning to learn. In comparison, part-task training allows for complex tasks to be broken down into sub-tasks and practiced, however, participants do not gain the opportunity to learn how to integrate the sub-

tasks together in the context of the full task (Lee, Boot, et al., 2012).

An alternative to the above training techniques is to use variable priority training (VPT), which has the advantages of both types of training whilst minimising the disadvantages. In VPT, individuals practice the full task whilst focusing on improving a particular sub-task at different times. This allows participants to concentrate on improving subtasks, which are manageable, but also to learn how the subtasks fit together within the broader context of the task (Lee, Boot, et al., 2012). In addition, it well established in the field of skill acquisition that training techniques that are variable, promote cognitive flexibility, and that avoid task-specific mastery can lead to greater levels of learning as well as broader transfer (Baniqued et al., 2013; Kramer, Larish, & Strayer, 1995; R. A. Schmidt & Bjork, 1992).

Training regimes that focus on variable and sub-part training result in greater improvements in learning when compared to traditional repetitive practice regimes (Bisoglio et al., 2014; C. S. Green & Bavelier, 2008; Prakash et al., 2012; R. A. Schmidt & Bjork, 1992). By varying the stimuli, the structure and representations of important features that need to be focussed on during that task are strengthened, and attentional resources are more efficiently allocated (Bavelier et al., 2012; Bisoglio et al., 2014; C. S. Green & Bavelier, 2008). Variable priority training also emphasises cognitive flexibility and thus leads to superior learning (Erickson et al., 2010; Lee, Boot, et al., 2012; Lee, Voss, et al., 2012; Mourany, 2011; Prakash et al., 2012; Voss et al., 2012). It improves not only the learning and retention of the skills, but enhances the transferability of these skills to other tasks (Voss et al., 2012). VPT is particularly useful when learning how to perform tasks that require simultaneous performance and coordination of multiple sub-tasks (Boot et al., 2010; Gopher et al., 2007). This has been shown in studies examining dual-task performance (Kramer et al., 1995), as well as in more complex video game-like tasks (Boot et al., 2010; Fabiani et al.,

1989; Gopher, Weil, & Siegel, 1989).

Most of the evidence for the use of variable priority training in video games comes from studies using *Space Fortress* (Lee, Boot, et al., 2012). It has previously been found that on this basic non-action video game, participants who receive VPT show greater improvements in performance compared to those who receive fixed emphasis training (FET), in which there is no emphasis or priority given to sub-tasks (Lee, Boot, et al., 2012; Voss et al., 2012). This game was designed by cognitive psychologists through the Learning Strategies Initiative (Donchin, 1989) to examine the effectiveness of different training techniques in enhancing skill acquisition (Fabiani et al., 1989; Gopher et al., 1989; Prakash et al., 2012). As part of the initiative, different strategies were compared: fixed emphasis training (FET), which is the most common mode of training, where the entire task is repeatedly practiced; part-task training; and variable priority training.

It has repeatedly been shown that those who receive VPT perform better overall, demonstrate faster learning, reach a higher level of game mastery (Boot et al., 2010; Fabiani et al., 1989; Gopher & Donchin, 1986), and demonstrate superior multitasking performance (Kramer et al., 1995), compared to those who receive FET (Prakash et al., 2012; Voss et al., 2012). In addition, improvements in *Space Fortress*, brought about from VPT, have been shown to transfer to tasks requiring similar skills (Voss et al., 2012). There are a number of possible explanations as to how VPT increases the transfer of learning (Boot et al., 2010). VPT consists of a number of features that are known to improve learning, for example increased training variability and the use of feedback (Gopher et al., 2007; R. A. Schmidt & Bjork, 1992). However, it may also be because VPT encourages participants to explore and engage in different strategies, allowing for them to develop a more complete representation of the task and its components (Boot et al., 2010). However, this does not necessarily explain the transfer of improvements to other tasks. Boot et al. (2010) suggested that this transfer

comes about from the participant learning the value of exploring and trying different strategies, and that this is then applied when performing novel tasks. Alternatively, VPT may assist in the development of executive control due to the need to monitor and adjust cognitive resources during training (Gopher, Well, & Bareket, 1994; Kramer et al., 1995).

**4.2 The present study**

It has previously been suggested that to effectively enhance an individual's perceptual and cognitive abilities, variable priority training on modern action video games should be used, rather than fixed emphasis training. However, to date, there has been no investigation of this possibility (Boot et al., 2010; Boot et al., 2008). Whilst *Space Fortress* is not an FPS game, to achieve the best performance, similar sub-tasks are required, such as, controlling the movement of a spaceship (character) and the speed and accuracy of shooting at a fortress (enemy) target. In terms of cognitive demands, similar to action FPS games, *Space Fortress* requires high levels of executive control, memory, and visual attention (Blumen, Gopher, Steinerman, & Stern, 2010; Boot et al., 2010). Therefore, it is hypothesised that the results of the present study will match those of studies using *Space Fortress*, in that those who receive VPT on an action video game will learn the game faster and demonstrate superior performance compared to those who receive FET. In addition, the results of the previous study (Chapter 3) provide evidence that playing action video games improves executive functioning. Variable priority training has been shown to assist with the development of executive control and thus the broad transfer of improved skills. Therefore, it is hypothesised that training on an action video game will improve participants’ executive functioning, which will be evidenced by improvements in sustained and divided attention performance, and that this transfer will be greater for those who receive variable priority training, compared to those who receive fixed emphasis training.

Further, there has been little research investigating whether cognitive improvements

from action video game training are retained after training has finished. Fortunately, Feng et al. (2007) were able to re-test all of their participants approximately five months (16-24 weeks) after completing training, although this was not originally planned, and found that participants who received action video game training either retained or improved their level of performance from initial post-test to follow-up test. However, their results are confounded as some participants continued playing video games after the training phase had ceased. The present study included a follow-up test three months after the post-test session, and participants were asked to not play any video games during that time. It was hypothesised that both groups would retain improved sustained and divided attention performance from post-test to follow-up test. However, there is currently not enough previous evidence to enable predictions as to whether one type of training will allow for greater retention of improved performance compared to the other.

In addition, video game, vigilance, and multitasking performance of participants was compared to the performance of the VGPs from Study 1 (Chapter 3), in order to determine how similar the NVGPs after training were to the VGPs. It was hypothesised that the VGPs would have higher levels of performance than the NVGPs after training, as the VGPs would have been playing video games for years, whilst the NVGPs would have only been playing for a few weeks.

## 4.3 Method

This study received approval from the Edith Cowan University Human Research Ethics Committee.

### 4.3.1 Participants.

Participants were recruited from the list of non-video-game players that participated in Study 1 (Chapter 3). Of those 24 NVGPs, six females and one male participated in the present study. An attempt was made to match participants between groups according to their

age, sex, and *Unreal Tournament 2004* performance from Study 1. Due to the unequal group sizes, and to remove the potential confound of sex, the male participants' data was removed from the analysis. Table 4.1 provides the demographic information for the remaining participants.

Table 4.1.

*Participants' demographic details and video game performance*

| Variable Priority Training (VPT) | | | Fixed Emphasis Training (FET) | | |
|---|---|---|---|---|---|
| Subject | Age | UT2004 score | Subject | Age | UT2004 score |
| 1 | 45 | -11.6 | 2 | 49 | -10.6 |
| 3 | 58 | -12.3 | 4 | 58 | -9.6 |
| 5 | 29 | -8.6 | 6 | 39 | -7 |

Participants were entered into a raffle with the chance to win one of two $50 gift cards provided by the ECU Cognition Research Group, and were also entered into a raffle to win one of two $500 gift cards. Participants also received a $20 gift-card when they returned for the three-month follow-up test.

**4.3.2 Tasks and Measures.**

Participants completed the same tasks as in Study 1 (Chapter 3, see Section 3.3.2). Performance on the action video game *Unreal Tournament 2004* was calculated by subtracting the number of deaths from the number of kills. This was then averaged over the number of trials, either 10 trials during the training phase, or three trials during the testing sessions. Performance on the gradCPT was assessed by measuring reaction times and reaction time variability (standard deviation) (see Section 3.3.2.1), and sensitivity (d') and criterion (c) levels (see Section 3.1). Performance on the MATB-II was assessed by measuring performance on eight measures and participants also completed the Workload

Rating Scale (WRS) as part of the MATB-II (see Section 3.3.2.2).

**4.3.3 Design.**

Study 1 (Chapter 3) was the pre-training test for the present experiment. After four weeks of video game training (ten 1-hour sessions), participants repeated the cognitive tests as outlined in Study 1. The only difference was that participants completed different versions of the MATB-II compared to the ones they completed in Study 1. The experimenter had created four versions, therefore in the post-test participants completed the two versions that they had not performed in Study 1. Participants were asked to come back for follow-up testing three months after their post-test session. The follow-up test was identical to that of Study 1, including the versions of the MATB-II that participants completed. Thus, a direct comparison could be made between performance on the pre-test and the follow-up test. It was assumed that there would be no memory of the initial versions of the MATB-II tasks that were completed in the pre-training session for two reasons; firstly, participants did not know that they would be completing exactly the same versions of the tasks; and secondly, it would be approximately 4-months since they had performed these particular versions, making it highly unlikely that their performance would be affected by any memory of the order in which the sub-tasks of the MATB-II would be presented.

**4.3.4 Training.**

During the training phase, participants completed ten 1-hour video game sessions. Each 60-minute video game training session consisted of ten 6-minute trials. Participants were pseudo-randomly assigned to either the VPT or the FET group (see Section 4.3.1). Participants who were assigned to the FET group were instructed to perform their best (maximise number of kills whilst minimising number of deaths) for all of the trials in all of the sessions. Those who were assigned to the VPT group were instructed to focus on one of five different variables in each trial. Thus, in each 60-minute session, participants practiced

each variable twice. The five variables were: (1) to obtain all of the weapons, obtain full ammunition for each weapon, obtain maximum health, and obtain full adrenaline; (2) to use each of the different weapons, and their two different firing options, and determine what the button-combo is for full adrenaline; (3) to evade the enemy target for as long as possible (die as few times as possible); (4) to attack the enemy target and kill them as many times as possible; (5) a combination of the previous four variables.

In the first training session, the variables were presented in the order listed above, and then repeated, as this order follows a natural progression of learning the different aspects of a novel video game, beginning with the easiest task and becoming more complex. For the remaining nine sessions, participants were presented with the five variables in a randomised order, followed by the five variables in another randomised order. A list of nine different variable presentation orders was made. Participants completed a different variable presentation order each training session, and these were randomised for each participant.

#### 4.3.5 Procedure.

The procedure of the pre-training, post-training, and three-month follow-up sessions was identical to that of Study 1 (Chapter 3). The procedure for the training phase is presented below.

Upon arrival at the laboratory for the first training session, participants read through an information letter (Appendix D) and signed a consent form (Appendix E). The experimenter then explained the structure of the training sessions. All instructions were read from a script to ensure that the instructions given were consistent between participants. The only difference between the groups was that the experimenter explained the five different variable priority tasks to the VPT group. Participants also received a sheet instructing them on what to do for each variable (Appendix F). Participants were not informed that there were two different training groups.

After receiving instructions about the experiment, participants watched a five-minute tutorial video, which was included as part of the video game, explaining the video game in greater detail than in the pre-training session. During the pre-training session (Study 1), the purpose of playing the video game was to assess participants' video game ability and in turn, use this to group them as either VGPs or NVGPs. Thus, it was not necessary to teach participants about all of the intricacies of the video game, and doing so would have reduced any difference between VGPs and NVGPs. However, as the purpose of the present study was to teach the NVGPs how to play the game and improve video game performance, it was necessary for them to learn about all aspects of the game.

After watching the video, participants completed the 10 six-minute video game trials. At the end of each six-minute trial, the video game presented participants with the number of enemies they killed and the number of times they had died, and participants recorded these numbers. Participants' video game play was also recorded using a video screen-capture program. This allowed the experimenter to watch a video recording of the video game and to confirm that participants recorded their performance correctly.

In each game trial, there was one enemy. The difficulty of the enemy was set at 'Experienced' for the first trial, and it was set to auto-adjust for the subsequent game trials. Thus, if participants performed well, the difficulty of the enemy would increase, and vice versa. The purpose of this was to ensure that participants did not become too bored or too overwhelmed, as this would have affected their motivation and thus their level of performance (Jin, 2012).

In order to maintain participants' level of motivation over the four weeks of training, at the beginning of each training session, participants were presented with a graph displaying their previous performance and encouraged to try to improve on this score.

At the completion of the last training session, participants were asked to return for the

post-training sessions as soon as was convenient. At the completion of the post-training session, participants were informed that they would be contacted in approximately three-months to return for a follow-up session.

## 4.4 Results

Participants completed the 10 training sessions in, on average, 4.5 weeks (*M* = 31.50 days, *SD* = 8.83). There was a delay of 6.17 days (*SD* = 7.11) between the final training session and the post-test. Participants returned for the follow-up test, on average, 3.5 months after the post-test (*M* = 107.68 days, *SD* = 33.28).

### 4.4.1 Method of Analysis.

Due to the small sample size of the study traditional and non-traditional methods were used to analyse the video game and gradCPT performance data. Specifically, multilevel linear modelling was used. Multilevel models incorporate both fixed effect parameters and random effects (Bates, 2010). Fixed effect parameters or factors are the independent variables under investigation in the experiment, are constant over all individuals in the sample and are the source of the systematic variability in the outcome. In multilevel modelling, random effects or factors are components of the predictor or independent variable in which a random subset of levels are sampled from a larger population. In the following analysis, subjects and measures of time (period of watch on the gradCPT, day, and testing session) are random factors because responses are grouped according to individual participants and time, which are random subsets of their respective populations. As such, the overall means for each subject and measure of time were estimated as ‘random intercepts’ while the amount of variation on the fixed effects across subjects and measure of time were estimated as ‘random slopes’. Thus, it is assumed that all subjects perform differently on each fixed effect, and that each subject’s performance changes differently over time.

Within this framework, significance values are not used, instead, models are

compared with each other to determine which one was the best at predicting the outcome variable. In the present study, the Akaike Information Criteria (AIC) was used to compare models and which model received higher support by the data. The AIC takes into account the goodness of fit of the model (i.e. the log-likelihood of the model) and penalises for each parameter added to the model; the lower the AIC the better the model. To determine differences of strengths between models, the interpretation of information criterion scores by Raftery (1995) were used. Differences between 0 and 2 indicate no real difference between the models; between 2 and 6 indicate positive evidence in favour of the model with the lower AIC; between 6 and 10 indicates strong evidence in favour of the model with the lower AIC; and differences greater than 10 indicate very strong evidence in favour of the model with the lower AIC. The process of creating models and including or removing parameters is described in the following subsections for each variable measured.

#### 4.4.2 Video game performance during training.

##### *4.4.2.1. Traditional Analysis.*

A 2 (training technique) x 10 (day) mixed-design ANOVA was conducted on the mean video game performance for each day of training. There was a significant difference in performance between the days of training, $F(9, 36) = 7.19$, $p < .001$, partial $\eta^2 = .64$. The trend was significantly linear, $F(1, 4) = 27.74$, $p = .006$, partial $\eta^2 = .87$, and significantly quadratic, $F(1, 4) = 65.74$, $p$ - .001, partial $\eta^2 = .94$ (see Figure 4.1).

There was no significant difference in performance between the two training techniques (VPT: $M = -0.99$, $SE = 0.64$; FET: $M = -1.66$, $SE = 0.64$), $F(1,4) = 0.54$, $p = .502$, partial $\eta^2 = .12$. In addition, there was no significant interaction between training technique and days of training on video game performance, $F(9, 36) = 1.00$, $p = .457$, partial $\eta^2 = .20$.

Pairwise comparisons revealed that there was a significant difference in video game performance between day 1 and days 5, 7, 8, 9, and 10 ($p$s < .05). No other comparisons were

significant.

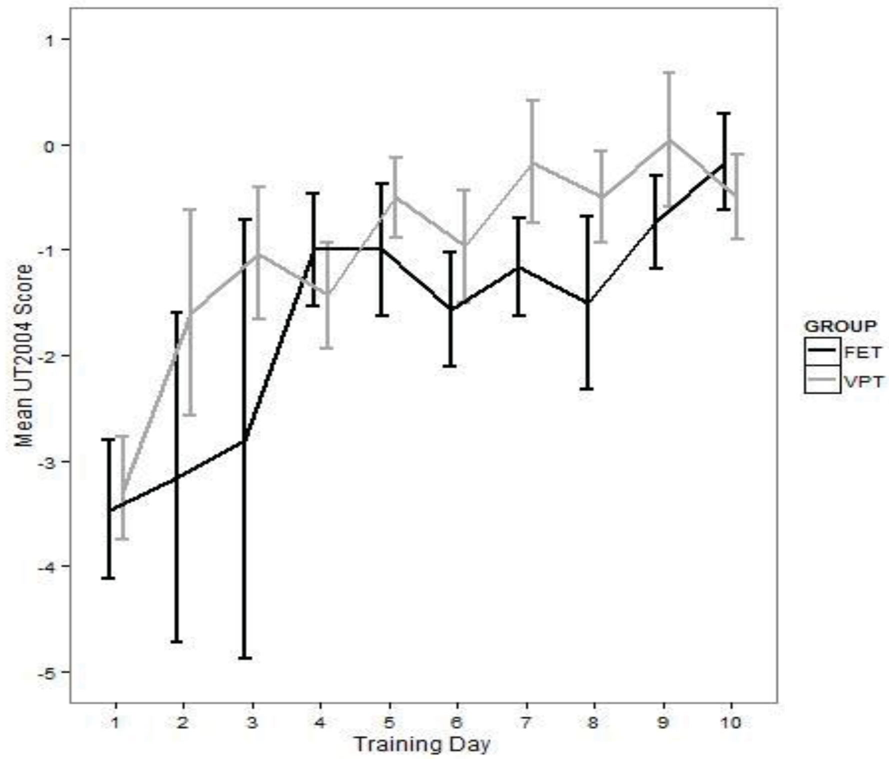


*Figure 4.1. Unreal Tournament 2004* (UT2004) performance during training. Error bars represent ±1 standard error.

***4.4.2.2 Multilevel Modelling.***

Table 4.2 provides the parameter estimates and fit statistics of the models created to estimate video game performance during the training phase of the experiment.

Table 4.2.

*Model output for the fixed and random factors of Unreal Tournament 2004 performance during training*

| Model | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|
| Parameters | Estimate | Std. Error | Estimate | Std. Error | Estimate | Std. Error |
| **Fixed Effects** | | | | | | |
| (Intercept) | -1.33 | 0.43 | -0.99 | 0.64 | -2.90 | 0.70 |
| Training Technique | - | - | -0.66 | 0.90 | - | - |
| Training Day | - | - | - | - | 0.29 | 0.06 |
| | Variance | Std. Dev. | Variance | Std. Dev. | Variance | Std. Dev. |
| **Random Effects** | | | | | | |
| Subject (Intercept) | 0.95 | 0.97 | 1.06 | 1.03 | 2.55 | 1.60 |
| Training Day | - | - | - | - | 0.01 | 0.11 |
| Residual | 1.60 | 1.26 | 1.60 | 1.26 | 0.77 | 0.88 |
| **Fit Statistics** | | | | | | |
| Deviance | 208.91 | | 208.46 | | 168.93 | |
| AIC | 214.77 | | 214.62 | | 185.37 | |

Model 1 is a null model that only takes into account variability in video game performance between individuals. When a model including age as a fixed effect was compared to the null model, there was no evidence that it was a better estimate of video game performance than the null model, therefore age was not included in subsequent models.

Models 2 and 3 included training technique and training day as fixed effects, respectively. Model 3 also included the effect of training day on each individual as a random effect. The AIC of Model 2 was lower than that of the null model, however the difference between them was less than two, indicating that adding training technique to the model did not improve its ability to estimate video game performance. Model 3 had the lowest AIC. The difference in AIC between the null model and Model 3 was greater than 10, indicating that there was very strong evidence in favour of Model 3 as the best estimate of video game performance. The coefficient of training day was positive, indicating that video game performance increased as the number of training days increased

**4.4.3 Video game performance during testing sessions.**

***4.4.3.1 Traditional Analysis.***

A 2 (training technique) x 3 (test session) mixed-design ANOVA was conducted on the mean video game performance for each test session. Mauchly's test indicated that the assumption of sphericity had not been violated, $\chi^2(2) = 1.60$, $p = .450$. Levene's test of equality of variances was not significant for any of the three test sessions (*p*s > .05).

The was a significant difference in video game performance between test sessions (Session 1: *M* = -9.94, *SE* = 0.83; Session 2: *M* = -0.39, *SE* = 1.51; Session 3: *M* = 0.94, *SE* = 2.08), $F(2, 8) = 48.88$, $p < .001$, partial $\eta^2 = .92$. The trend was significantly linear, $F(1, 4) = 58.92$, $p = .002$ partial $\eta^2 = .94$, and significantly quadratic, $F(1,4) = 25.77$, $p = .007$, partial $\eta^2 = .87$ (see Figure 4.2).

There was no significant difference in video game performance between the two

training techniques, $F(1, 4) = 0.17$, $p = .703$, partial $\eta^2 = .04$. In addition, there was no significant interaction between training technique and test session on video game performance, $F(2, 8) = 2.33$, $p = .159$, partial $\eta^2 = .37$.

Pairwise comparisons revealed that there was a significant difference in video game performance between test sessions 1 and 2 ($p = .001$), and between sessions 1 and 3 ($p = .005$). There was no significant difference between session 2 and session 3 ($p = 1.00$).

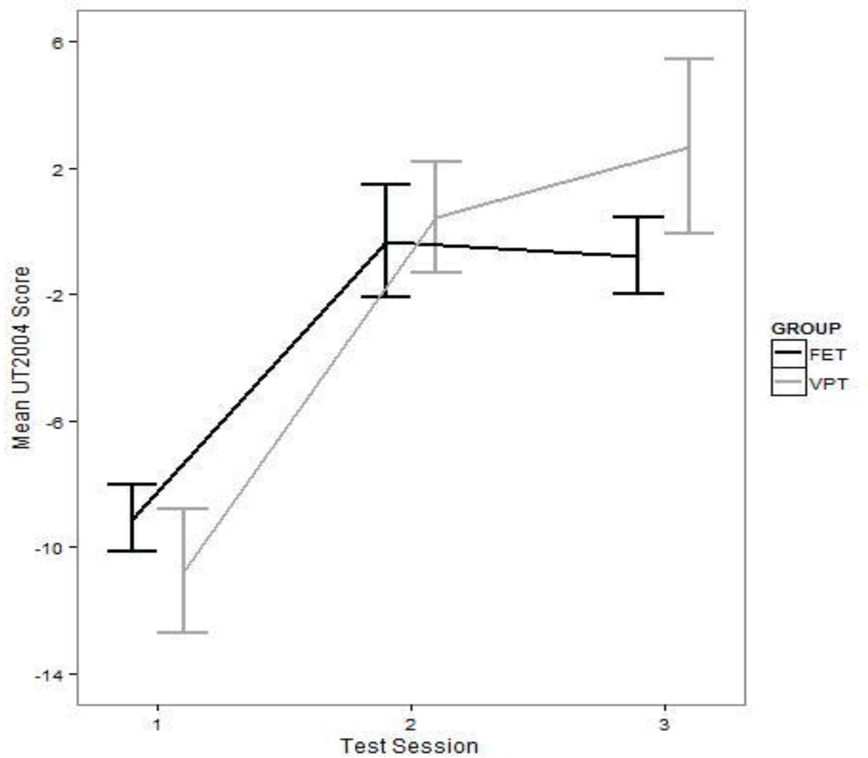


*Figure 4.2. Unreal Tournament 2004* (UT2004) performance during testing. Error bars represent ±1 standard error.

#### *4.4.3.2 Multilevel Modelling.*

Table 4.3 provides the parameter estimates and fit statistics of the models created to estimate video game performance during the testing phases of the experiment.

Table 4.3.

*Model output for the fixed and random factors of Unreal Tournament 2004 performance during testing*

| Model | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|
| Parameters | Estimate | Std. Error | Estimate | Std. Error | Estimate | Std. Error |
| **Fixed Effects** | | | | | | |
| (Intercept) | -2.98 | 1.22 | -2.56 | 1.91 | -9.94 | 1.22 |
| Training Technique | - | - | -0.85 | 2.70 | - | - |
| Testing Session: Post-test | - | - | - | - | 10.00 | 1.65 |
| Testing Session: Follow-up test | - | - | - | - | 10.89 | 2.01 |
| | Variance | Std. Dev. | Variance | Std. Dev. | Variance | Std. Dev. |
| **Random Effects** | | | | | | |
| Subject (Intercept) | 3.33 | 1.83 | 5.31 | 2.30 | 1.46 | 1.21 |
| Testing Session | - | - | - | - | 0.01 | 0.11 |
| Residual | 50.77 | 7.13 | 50.77 | 7.13 | 22.57 | 4.75 |
| **Fit Statistics** | | | | | | |
| Deviance | 367.10 | | 367.26 | | 327.23 | |
| AIC | 370.87 | | 369.04 | | 339.66 | |

Model 1 is a null model that only takes into account variability in video game performance between individuals. When a model including age as a fixed effect was compared to the null model, there was no evidence that it was a better estimate of video game performance than the null model, therefore age was not included in subsequent models.

Models 2 and 3 included training technique and testing session as fixed effects, respectively. Model 3 also included the effect of testing session on each individual as a random effect. Of these two models, Model 3 had the lowest AIC. The AIC of Model 2 was lower than that of the null model, however the difference between them was less than two, indicating that adding training technique to the model did not improve its ability to estimate video game performance. The difference in AIC between the null model and Model 3 was greater than 10, indicating that there was very strong evidence in favour of Model 3 as the best estimate of video game performance. The coefficients of testing sessions were positive, indicating that video game performance increased from pre-test to post-test, and from pre-test to three-month follow-up test.

**4.4.4 Sustained Attention.**

The results of the traditional multivariate analysis are presented below, whilst the follow-up univariate tests for each of the four measures are presented in the following subsections along with the corresponding multilevel linear modelling results.

A 2 (training technique) x (testing session) x 10 (period of watch) Multiple Analysis of Variance (MANOVA) was conducted on the four measures of sustained attention; reaction time, reaction time variability, sensitivity levels, and criterion levels.

Box’s Test of Equality of Covariances could not be computed. Mauchly’s test of sphericity could only be conducted for testing session, and was not significant for all four measures (*p*s > .05).

There was no significant difference between testing sessions $V = 0.72$, $F(8, 12) =$

0.84, $p$ = .585, partial $\eta^2$ = .36. The difference between periods of watch was not significant, $V$ = 1.09, $F$(36, 144) = 1.49, $p$ = .052, partial $\eta^2$ = .27. There was no significant difference between training techniques, $V$ = 0.86, $F$(4, 1) = 1.52, $p$ = .538, partial $\eta^2$ = .86. The interaction between testing session and training technique was not significant, $V$ = 0.72, $F$(8, 12) = 0.84, $p$ = .588, partial $\eta^2$ = .36. The interaction between period of watch and training technique was not significant, $V$ = 0.72, $F$(36, 144) = 0.88, $p$ = .670, partial $\eta^2$ = .18. The interaction between testing sessions and period of watch was not significant, $V$ = 0.94, $F$(72, 288) = 1.23, $p$ = .119, partial $\eta^2$ = .24. The three-way interaction between testing session, period of watch, and training technique, was not significant, $V$ = 0.87, $F$(72, 288) = 1.11, $p$ = .266, partial $\eta^2$ = .22.

#### ***4.4.4.1 Reaction Time.***

##### *4.4.4.1.1 Traditional analysis.*

Results of the univariate analysis on RT reveal that there was no significant difference between testing sessions, $F$(2, 8) = 2.95, $p$ = .110, partial $\eta^2$ = .43. There was no significant difference between periods of watch, $F$(9, 36) = 1.05, $p$ = .423, partial $\eta^2$ = .21. There was no significant difference between training techniques, $F$(1, 4) = 0.09, $p$ = .775, partial $\eta^2$ = .02 (see Figure 4.3).

There was no significant interaction between testing session and training technique, $F$(2, 8) = 0.53, $p$ = .608, partial $\eta^2$ = .12. There was no significant interaction between periods of watch and training technique, $F$(9, 36) = 1.15, $p$ = .354, partial $\eta^2$ = .22. There was no significant interaction between testing session and period of watch, $F$(18, 72) = 1.54, $p$ = .101, partial $\eta^2$ = .28. The three-way interaction between testing session, period of watch, and training technique, was not significant, $F$(18, 72) = 1.57, $p$ = .092, partial $\eta^2$ = .28.

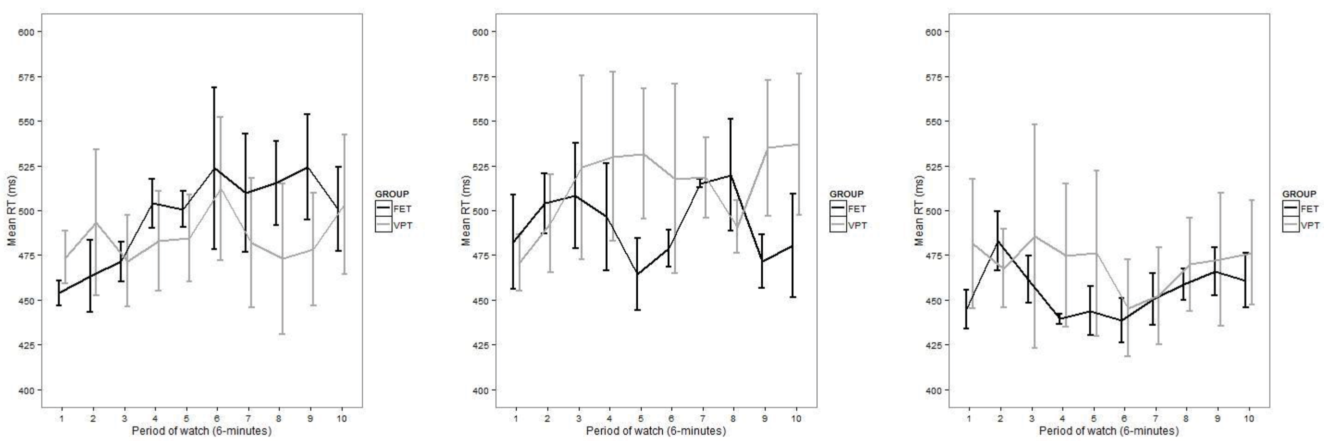


*Figure 4.3*. Reaction time (RT) on gradCPT at pre-test, post-test, and three-month follow-up test (left to right). Error bars represent ±1 standard error.

*4.4.4.1.2 Multilevel Modelling.*

Table 4.4 provides the parameter estimates and fit statistics of the models created to estimate reaction time (RT) on the gradCPT.

Table 4.4.

*Model output for the fixed and random effects estimating reaction times*

| Model | 1 | | 2 | | 3 | | 4 | |
|---|---|---|---|---|---|---|---|---|
| Parameters | Estimate | Std. Error | Estimate | Std. Error | Estimate | Std. Error | Estimate | Std. Error |
| **Fixed Effects** | | | | | | | | |
| (Intercept) | 483.09 | 13.49 | 497.93 | 47.04 | 473.81 | 14.17 | 488.18 | 16.03 |
| Training Technique | - | - | -9.89 | 29.75 | - | - | - | - |
| Period of watch | - | - | - | - | 1.69 | 0.64 | - | - |
| Testing Session: Post-test | - | - | - | - | - | - | 12.38 | 20.90 |
| Testing Session: Follow-up test | - | - | - | - | - | - | -27.45 | 16.98 |
| Training Technique X Period of watch | - | - | - | - | - | - | - | - |
| Training Technique X Post-test | - | - | - | - | - | - | - | - |
| Training Technique X Follow-up test | - | - | - | - | - | - | - | - |
| Period of watch X Post-test | - | - | - | - | - | - | - | - |
| Period of watch X Follow-up test | - | - | - | - | - | - | - | - |
| | Variance | Std. Dev. | Variance | Std. Dev. | Variance | Std. Dev. | Variance | Std. Dev. |
| **Random Effects** | | | | | | | | |
| Subject (intercept) | 1090.00 | 33.01 | 1326.00 | 36.41 | 1195.83 | 34.58 | 1537.00 | 39.21 |
| Period of watch | - | - | - | - | 2.24 | 1.50 | - | - |
| Testing Session: Post-test | - | - | - | - | - | - | 2611.00 | 51.10 |
| Testing Session: Follow-up test | - | - | - | - | - | - | 1721.00 | 41.48 |
| Residual | 10593.00 | 102.92 | 10593 | 102.92 | 10553.94 | 102.73 | 9869.00 | 99.34 |
| **Fit Statistics** | | | | | | | | |
| Deviance | 427020.70 | | 427020.90 | | 426905.20 | | 424579.70 | |
| AIC | 427019.70 | | 427013 | | 426909.30 | | 424578.90 | |

Table 4.4 continued

| Model | 5 | | 6 | | 7 | | 8 | |
|---|---|---|---|---|---|---|---|---|
| Parameters | Estimate | Std. Error | Estimate | Std. Error | Estimate | Std. Error | Estimate | Std. Error |
| **Fixed Effects** | | | | | | | | |
| (Intercept) | 487.92 | 47.19 | 497.71 | 46.98 | 478.94 | 15.71 | 484.29 | 45.30 |
| Training Technique | -9.41 | 29.74 | -6.35 | 29.06 | 1.69 | 0.66 | -3.56 | 28.00 |
| Period of watch | 1.69 | 0.64 | - | - | - | - | 1.69 | 0.66 |
| Testing Session: Post-test | - | - | 12.38 | 20.9 | 12.34 | 20.91 | 12.34 | 20.91 |
| Testing Session: Follow-up test | - | - | -27.45 | 16.99 | -27.53 | 16.99 | -27.53 | 16.99 |
| Training Technique X Period of watch | - | - | - | - | - | - | - | - |
| Training Technique X Post-test | - | - | - | - | - | - | - | - |
| Training Technique X Follow-up test | - | - | - | - | - | - | - | - |
| Period of watch X Post-test | - | - | - | - | - | - | - | - |
| Period of watch X Follow-up test | - | - | - | - | - | - | - | - |
| | Variance | Std. Dev. | Variance | Std. Dev. | Variance | Std. Dev. | Variance | Std. Dev. |
| **Random Effects** | | | | | | | | |
| Subject (intercept) | 1411.08 | 37.56 | 1842.00 | 42.92 | 1470.47 | 38.35 | 1723.27 | 41.51 |
| Period of watch | 2.24 | 1.50 | - | - | 2.43 | 1.56 | 2.43 | 1.56 |
| Testing Session: Post-test | - | - | 2611.00 | 51.10 | 2612.37 | 51.11 | 2613.08 | 51.12 |
| Testing Session: Follow-up test | - | - | 1721.00 | 41.48 | 1721.71 | 41.49 | 1722.28 | 41.50 |
| Residual | 10553.94 | 102.73 | 9869.00 | 99.34 | 9829.08 | 99.14 | 9829.10 | 99.14 |
| **Fit Statistics** | | | | | | | | |
| Deviance | 426905.40 | | 424579.90 | | 424436.60 | | 424436.90 | |
| AIC | 426902.60 | | 424572.40 | | 424447.10 | | 424440.70 | |

Table 4.4. continued

| Model | 9 | | 10 | | 11 | | 12 | |
|---|---|---|---|---|---|---|---|---|
| Parameters | Estimate | Std. Error | Estimate | Std. Error | Estimate | Std. Error | Estimate | Std. Error |
| **Fixed Effects** | | | | | | | | |
| (Intercept) | 489.74 | 47.97 | 468.19 | 55.23 | 471.68 | 45.37 | 455.31 | 55.29 |
| Training Technique | -7.20 | 29.84 | 7.17 | 34.95 | -3.72 | 28.03 | 7.20 | 34.96 |
| Period of watch | 1.45 | 0.92 | 1.69 | 0.66 | 4.04 | 0.71 | 4.04 | 0.71 |
| Testing Session: Post-test | 12.34 | 20.91 | 49.15 | 60.46 | 26.09 | 21.05 | 63.02 | 60.33 |
| Testing Session: Follow-up test | -27.53 | 16.99 | 9.89 | 56.42 | -2.74 | 17.15 | 34.69 | 56.39 |
| Training Technique X Period of watch | 0.16 | 0.43 | - | - | - | - | - | - |
| Training Technique X Post-test | - | - | -24.54 | 37.73 | - | - | -24.62 | 37.61 |
| Training Technique X Follow-up test | - | - | -24.95 | 35.68 | - | - | -24.95 | 35.63 |
| Period of watch X Post-test | - | - | - | - | -2.52 | 0.45 | -2.52 | 0.45 |
| Period of watch X Follow-up test | - | - | - | - | -4.52 | 0.45 | -4.52 | 0.45 |
| | Variance | Std. Dev. | Variance | Std. Dev. | Variance | Std. Dev. | Variance | Std. Dev. |
| **Random Effects** | | | | | | | | |
| Subject (intercept) | 1780.09 | 42.19 | 1824.86 | 42.72 | 1725.06 | 41.53 | 1824.92 | 41.72 |
| Period of watch | 2.39 | 1.55 | 2.40 | 1.55 | 2.44 | 1.56 | 2.42 | 1.55 |
| Testing Session: Post-test | 2612.73 | 51.12 | 2698.66 | 51.95 | 2611.39 | 51.1 | 2694.35 | 51.91 |
| Testing Session: Follow-up test | 1722.26 | 41.5 | 1903.31 | 43.93 | 1719.12 | 41.46 | 1898.61 | 43.57 |
| Residual | 9829.33 | 99.14 | 9829.32 | 99.14 | 9801.45 | 99.00 | 9801.67 | 99.00 |
| **Fit Statistics** | | | | | | | | |
| Deviance | 424436.80 | | 424436.60 | | 424335.60 | | 424335.30 | |
| AIC | 424442.50 | | 424429.90 | | 424343.30 | | 424332.40 | |

Model 1 is a null model that only takes into account variability in RT between individuals. When a model including age as a fixed effect was compared to the null model, there was no evidence that it was a better estimate of RT than the null model, therefore age was not included in subsequent models.

Models 2, 3, and 4 included training technique, period of watch, and testing session as fixed effects, respectively. Models 3 and 4 also included the effect of period of watch and testing session, on each individual as random effects, respectively. All three models had AICs lower than the null models, and differences greater than 2, therefore the fixed effects were kept for subsequent models.

Models 5, 6, and 7 each included two of three main fixed effects, and Model 8 included all three of the main fixed effects together. Of these four models, Model 8 had the lowest AIC, and the difference in AICs when compared to the other three models was at least greater than 6, indicating that it was the better of the four models.

Models 9, 10, and 11 included all three of the fixed effects together, and each model included one two-way interaction between two of the three fixed effects. These three models were then compared to Model 8 to determine if adding an interaction improved the ability to estimate RT. The AIC of Model 9 was greater than that of Model 8, indicating that the model with the interaction between training technique and period of watch was less supported by the data than the model without the interaction, therefore, this interaction was not included in subsequent models. The AICs of models 10 and 11 were both lower than the AIC of Model 8, and the differences were greater than 10, therefore both fixed effect interactions were kept for the subsequent model.

Model 12 included the three main fixed effects, as well as the interaction of training technique and testing session, and the interaction of period of watch and testing session. When compared to Models 10 and 11, Model 12 had the lowest AIC, and the difference was

greater than 10, indicating that there was very strong evidence in favour of Model 12 as the best estimate of RT.

In Model 12, the coefficient of training technique is positive, indicating that overall, the FET group had longer RT. However, due to the large standard error, the ability of training technique to predict RT should be interpreted cautiously. The coefficient of period of watch was positive, indicating that RT increased as period of watch increased. The coefficients of testing sessions were positive, indicating that RT increased from pre-test to post-test, and from pre-test to three-month follow-up test. However, due to the large standard errors, the ability of testing session to predict RT should be interpreted cautiously.

The coefficient of the training technique x post-test interaction was negative indicating that the difference in RT between pre-test and post-test was greater for the VPT group than the FET group. However, inspection of the means reveals that RT of the VPT got longer, whilst the RT of the FET group got shorter. The coefficient of the training technique x three-month follow-up test interaction was negative indicating that RT for both groups in the follow-up test were shorter than in the pre-test. However, due to the large standard errors, the ability of these interactions to predict RT should be interpreted cautiously.

The coefficients of the period of watch by testing session interactions were negative indicating that the change in RT over period of watch was greater in the pre-test compared to both the post-test and three-month follow-up test. Inspection of Figure 4.3 reveals that RT increased in the pre-test and post-test while in the three-month follow-up test, RTs were shorter, and there was either a small decrease or no change in RT over periods of watch.

***4.4.4.2 Reaction time variability (Standard deviation).***

*4.4.4.2.1 Traditional analysis.*

Results of the univariate analysis on reaction time variability (standard deviation) reveal that there was a significant difference between testing sessions, $F(2, 8) = 4.55$, $p =$

.048, partial $\eta^2$ = .53, however, none of the post hoc pairwise comparisons were significant (pre-test: *M* = 96.50, *SE* = 10.21; post-test: *M* = 101.53, *SE* = 11.43; follow-up test: *M* = 71.51, *SE* = 4.55; *p*s > .05) (see Figure 4.4).

There was no significant difference between periods of watch, *F*(9, 36) = 2.03, *p* = .065, partial $\eta^2$ = .34. There was no significant difference between training techniques, *F*(1, 4) = 0.05, *p* = .839, partial $\eta^2$ = .01.

There was no significant interaction between testing session and training technique, *F*(2, 8) = 1.02, *p* = .404, partial $\eta^2$ = .20. There was no significant interaction between periods of watch and training technique, *F*(9, 36) = 0.68, *p* = .723, partial $\eta^2$ = .15. There was no significant interaction between testing session and period of watch, *F*(18, 72) = 1.46, *p* = .133, partial $\eta^2$ = .27. The three-way interaction between testing session, period of watch, and training technique, was not significant, *F*(18, 72) = 1.16, *p* = .320, partial $\eta^2$ = .22.

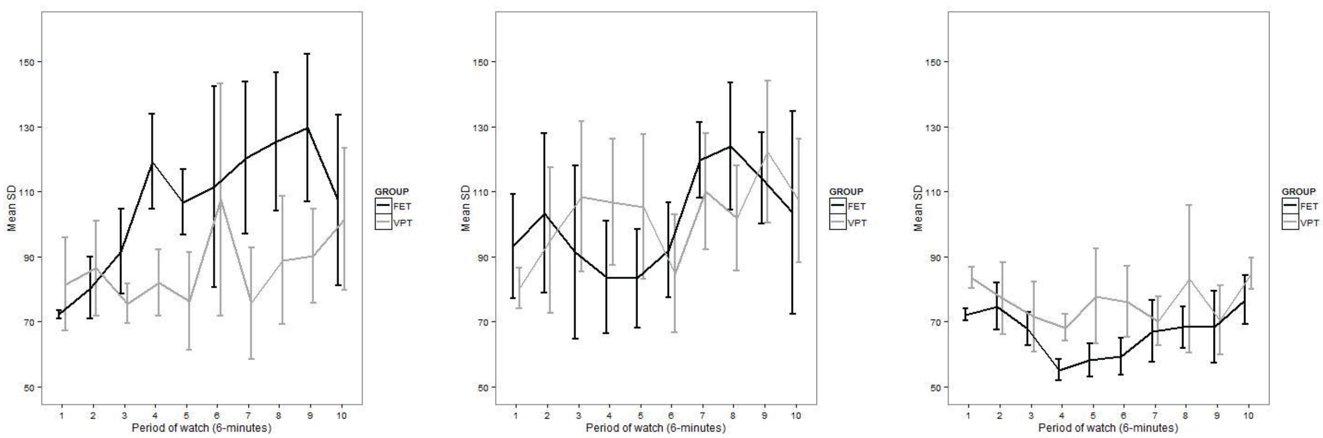


*Figure 4.4*. Reaction time variability (SD) on gradCPT at pre-test, post-test, and three-month follow-up test (left to right). Error bars represent ±1 standard error.

*4.4.4.2.2 Multilevel modelling.*

Table 4.5 provides the parameter estimates and fit statistics of the models created to estimate reaction time variability (standard deviation; SD) on the gradCPT.

Table 4.5

*Model output for the fixed and random effects estimating reaction time variability*

| Model | 1 | | 2 | | 3 | | 4 | |
|---|---|---|---|---|---|---|---|---|
| Parameters | Estimate | Std. Error | Estimate | Std. Error | Estimate | Std. Error | Estimate | Std. Error |
| **Fixed Effects** | | | | | | | | |
| (Intercept) | 89.85 | 6.19 | 88.35 | 9.73 | 78.60 | 6.14 | 96.50 | 10.16 |
| Training Technique | - | - | 2.99 | 13.76 | - | - | - | - |
| Period of watch | - | - | - | - | 2.05 | 0.74 | - | - |
| Testing Session: Post-test | - | - | - | - | - | - | 5.03 | 11.60 |
| Testing Session: Follow-up test | - | - | - | - | - | - | -24.99 | 10.36 |
| Training Technique X Period of watch | - | - | - | - | - | - | - | - |
| Training Technique X Post-test | - | - | - | - | - | - | - | - |
| Training Technique X Follow-up test | - | - | - | - | - | - | - | - |
| Period of watch X Post-test | - | - | - | - | - | - | - | - |
| Period of watch X Follow-up test | - | - | - | - | - | - | - | - |
| Training Technique X Period of watch X Post-test | - | - | - | - | - | - | - | - |
| Training Technique X Period of watch X Follow-up test | - | - | - | - | - | - | - | - |
| | Variance | Std. Dev. | Variance | Std. Dev. | Variance | Std. Dev. | Variance | Std. Dev. |
| **Random Effects** | | | | | | | | |
| Subject (intercept) | 205.10 | 14.32 | 259.20 | 16.10 | 115.48 | 10.75 | 579.80 | 24.08 |
| Period of watch | - | - | - | - | 0.43 | 0.66 | - | - |
| Testing Session: Post-test | - | - | - | - | - | - | 728.00 | 26.98 |
| Testing Session: Follow-up test | - | - | - | - | - | - | 564.90 | 23.77 |
| Residual | 744.10 | 27.28 | 744.10 | 27.28 | - | - | 396.50 | 19.91 |
| **Fit Statistics** | | | | | | | | |
| Deviance | 1713.38 | | 1713.64 | | 1704.12 | | 1623.42 | |
| AIC | 1713.90 | | 1708.87 | | 1709.53 | | 1625.81 | |

Table 4.5 continued

| Model | 5 | | 6 | | 7 | | 8 | |
|---|---|---|---|---|---|---|---|---|
| Parameters | Estimate | Std. Error | Estimate | Std. Error | Estimate | Std. Error | Estimate | Std. Error |
| **Fixed Effects** | | | | | | | | |
| (Intercept) | 79.00 | 9.35 | 101.70 | 12.40 | 85.25 | 8.36 | 90.64 | 10.26 |
| Training Technique | -0.80 | 12.97 | -10.39 | 9.01 | - | - | -10.78 | 8.26 |
| Period of watch | 2.05 | 0.74 | - | - | 2.05 | 0.75 | 2.05 | 0.68 |
| Testing Session: Post-test | - | - | 5.03 | 11.60 | 5.03 | 11.64 | 5.03 | 11.84 |
| Testing Session: Follow-up test | | - | -24.99 | 10.36 | -24.99 | 10.36 | -24.99 | 10.29 |
| Training Technique X Period of watch | - | - | - | - | - | - | - | - |
| Training Technique X Post-test | - | - | - | - | - | - | - | - |
| Training Technique X Follow-up test | - | - | - | - | - | - | - | - |
| Period of watch X Post-test | - | - | - | - | - | - | - | - |
| Period of watch X Follow-up test | - | - | - | - | - | - | - | - |
| Training Technique X Period of watch X Post-test | - | - | - | - | - | - | - | - |
| Training Technique X Period of watch X Follow-up test | - | - | - | - | - | - | - | - |
| | Variance | Std. Dev. | Variance | Std. Dev. | Variance | Std. Dev. | Variance | Std. Dev. |
| **Random Effects** | | | | | | | | |
| Subject (intercept) | 161.55 | 12.71 | 760.60 | 27.58 | 342.90 | 18.52 | 451.80 | 21.26 |
| Period of watch | 0.37 | 0.61 | - | - | 2.01 | 1.42 | 1.39 | 1.18 |
| Testing Session: Post-test | - | - | 728.00 | 26.98 | 743.97 | 27.28 | 771.13 | 27.77 |
| Testing Session: Follow-up test | - | - | 564.90 | 23.77 | 575.47 | 23.99 | 565.70 | 23.78 |
| Residual | 709.77 | 26.64 | 396.50 | 19.91 | 343.52 | 18.53 | 349.53 | 18.70 |
| **Fit Statistics** | | | | | | | | |
| Deviance | 1704.42 | | 1622.66 | | 1600.11 | | 1601.29 | |
| AIC | 1704.68 | | 1620.79 | | 1611.98 | | 1609.20 | |

Table 4.5 continued

| Model | 9 | | 10 | | 11 | | 12 | |
|---|---|---|---|---|---|---|---|---|
| Parameters | Estimate | Std. Error | Estimate | Std. Error | Estimate | Std. Error | Estimate | Std. Error |
| **Fixed Effects** | | | | | | | | |
| (Intercept) | 90.89 | 10.44 | 79.88 | 12.14 | 83.30 | 11.04 | 78.74 | 11.68 |
| Training Technique | -11.27 | 8.12 | 10.74 | 17.06 | -11.08 | 7.89 | 13.03 | 16.52 |
| Period of watch | 1.96 | 0.98 | 2.05 | 0.74 | 3.41 | 1.01 | 1.42 | 0.94 |
| Testing Session: Post-test | 5.03 | 11.62 | 10.00 | 15.13 | 9.82 | 13.25 | 15.67 | 17.15 |
| Testing Session: Follow-up test | -24.99 | 10.37 | -13.03 | 12.17 | -7.31 | 12.16 | -10.27 | 12.47 |
| Training Technique X Period of watch | 0.18 | 1.22 | - | - | - | - | 1.25 | 1.33 |
| Training Technique X Post-test | - | - | -9.94 | 19.15 | - | - | -21.29 | 24.26 |
| Training Technique X Follow-up test | - | - | -23.92 | 16.57 | - | - | -29.45 | 17.63 |
| Period of watch X Post-test | - | - | - | - | -0.87 | 1.16 | - | - |
| Period of watch X Follow-up test | - | - | - | - | -3.21 | 1.16 | - | - |
| Training Technique X Period of watch X Post-test | - | - | - | - | - | - | - | - |
| Training Technique X Period of watch X Follow-up test | - | - | - | - | - | - | - | - |
| | Variance | Std. Dev. | Variance | Std. Dev. | Variance | Std. Dev. | Variance | Std. Dev. |
| **Random Effects** | | | | | | | | |
| Subject (intercept) | 478.33 | 21.87 | 371.02 | 19.26 | 483.87 | 22.00 | 331.23 | 18.20 |
| Period of watch | 2.20 | 1.48 | 1.91 | 1.38 | 2.06 | 1.44 | 1.23 | 1.11 |
| Testing Session: Post-test | 741.70 | 27.23 | 754.20 | 27.46 | 745.22 | 27.30 | 812.24 | 28.50 |
| Testing Session: Follow-up test | 576.14 | 24.00 | 407.55 | 20.19 | 578.44 | 24.05 | 395.99 | 19.90 |
| Residual | 344.33 | 18.56 | 344.15 | 18.55 | 330.16 | 18.17 | 351.40 | 18.75 |
| **Fit Statistics** | | | | | | | | |
| Deviance | 1598.88 | | 1597.13 | | 1590.62 | | 1598.74 | |
| AIC | 1606.64 | | 1594.07 | | 1598.69 | | 1595.30 | |

Table 4.5 continued

| Model | 13 | | 14 | | 15 | | 16 | |
|---|---|---|---|---|---|---|---|---|
| Parameters | Estimate | Std. Error | Estimate | Std. Error | Estimate | Std. Error | Estimate | Std. Error |
| **Fixed Effects** | | | | | | | | |
| (Intercept) | 83.41 | 11.04 | 72.46 | 12.65 | 71.25 | 12.73 | 76.99 | 13.24 |
| Training Technique | -11.29 | 8.02 | 10.60 | 16.99 | 13.03 | 17.23 | 1.544 | 18.73 |
| Period of watch | 3.32 | 1.18 | 3.41 | 0.995 | 2.78 | 1.27 | 1.74 | 1.43 |
| Testing Session: Post-test | 9.82 | 13.25 | 14.70 | 16.39 | 20.46 | 17.93 | 12.28 | 19.02 |
| Testing Session: Follow-up test | -7.31 | 12.17 | 4.62 | 13.73 | 7.41 | 14.17 | -1.64 | 15.53 |
| Training Technique X Period of watch | 0.18 | 1.21 | - | - | 1.25 | 1.52 | 3.34 | 2.02 |
| Training Technique X Post-test | - | - | -9.76 | 19.06 | -21.29 | 23.70 | -4.90 | 26.90 |
| Training Technique X Follow-up test | - | - | -23.86 | 16.57 | -29.45 | 17.91 | -11.34 | 21.96 |
| Period of watch X Post-test | -0.87 | 1.16 | -0.87 | 1.16 | -0.87 | 1.16 | 0.62 | 1.63 |
| Period of watch X Follow-up test | -3.20 | 1.16 | -3.21 | 1.16 | -3.21 | 1.16 | -1.57 | 1.63 |
| Training Technique X Period of watch X Post-test | - | - | - | - | - | - | -2.98 | 2.31 |
| Training Technique X Period of watch X Follow-up test | - | - | - | - | - | - | -3.29 | 2.31 |
| | Variance | Std. Dev. | Variance | Std. Dev. | Variance | Std. Dev. | Variance | Std. Dev. |
| **Random Effects** | | | | | | | | |
| Subject (intercept) | 479.47 | 21.90 | 371.92 | 19.29 | 371.66 | 19.28 | 371.74 | 19.28 |
| Period of watch | 2.21 | 1.49 | 1.93 | 1.39 | 2.12 | 1.46 | 2.12 | 1.46 |
| Testing Session: Post-test | 744.15 | 27.28 | 756.81 | 27.51 | 776.54 | 27.87 | 776.73 | 27.87 |
| Testing Session: Follow-up test | 578.70 | 24.06 | 410.18 | 20.25 | 414.79 | 20.37 | 414.99 | 20.37 |
| Residual | 331.37 | 18.20 | 331.20 | 18.20 | 331.38 | 18.20 | 330.41 | 18.18 |
| **Fit Statistics** | | | | | | | | |
| Deviance | 1590.70 | | 1588.83 | | 1588.14 | | 1585.53 | |
| AIC | 1598.53 | | 1585.96 | | 1583.62 | | 1579.41 | |

Model 1 is a null model that only takes into account variability in SD between individuals. When a model including age as a fixed effect was compared to the null model, there was no evidence that it was a better estimate of SD than the null model, therefore age was not included in subsequent models.

Models 2, 3, and 4 included training technique, period of watch, and testing session as fixed effects, respectively. Models 3 and 4 also included the effect of period of watch and testing session, on each individual as random effects, respectively. All three models had AICs lower than the null models, and differences greater than 2, therefore the fixed effects were kept for subsequent models.

Models 5, 6, and 7 each included two of three main fixed effects, and Model 8 included all three of the main fixed effects together. Of these four models, Model 8 had the lowest AIC, and the difference in AICs when compared to the other three models was at least greater than 2, indicating that it was the better of the four models.

Models 9, 10, and 11 included all three of the fixed effects together, and each model included one two-way interaction between two of the three fixed effects. These three models were then compared to Model 8 to determine if adding an interaction improved the ability to estimate RT. The AICs of models 9, 10 and 11 were all lower than the AIC of Model 8, and the differences were at least greater than 2, therefore each of the three fixed effect interactions were kept for subsequent models.

Models 12, 13 and 14 each included the three main fixed effects, as well as two of the three two-way interactions. Model 15 included the three main fixed effects as well as all three of the two-way interactions. When compared to Models 12, 13, and 14, Model 15 had the lowest AIC, and the difference was at least greater than 2, indicating that there was very positive evidence in favour of Model 15 as the better of the four models.

Model 16 included the same fixed effects as Model 15, as well as the three-way

interaction between training technique, period of watch, and testing session. The AIC of Model 16 was lower than that of Model 15, and the difference was greater than 2 indicating positive evidence in favour of Model 16 being the best estimate of reaction time variability.

In Model 16, the coefficient of training technique is positive, indicating that the FET group had larger RT variability. However, due to the large standard error, the ability of training technique to predict RT variability should be interpreted cautiously. The coefficient of period of watch was positive, indicating that RT variability increased as period of watch increased. The coefficients of testing sessions was positive for the post-test, indicating that RT variability was higher than in the pre-test, and the coefficient was negative for the three-month follow-up test, indicating that RT variability was lower than in pre-test. However, due to the large standard errors, the ability of testing session to predict RT variability should be interpreted cautiously.

The coefficient of the training technique x period of watch interaction was positive, indicating that the change in RT variability over period of watch was greater for the FET group than the VPT group. Inspection of the Figure 4.4 reveals that both groups exhibited increases in RT variability, but this was greater for the FET group.

The coefficient of the training technique x post-test interaction was negative indicating that the difference in RT variability from pre-test to post-test was greater for the VPT group than the FET group. However inspection of the Figure 4.4 reveals that the RT variability of the VPT group increased from pre-test to post-test, whilst the RT variability of the FET group decreased from pre-test to post-test. The coefficient of the training technique x three-month follow-up test interaction was negative indicating that RT variability for both groups was greater in the pre-test compared to the three-month follow-up test.

The coefficient of the period of watch x post-test interaction was negative indicating that the change in RT variability over period of watch was greater in the post-test compared

to the pre-test. Inspection of Figure 4.4 reveals that RT variability increased over period of watch in both testing sessions. The coefficient of the period of watch x three-month follow-up test interaction was positive indicating that the change in RT variability over period of watch was greater in the pre-test compared to the three-month follow-up test. Inspection of the Figure 4.4 reveals that there was a small decrease to no change in RT variability over period of watch during the three-month follow-up test.

The coefficient of the training technique x period of watch x post-test three-way interactions was negative. This indicates that the difference in the change in RT variability over period of watch between the VPT group and the FET group was greater in the pre-test compared to the post-test. Alternatively, the difference in the change in RT variability between pre-test and post-test was greater for the VPT than the FET group. Inspection of the Figure 4.4 reveals that RT variability of the VPT group increased from pre- to post-test while there was little to no change in the FET group from pre- to post-test.

In addition, the coefficient of the training technique x period of watch x three-month follow-up post-test three-way interactions was also negative. This indicates that the difference in the change in RT variability over period of watch between the VPT group and the FET group was greater in the pre-test compared to the three-month follow-up test.

***4.4.4.3 Sensitivity.***

*4.4.4.3.1 Traditional analysis.*

Results of the univariate analysis on sensitivity levels reveal that there was no significant difference between testing sessions, $F(2, 8) = 3.05$, $p = .103$, partial $\eta^2 = .43$. There was no significant difference between periods of watch, $F(9, 36) = 2.05$, $p = .061$, partial $\eta^2 = .34$. There was no significant difference between training techniques, $F(1, 4) = 0.311$, $p = .607$, partial $\eta^2 = .07$ (see Figure 4.5).

There was no significant interaction between testing session and training technique,

$F(2, 8) = 0.07$, $p = .932$, partial $\eta^2 = .02$. There was no significant interaction between periods of watch and training technique, $F(9, 36) = 0.44$, $p = .905$, partial $\eta^2 = .10$. There was no significant interaction between testing session and period of watch, $F(18, 72) = 1.71$, $p = .057$, partial $\eta^2 = .30$. The three-way interaction between testing session, period of watch, and training technique, was not significant, $F(18, 72) = 1.41$, $p = .155$, partial $\eta^2 = .26$.

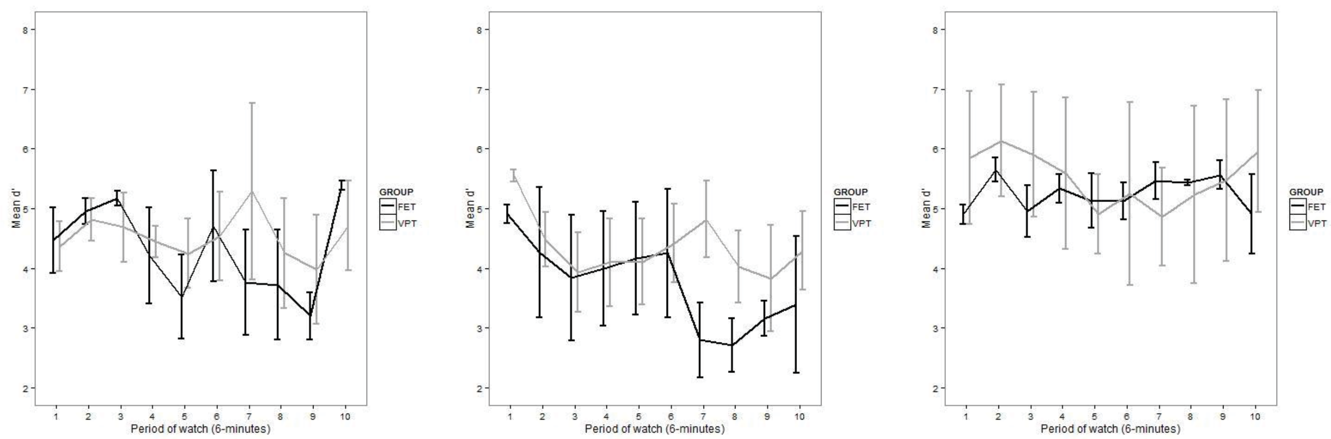


*Figure 4.5*. Sensitivity levels (d') on gradCPT at pre-test, post-test, and three-month follow-up test (left to right). Error bars represent ±1 standard error.

*4.4.4.3.2 Multilevel Modelling.*

Table 4.6 provides the parameter estimates and fit statistics of the models created to estimate sensitivity levels (d') on the gradCPT.

Table 4.6

*Model output for the fixed and random effects estimating sensitivity levels*

| Model | 1 | | 2 | | 3 | | 4 | |
|---|---|---|---|---|---|---|---|---|
| Parameters | Estimate | Std. Error | Estimate | Std. Error | Estimate | Std. Error | Estimate | Std. Error |
| **Fixed Effects** | | | | | | | | |
| (Intercept) | 4.62 | 0.31 | 4.80 | 0.47 | 4.97 | 0.24 | 4.42 | 0.36 |
| Training Technique | - | - | -0.37 | 0.66 | - | - | - | - |
| Period of watch | - | - | - | - | -0.06 | 0.04 | - | - |
| Testing Session: Post-test | - | - | - | - | - | - | -0.37 | 0.53 |
| Testing Session: Follow-up test | - | - | - | - | - | - | 0.96 | 0.38 |
| | Variance | Std. Dev. | Variance | Std. Dev. | Variance | Std. Dev. | Variance | Std. Dev. |
| **Random Effects** | | | | | | | | |
| Subject (intercept) | 1090.00 | 33.01 | 0.60 | 0.78 | 0.15 | 0.38 | 0.71 | 0.84 |
| Period of watch | - | - | - | - | $3.74x10^{-3}$ | 0.06 | - | - |
| Testing Session: Post-test | - | - | - | - | - | - | 1.52 | 1.23 |
| Testing Session: Follow-up test | - | - | - | - | - | - | 0.72 | 0.85 |
| Residual | 1.41 | 1.19 | 1.41 | 1.19 | 1.35 | 1.16 | 0.70 | 0.84 |
| **Fit Statistics** | | | | | | | | |
| Deviance | 586.19 | | 586.07 | | 578.42 | | 488.13 | |
| AIC | 592.73 | | 593.47 | | 596.08 | | 508.46 | |

Model 1 is a null model that only takes into account variability in sensitivity levels between individuals. When a model including age as a fixed effect was compared to the null model, there was no evidence that it was a better estimate of sensitivity levels than the null model, therefore age was not included in subsequent models.

Models 2, 3, and 4 included training technique, period of watch, and testing session as fixed effects, respectively. Models 3 and 4 also included the effect of period of watch and testing session, on each individual as random effects, respectively. Models 2 and 3 had AICs greater than that of the null model indicating that the model with training technique or period of watch received less support by the data than that of the null model. Model 4 had the lowest AIC and the difference in AIC between the null model and Model 4 was greater than 10, indicating that there was very strong evidence in favour of Model 4 as the best estimate of sensitivity levels. The coefficient for the post-test estimate was negative, indicating that sensitivity levels were higher in the pre-test than in the post-test. However, due to the large standard error this should be interpreted cautiously. The coefficient for the three-month follow-up test estimate was positive, indicating that sensitivity levels were higher in the follow-up test than in the pre-test.

***4.4.4.4 Criterion.***

*4.4.4.4.1 Traditional analysis.*

Results of the univariate analysis on criterion levels reveal that there was no significant difference between testing sessions, $F(2, 8) = 0.57$, $p = .589$, partial $\eta^2 = .12$. There was no significant difference between periods of watch, $F(9, 36) = 1.91$, $p = .081$, partial $\eta^2 = .32$. There was no significant difference between training techniques, $F(1, 4) = 0.74$, $p = .438$, partial $\eta^2 = .16$ (see Figure 4.6).

There was no significant interaction between testing session and training technique, $F(2, 8) = 0.23$, $p = .803$, partial $\eta^2 = .05$. There was no significant interaction between periods

of watch and training technique, $F(9, 36) = 1.10$, $p = .385$, partial $\eta^2 = .22$. There was no significant interaction between testing session and period of watch, $F(18, 72) = 1.53$, $p = .104$, partial $\eta^2 = .28$. The three-way interaction between testing session, period of watch, and training technique, was not significant, $F(18, 72) = 1.08$, $p = .386$, partial $\eta^2 = .21$.

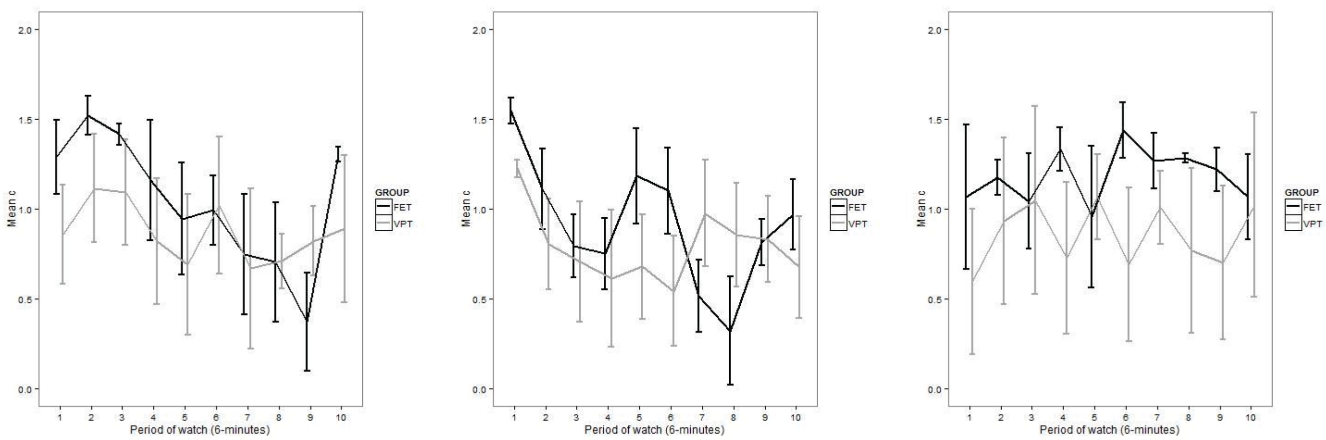


*Figure 4.6*. Criterion levels (c) on gradCPT at pre-test, post-test, and three-month follow-up test (left to right). Error bars represent ±1 standard error.

*4.4.4.4.2 Multilevel Modelling.*

Table 4.7 provides the parameter estimates and fit statistics of the models created to estimate criterion levels (c) on the gradCPT.

Table 4.7

*Model output for the fixed and random effects estimating criterion levels*

| Model | 1 | | 2 | | 3 | | 4 | |
|---|---|---|---|---|---|---|---|---|
| Parameters | Estimate | Std. Error | Estimate | Std. Error | Estimate | Std. Error | Estimate | Std. Error |
| **Fixed Effects** | | | | | | | | |
| (Intercept) | 0.94 | 0.12 | 0.84 | 0.17 | 1.09 | 0.15 | 0.96 | 0.14 |
| Training Technique | - | - | 0.21 | 0.24 | - | - | - | - |
| Period of watch | - | - | - | - | -0.03 | 0.01 | - | - |
| Testing Session: Post-test | - | - | - | - | - | - | -0.11 | 0.11 |
| Testing Session: Follow-up test | - | - | - | - | - | - | 0.06 | 0.18 |
| | Variance | Std. Dev. | Variance | Std. Dev. | Variance | Std. Dev. | Variance | Std. Dev. |
| **Random Effects** | | | | | | | | |
| Subject (intercept) | 1090.00 | 33.01 | 0.60 | 0.78 | 0.15 | 0.38 | 0.71 | 0.84 |
| Period of watch | - | - | - | - | $7.24 \times 10^{-5}$ | 0.01 | - | - |
| Testing Session: Post-test | - | - | - | - | - | - | 0.04 | 0.19 |
| Testing Session: Follow-up test | - | - | - | - | - | - | 0.16 | 0.40 |
| Residual | 0.19 | 0.43 | 0.19 | 0.43 | 0.18 | 0.42 | 0.15 | 0.39 |
| **Fit Statistics** | | | | | | | | |
| Deviance | 222.71 | | 222.02 | | 216.23 | | 200.90 | |
| AIC | 231.15 | | 233.41 | | 237.85 | | 228.26 | |

Model 1 is a null model that only takes into account variability in criterion levels between individuals. When a model including age as a fixed effect was compared to the null model, there was no evidence that it was a better estimate of criterion levels than the null model, therefore age was not included in subsequent models.

Models 2, 3, and 4 included training technique, period of watch, and testing session as fixed effects, respectively. Models 3 and 4 also included the effect of period of watch and testing session, on each individual as random effects, respectively. Models 2 and 3 had AICs greater than that of the null model indicating that the models with training technique or period of watch received less support by the data than that of the null model. Model 4 had the lowest AIC and the difference in AIC between the null model and Model 4 was greater than 2, indicating that there was positive evidence in favour of Model 4 as the best estimate of criterion levels. The coefficient for the post-test estimate was negative, indicating that criterion levels were higher in the pre-test than in the post-test. The coefficient for the three-month follow-up test estimate was positive, indicating that criterion levels were higher in the follow-up test than in the pre-test. However, due to the large standard errors, the ability of the testing session to predict criterion levels should be interpreted cautiously.

**4.4.5 Divided Attention.**

***4.4.5.1 Missing data.***

In the first MATB-II session of the pre-test (Study 1), there was missing data for one participant (VPT group) for both the Communications task RT and System monitoring Scales task RT. As this data was collected as part of Study 1 (Chapter 3), the missing values were replaced with the mean values of those measures from the NVGP group in Study 1.

In the first MATB-II session of the post-test, there was missing data for one participant (FET group) in the Communications task RT. Due to the small sample size of the group, it was considered that the best estimate of the missing data was the average of the

participants' other Communications task RT performance over the entire study period, as opposed to the mean of the group's performance for that task, therefore this was used as a replacement.

***4.4.5.2 Analysis.***

A 3 (testing session) x 2 (MATB-II session) x 2 (training technique) MANOVA was conducted on the eight measures of the MATB-II.

Mauchly's test of sphericity was only significant for System Monitoring - Scale RT ($p$ =.014) within testing sessions. No other measures were significant ($p$s > .05).

There was a significant difference in MATB-II performance between testing sessions, $V$ = 1.95, $F$ (16,4) = 9.40, $p$ = .021, partial $\eta^2$ = .97. There was no significant difference in performance between MATB-II sessions, $V$ = .91, $F$ (4,1) = 2.67, $p$ = .426, partial $\eta^2$ = .91. There was no significant difference between training techniques, $V$ = .994, $F$(4, 1) = 40.43, $p$ = .117, $\eta^2$ = .99. The interaction between testing session and training technique was not significant, $V$ = 1.70, $F$ (16,4) = 1.43, $p$ = .397, partial $\eta^2$ = .85. The interaction between MATB-II session and training technique was not significant, $V$ = .60, $F$ (4,1) = 0.37, $p$ = .825, partial $\eta^2$ = .60. The interaction between testing sessions and MATB-II session was not significant, $V$ = 1.46, $F$ (16,4) = 0.68, $p$ = .741, partial $\eta^2$ =.73. The three-way interaction between testing session, MATB-II session, and training technique, was significant, $V$ = 1.93, $F$ (16,4) = 7.16, $p$ = .035, partial $\eta^2$ = .97.

Due to the large number of post hoc analyses, only those that were significant in the MANOVA are included here.

The difference in System Monitoring - Light accuracy performance was significantly different between testing sessions, $F$(2,8) = 17.15, $p$ = .001, partial $\eta^2$ = .81. Post hoc analysis revealed that there was a significant difference between pre-test ($M$ = 0.75, $SE$ = 0.06) and post-test ($M$ = 0.86, $SE$ = 0.05), and between pre-test and follow-up test ($M$ = 0.96, $SE$ =

0.22) (*p*s < .05).

The difference in System Monitoring – Scale RT performance was significantly different between testing sessions, $F(2,8) = 4.60$, $p = .047$, partial $\eta^2 = .54$. Post hoc analysis revealed that there was a significant difference between pre-test ($M = 4.72$s, $SE = 0.32$) and post-test ($M = 3.96$s, $SE = 0.35$) ($p = .001$).

The difference in System Monitoring – Scale accuracy performance was significantly different between testing sessions, $F(2,8) = 8.96$, $p = .009$, partial $\eta^2 = .69$. Post hoc analysis revealed that there was a significant difference between post-test ($M = 0.78$, $SE = 0.06$) and follow-up test ($M = 0.84$, $SD = 0.05$) ($p = .05$).

Due to the significant three-way interaction in the MANOVA, separate 2 (MATB-II session) x 3 (testing session) ANOVAs were conducted for each training technique. Descriptive statistics for each measure of the MATB-II, for each training technique, for each testing session are presented in Table 4.8.

Table 4.8

*MATB-II sub-task performance across testing sessions*

| | | | Testing Session | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | | | | 2 | | | | 3 | | | |
| | | MATB-II session | 1 | | 2 | | 1 | | 2 | | 1 | | 2 | |
| Task | Measure | Training Technique | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Communications | RT | VPT | 3.91 | 1.33 | 4.23 | 2.37 | 4.90 | 2.69 | 3.44 | 1.34 | 3.86 | 2.44 | 3.27 | 0.92 |
| | | FET | 3.44 | 1.47 | 3.06 | 1.62 | 2.80 | 1.88 | 3.76 | 2.34 | 2.70 | 1.31 | 2.72 | 1.85 |
| | Acc. | VPT | 0.78 | 0.24 | 0.98 | 0.01 | 0.98 | 0.01 | 0.99 | 0.01 | 0.93 | 0.07 | 0.97 | 0.04 |
| | | FET | 0.91 | 0.09 | 0.98 | 0.01 | 0.83 | 0.29 | 0.99 | 0.01 | 0.96 | 0.01 | 0.98 | 0.01 |
| Resource Management | Mean | VPT | 761.21 | 559.41 | 360.77 | 200.93 | 480.48 | 293.71 | 395.93 | 311.56 | 390.04 | 244.81 | 343.74 | 266.22 |
| | | FET | 425.57 | 255.59 | 369.21 | 156.65 | 380.71 | 146.45 | 222.58 | 111.45 | 320.84 | 298.04 | 231.66 | 155.37 |
| Tracking | RMSD | VPT | 45.68 | 18.51 | 42.24 | 11.09 | 40.92 | 5.72 | 33.10 | 3.97 | 35.42 | 9.63 | 33.45 | 10.49 |
| | | FET | 48.75 | 11.04 | 39.78 | 8.14 | 42.63 | 11.31 | 40.14 | 6.39 | 43.16 | 9.37 | 36.90 | 2.86 |
| System Monitoring: Lights | RT | VPT | 3.76 | 1.19 | 3.22 | 0.59 | 3.32 | 1.15 | 3.16 | 1.77 | 2.77 | 1.00 | 2.84 | 1.64 |
| | | FET | 4.13 | 1.88 | 3.27 | 0.75 | 3.56 | 1.05 | 3.30 | 0.92 | 2.78 | 0.48 | 2.87 | 0.29 |
| | Acc. | VPT | 0.78 | 0.20 | 0.84 | 0.16 | 0.95 | 0.06 | 0.93 | 0.12 | 0.96 | 0.07 | 0.99 | 0.02 |
| | | FET | 0.58 | 0.17 | 0.78 | 0.05 | 0.78 | 0.11 | 0.78 | 0.14 | 0.94 | 0.06 | 0.94 | 0.07 |
| System Monitoring: Scales | RT | VPT | 5.31 | 0.58 | 3.86 | 1.23 | 3.62 | 1.14 | 3.26 | 0.98 | 3.51 | 2.10 | 3.71 | 1.67 |
| | | FET | 4.77 | 0.63 | 4.94 | 0.73 | 4.56 | 0.53 | 4.39 | 0.82 | 4.02 | 0.85 | 3.92 | 0.69 |
| | Acc. | VPT | 0.43 | 0.37 | 0.75 | 0.10 | 0.91 | 0.08 | 0.80 | 0.21 | 0.78 | 0.24 | 0.89 | 0.10 |
| | | FET | 0.46 | 0.11 | 0.64 | 0.03 | 0.71 | 0.19 | 0.70 | 0.12 | 0.84 | 0.09 | 0.85 | 0.06 |

RT = Reaction time; Acc. = Accuracy; SD = Standard Deviation

*4.4.5.2.1 Variable Priority Training (VPT).*

Mauchly's test of sphericity was only significant for RMSD within testing sessions ($p < .05$). No other measures were significant ($p$s > .05).

The difference in performance between MATB-II sessions was not significant, $V = .96$, $F(2, 1) = 10.83$, $p = .21$, partial $\eta^2 = .96$. The different between testing sessions was not significant, $V = 1.83$, $F(8, 4) = 5.54$, $p = .058$, partial $\eta^2 = .92$. The interaction between test sessions and MATB-II sessions was not significant, $V = 1.81$, $F(8, 4) = 4.82$, $p = .073$, partial $\eta^2 = .91$.

Despite the non-significant results, univariate results were analysed as it is possible that the two groups focussed on different sub-tasks at different times or that the different training techniques improved different areas of multitasking. There was no significant difference between testing sessions on any of the MATB-II measures. There was a significant difference in System Monitoring – Scale RT between the first ($M = 4.15$s, $SE = 0.72$) and second ($M = 3.61$s, $SE = 0.73$) MATB-II sessions, $F(1,2) = 24.60$, $p = .038$, partial $\eta^2 = .93$.

*4.4.5.2.2 Fixed Emphasis Training (FET).*

Mauchly's test of sphericity was not significant for all MATB-II measures ($p$s < .05).

The difference between MATB-II sessions was not significant, $V = 0.72$, $F(2, 1) = 1.30$, $p = .527$, partial $\eta^2 = .72$. The difference between testing sessions was not significant, $V = 1.28$, $F(8, 4) = 0.90$, $p = .586$, partial $\eta^2 = .64$. The interaction between testing sessions and MATB-II sessions was not significant, $V = 0.88$, $F(8, 4) = 0.39$, $p = .879$, partial $\eta^2 = .44$.

Univariate analyses revealed that there was a significant difference in System monitoring – Light accuracy between testing sessions, $F(2, 4) = 19.24$, $p = .009$, partial $\eta^2 = .91$. There was also a significant difference in System monitoring – Scale accuracy between testing sessions, $F(2,4) = 7.93$, $p = .041$, partial $\eta^2 = .80$. However, pairwise comparisons for both measures between testing sessions were not significant.

**4.4.6 Workload Rating Scale (WRS).**

A 3 (test session) x 2 (MATB-II session) x 2 (training technique) mixed-design MANOVA was conducted on the six WRS items.

Mauchly's test of sphericity was not significant for any of the item (*p*s > .05). There was no significant difference in WRS between testing sessions, $V = 1.32$, $F\ (12,8) = 1.31$, $p = .361$, partial $\eta^2 = .66$. There was no significant difference in WRS between MATB-II sessions, $V = 0.97$, $F\ (4,1) = 6.83$, $p = .278$, partial $\eta^2 = .97$. There was no significant difference between training techniques, $V = 0.95$, $F(4, 1) = 4.73$, $p = .331$, partial $\eta^2 = .95$. The interaction between testing session and training technique was not significant, $V = 1.56$, $F\ (12,8) = 2.35$, $p = .116$, partial $\eta^2 = .78$. The interaction between MATB-II session and training technique was not significant, $V = 0.94$, $F\ (4,1) = 3.93$, $p = .359$, partial $\eta^2 = .94$. The interaction between testing sessions and MATB-II session was not significant, $V = 1.24$, $F\ (12,8) = 1.09$, $p = .465$, partial $\eta^2 = .62$. The three-way interaction between testing session, MATB-II session, and training technique, was not significant, $V = 0.94$, $F\ (12, 8) = .588$, $p$ .803, partial $\eta^2 = .47$.

Univariate results were analysed to determine if groups differed on any of the individual items. Due to the large number of analyses, only the significant results are included here. There was a significant difference between testing sessions on the *physical* item, $F(2, 8) = 12.41$, $p = .004$, partial $\eta^2 = .76$. Pairwise comparisons revealed that there was a significant difference between pre-test ($M = 54.08$, SE = 6.89) and post-test ($M = 26.83$, $SE = 6.11$) on the *physical* item ($p = .032$).

There was a significant difference between the first MATB-II session ($M = 43.89$, $SE = 4.52$) and the second ($M = 31.83$, $SE = 3.60$) on the *performance* item, $F(2, 8) = 10.60$, $p = .031$, partial $\eta^2 = .73$. The interaction between testing session and MATB-II session was significant on the *physical* item, $F(2, 8) = 8.52$, $p = .01$, partial $\eta^2 = .68$, and the *performance*

item $F(2, 8) = 5.44$, $p = .032$, partial $\eta^2 = .58$.

**4.4.7 Comparison to VGP performance.**

Participants' performance was compared to the performance of the VGPs from Study 1 (Chapter 3). Both training groups were combined to ensure a large enough sample size and to examine the overall impact of video game training, regardless of training technique. As participants' overall performance at the three-month follow-up was better than the performance at post-test, only the three-month follow-up performance was compared to that of the VGPs from Study 1.

***4.4.7.1 Video game performance.***

A t-test was conducted comparing the *Unreal Tournament 2004* performance of the trained NVGPs at the three-month follow-up test to the performance of the VGPs. Levene's test of equality of variances was not significant ($p > .05$). The trained NVGPs ($M = 0.94$, $SD = 4.94$) performed significantly worse than the VGPs ($M = 6.39$, $SD = 3.35$), $t(22) = 3.07$, $p < .006$.

***4.4.7.2 Sustained Attention.***

A 10 (period of watch) x 2 (group) MANOVA was conducted, comparing the three-month follow-up test performance of the trained NVGPs with the performance of the VGPs on each of the four vigilance measures.

At the multivariate level, the difference between the groups was not significant, $V = 0.37$, $F(4, 19) = 2.77$, $p = .057$, partial $\eta^2 = .37$. There was no significant difference between periods of watch, $V = 0.18$, $F(36, 792) = 1.05$, $p = .391$, partial $\eta^2 = .05$. There was no significant interaction between group and periods of watch, $V = 0.14$, $F(36, 792) = 0.82$, $p = .765$, partial $\eta^2 = 0.04$. Mauchly's test of sphericity was significant for reaction time, reaction time variability, and sensitivity levels ($p$s > .05), therefore the Greenhouse-Geisser adjustment was used for the univariate analyses. At the univariate level, there was no

significant difference between periods of watch for any of the four measures of sustained attention (*p*s > .05). In addition, there was no significant interaction between period of watch and group for any of the four measures. There was no significant difference between the trained NVGPs and the VGPs in reaction times, reaction time variability, or criterion levels (*p*s > .05). However there was a significant difference between trained NVGPs (*M* = 5.38, *SE* = 0.42) and VGPs (*M* = 3.95, *SE* = 0.24) in sensitivity levels, $F(1, 22) = 8.85$, $p = .007$, partial $\eta^2 = .29$.

***4.4.7.3 Divided Attention.***

A 2 (MATB-II session) x 2 (group) MANOVA was conducted on the eight measures of the MATB-II.

At the multivariate level there was a significant difference between groups, $V = 0.67$, $F(8, 15) = 3.73$, $p = .014$, partial $\eta^2 = .67$. There was a significant difference between MATB-II sessions, $V = 0.59$, $F(8, 15) = 2.69$, $p = .047$, partial $\eta^2 = .59$. The interaction between group and MATB-II session was not significant, $V = 0.34$, $F(8, 15) = 0.97$, $p = .494$, partial $\eta^2 = .34$.

Due to the large number of univariate analyses, only those that were significant in the MANOVA are included here. In addition, differences between MATB-II sessions was not of interest in the current analysis, therefore only differences between groups, and the interaction between group and MATB-II session are reported.

There was a significant difference between the trained NVGP group (*M* = 0.96, *SE* = 0.04) and the VGP group (*M* = 0.86, *SE* = 0.02), in System Monitoring– Light accuracy, $F(1, 22) = 4.43$, $p = .047$, partial $\eta^2 = .17$. There were no other significant differences between groups. There was a significant interaction between group and MATB-II session on Communication task accuracy, $F(1, 22) = 4.92$, $p = .037$, partial $\eta^2 = .18$. No other interactions were significant.

## 4.5 Discussion

### 4.5.1 Video game performance.

Traditional analysis of video game performance during the training phase revealed that video game training significantly improved performance. This result is not surprising as practicing a task invariably leads to learning and thus improved performance (Boot et al., 2010; Lee, Boot, et al., 2012). However, contrary to previous studies comparing VPT and FET on a video game (Boot et al., 2010), there was no advantage of VPT over FET in improving performance. A discussion of possible explanations is provided in Section 4.5.4.

Due to the small sample size of the study, the results of traditional significance testing are limited, therefore non-traditional analyses were also conducted. The results of the multilevel linear modelling support those of the traditional analysis. Including the training technique factor did not improve the ability of the model to estimate video game performance during training, however including training day in the model did. Combined, the results of both analyses provide evidence that training on a video game for ten hours over four weeks does significantly improve video game performance, however there is no advantage of one type of training technique over the other.

Traditional analysis of video game performance during the testing sessions revealed that video game training significantly improved performance and that this improvement was maintained at a three-month follow-up test. The results of the post-test confirm those of the training phase, that video game training does improve video game performance. However, again, there was no significance difference in video game performance between the two training techniques. In addition, the results of the multilevel linear modelling support those of the traditional analysis. Including the training technique factor did not improve the ability of the model to estimate video game performance prior to and after training, however including testing sessions in the model did. Combined, the results of both traditional and non-traditional

analyses of video game performance during training, and between testing sessions, provides evidence that training on a video game improves video game performance, and that this improvement is maintained three months later.

**4.5.2 Sustained attention performance.**

Results of the traditional analyses suggest that video game training does not lead to improvements in performance on vigilance tasks. At the multivariate levels there were no significant effects of training technique, testing session, or period of watch, or the interactions between these variables, on the four measures of sustained attention. The lack of differences between training techniques are discussed in Section 4.5.4

The lack of difference between testing sessions is surprising, given the results of Study 1 (Chapter 3), which showed that VGPs, when compared to NVGPs, demonstrated superior sustained attention. Previous research has shown that video game training can improve a range of cognitive and attentional skills that relate to sustained attention. However, previous research has only examined the differences in sustained attention performance between VGPs and NVGPs and not explored the effect of video game training on improving sustained attention performance directly. Therefore it is possible that either more training is required, or that sustained attention is not developed by action video games, and that in fact, individuals who become VGPs already possess the superior sustained attention skills which allow them to perform well on action video games (Adams & Mayer, 2012).

The difference in performance over periods of watch approached significance, and it is likely that this would have been significant with a larger sample. A significant difference in performance over periods of watch would be consistent with the results of Study 1 (Chapter 3) and the research on cognitive fatigue in general , as performing any task for an extended period of time will eventually result in decreased performance (Ackerman, 2011; Guastello et al., 2013; Lal & Craig, 2001; Van Dongen et al., 2011). As the interaction between period of

watch and training technique, and the three-way interaction between period of watch, training technique, and testing session were not significant, this suggests that all participants experienced similar levels of cognitive fatigue whilst performing the vigilance task, and that there was no effect of video game training or training technique on resisting the effects of cognitive fatigue. These results support those of Study 1 whereby both VGPs and NVGPs experienced similar levels of cognitive fatigue as evidenced by declining sustained attention performance over periods of watch.

However, due to the small sample size, the results of the traditional multivariate analyses should be interpreted cautiously. The following sections examine both the traditional univariate analyses and the non-traditional analyses of each of the four sustained attention measures.

#### *4.5.2.1 Reaction time.*

Results of the univariate analysis revealed that there was no significant effect of testing session, period of watch, or training technique, nor of the interactions between these variables, on reaction times in the vigilance task. These results are consistent with those of Study 1 (Chapter 3) whereby there was no change in reaction times over periods of watch, nor any difference between VGPs and VGPs. It is possible that the lack of change in reaction times over time is due to the design of the vigilance task itself. The continuous performance design of the vigilance task was chosen as it can measure moment-to-moment fluctuations in reaction times. However, due to the length of the task, for ease of analysis, reaction times were collapsed into 10 six-minute periods of watch. This process reduces variation and thus affects the likelihood of detecting a significant difference between periods. Due to this, reaction time variability was also measured, which is discussed further in the next section. It is suggested for future investigations of sustained attention and cognitive fatigue, that the traditional design of the vigilance task be used for long task durations.

Results of the multilevel linear modelling approach revealed that the model that is best able to predict RT performance includes the three main effects, training technique, period of watch, and testing session, as well as the interaction between training technique and test sessions and the interaction between period of watch and testing sessions. Thus, all of these effects contribute to accurately estimating RT. However, these should be interpreted cautiously due to the large standard errors of most of the estimates. Therefore. only the effects with small standard errors are considered here for discussion. The effects with relatively low standard errors are period of watch, and the interaction between period of watch and testing sessions. Overall, as period of watch increased, so too did reaction times. This result is consistent with previous research on the vigilance decrement, the time-on-task effect, and research on fatigue in general (Ackerman, 2011; Guastello et al., 2013; Lal & Craig, 2001; Van Dongen et al., 2011). This result also demonstrates the advantage of multilevel linear modelling over traditional significance testing, as raw reaction times can be included in the model, providing a more accurate representation of the relationships between the variables.

The interaction between period of watch and testing sessions reveals that the increase in reaction time over period of watch during the task was greater in the pre-test than in the post- and follow-up test sessions. This indicates that participants became less fatigued during the vigilance task in the post- and follow-up testing sessions than compared to the pre-test. Further, this suggests that video game training can improve the ability to sustain attention in vigilance tasks, as evidenced by a reduced increase in reaction time as time-on-task increases. This is one of the first studies to investigate the relationship between video game training and sustained attention performance. Therefore, further research is needed to confirm these findings, as the present results only provided preliminary evidence that there is a meaningful relationship between these factors.

***4.5.2.2 Reaction time variability.***

Results of the univariate analysis revealed that there was no significant effect of period of watch, or training technique, nor of the interactions between testing session, period of watch and training technique, on reaction time variability in the vigilance task. There was however, a significant effect of testing session on reaction time variability, although post hoc tests were not significant. Inspection of the means reveals that reaction time variability was the lowest at the three-month follow-up test, however there was no substantial difference between pre-test and post-test. It is unclear why this was the case, it was expected that performance would decline after three months without training, however the three-month break resulted in improved performance with more consistent reaction time speed. It is possible that at the post-test, participants had lost motivation from repeatedly coming to the laboratory and that this resulted in poorer performance, whilst three months later, participants' motivation had returned.

Overall, the results of the traditional analysis indicate that video game training and training technique do not affect reaction time variability on vigilance tasks. In addition, reaction time variability was not affected by time-on-task. This is inconsistent with the results of Study 1 (Chapter 3), and the literature on cognitive fatigue that has found that the decline in task performance associated with fatigue is also related to higher levels of response variability (Guastello et al., 2013). It is possible that there were increases in reaction time variability over periods of watch in some of the testing sessions but that this was masked by reductions, or no change, in reaction time variability in other sessions, however if this was the case, an interaction between period of watch and testing session would be.

Results of the multilevel linear modelling approach revealed that the model that was best able to predict reaction time variability includes the three main effects, training technique, period of watch, and testing session, as well as the two-way interactions and the

three-way interaction between these factors. Thus all parameters were important in predicting reaction time variability. However, as discussed previously, large standard errors for the estimates of some factors indicate that the model should be interpreted cautiously. The effects which had relatively small standard errors were period of watch, and the interaction between training technique and period of watch. These reveal that as time increased so too did reaction time variability, which is consistent with previous research on fatigue (Guastello et al., 2013), but is inconsistent with the results of the traditional analysis. In addition, the interaction between period of watch and training technique reveals that the increase in reaction time variability was greater for those in the FET group compared to the VPT. This provides further evidence as to the advantage of VPT over FET (Prakash et al., 2012; Voss et al., 2012), and preliminary evidence that VPT training on an action video game is more beneficial than the standard FET in improving the transfer to sustained attention skills.

***4.5.2.3 Performance accuracy: Sensitivity and Criterion levels.***

Results of the univariate analysis revealed that there was no significant effect of testing session, period of watch, or training technique, nor of the interactions between these variables, on performance accuracy in the vigilance task as measured by sensitivity and criterion levels. These results suggest that video game training does not affect response accuracy when performing vigilance tasks. This is consistent with results from Study 1 (Chapter 3) in that VGPs and NVGPs did not differ in sensitivity and criterion levels. However, the lack of significant difference between periods of watch is inconsistent with the results of Study 1 and with the literature on cognitive fatigue that shows that performance accuracy decreases as fatigue increases (Van Dongen et al., 2011). The most likely explanation for this is that the lack of significant result is accounted for the large variability in accuracy performance.

Results of the multilevel linear modelling approach revealed the models that best

predicted sensitivity and criterion levels only included the testing session fixed effects. This provides further evidence that there is no advantage of either training technique in improving sustained attention performance. It is surprising that period of watch was not included in the best model given the results of the previous study (Chapter 3) where there was a significant decline in sensitivity and criterion levels over time. However, this result confirms the findings from the traditional analyses. The testing session variable was included in the best model, suggesting that there was an effect of video game training on sensitivity and criterion levels. However, the relatively large standard errors for both measures indicates a large amount of variance, and that the amount video game training provided in the current study is not enough to affect sustained attention accuracy. In addition, accuracy is an important factor in most video games (i.e. it is important to be able to shoot enemy targets and not friendly targets). However, in the video game used in the present study there was only one enemy target and no friendly targets. Thus, there was no need for participants to develop higher accuracy, in fact it would have been most beneficial for them to react to any stimulus that they thought to be the enemy target.

**4.5.3 Divided Attention.**

The results of the MANOVA, at the multivariate level, indicate that MATB-II performance improved after video game training. However, there was no difference between MATB-II sessions or between training techniques. In addition, none of the two-way interactions were significant. Although, the three-way interaction between testing session, MATB-II session, and training technique was significant.

Univariate results were analysed to determine on which MATB-II measures performance improved. It was found that of the eight measures, three improved from pre-test to post-test or from post-test to follow-up test. Interestingly, all measures were from the System monitoring task which is a secondary sub-task of the MATB-II (Chiappe et al., 2013).

This result is consistent with the previous study (Chapter 3), and previous research (Chiappe et al., 2013), that has found that VGPs performed significantly better on the secondary tasks without a trade-off in performance on the primary tasks. This suggests that 10 hours of video game training over four weeks improves visual attention, in that more attention is paid to a larger visual field, which is consistent with reports that video game training improves performance on the Useful (Functional) field of view task (Feng et al., 2007; C. S. Green & Bavelier, 2003) (see Section 2.1.1.1).

The lack of significant difference between the two MATB-II sessions is inconsistent with the results of the previous study (Chapter 3). However, inspection of the means of each measure indicates that in each testing session, performance improved from the first to second MATB-II session. This indicates that the cognitive fatigue induced by performing the vigilance task did not affect MATB-II performance, and this is consistent with the previous study (Chapter 3). It also provides further support to the suggestion that when measuring cognitive fatigue only tasks on which optimal performance can be achieved in a short period of time should be used as these will be more likely to show fatigue-related performance decrements (Ackerman, 2011).

#### 4.5.4 Workload Rating Scale (WRS).

On the WRS, at the multivariate level, no effects or interactions were significant. However, similar to previous study (Chapter 3), univariate results were analysed to determine if there were any differences on individual measures. There was no significant difference on the main measures of workload, however, there were significant differences on the *physical* and subjective *performance* scales. Physical workload was significantly lower in the pre-test compared to the post-test, and participants estimated their performance to be better in the second MATB-II sessions compared to the first. The improved estimate of performance is consistent with the objective measures of MATB-II performance. It is surprising that physical

workload was reduced in the post-test session as the most physical part of the MATB-II was controlling the joystick, which requires little physical effort, and there was no corresponding significant improvement in the sub-task that required joystick control.

Overall, although there were no differences between training techniques in MATB-II performance, the results do provided evidence that video game training in general can improve the performance of secondary tasks when multitasking. However, there appears to be no benefit of video game training on improving overall sustained attention performance, and that individuals are just as susceptible to the effect of cognitive fatigue after video game training as they are beforehand. The lack of significant differences between training techniques is discussed in the following section.

**4.5.5 Effect of training technique.**

There are a number of factors that may have resulted in the lack of significant differences between the two training techniques. It may be that the instructions and guidance given to participants in the VPT group did not differ enough from the FET group to distinguish the two as different training techniques. Whilst there is strong theory behind using the VPT technique, there is little work on how to practically apply this to different tasks outside of Space Fortress. As this is the first study to apply the technique to a commercial video game, more research is required in terms of which variables in the game should be prioritised and how to assist participants in prioritising these variables whilst playing the game. Further, the primary characteristic of VPT is the amount of variability in sub-tasks provided during training. Therefore it is possible that including a range of action video games for participants to train on, instead of just one, would increase task variability and thus increase the transfer of improvements in video game performance to sustained and divide attention tasks (Chiappe et al., 2013; C. S. Green et al., 2009).

In addition, it is possible that more training is required within the four weeks, or in

extending the training regime for a longer period. However, from the present data, it can be seen that the performance for both groups increased to a similar extent with overlaps in performance and no clear advantage to either group, suggesting that this trend would continue beyond the tenth training day. Thirdly, and likely the most reasonable explanation as to the lack of significant difference between the groups is the small sample size. When sample sizes are small, the results are more heavily impacted by individual differences. This is particularly relevant in training studies and studies on fatigue where levels of motivation can influence performance (Kanfer, 2011; Matthews, 2011). In complex training situations, motivation can play a decisive role in the effectiveness of training (Strobach et al., 2012). Whilst participants were motivated to improve on their previous performance there may be individual differences in pre-disposition of preferred training style that could have affected enjoyment of the task and thus motivation to perform well. Previous research has shown that personality factors may explain why some people engage in different types of practice more than others (Hambrick et al., 2014). Whilst all participants were required to practice for the same amount of time, a pre-disposition towards or against their assigned training technique may have influenced their motivation to engage in the video game training, and thus affected their performance.

**4.5.6 Comparison to VGP performance.**

Participants' performance at the three-month follow-up test was compared to the performance of the VGPs from Study 1 (Chapter 3). Not surprisingly, the video game performance of the VGPs was significantly better than that of the trained NVGPs, demonstrating that one month of video game training is not enough to turn NVGPs into VGPs. However, there were interesting results when analysing sustained and divided attention performance. In Study 1, at the multivariate level, there was a significant difference between the VGPs and the NVGPs, indicating that VGPs had superior sustained attention.

However, in the present study, there was no significant difference between the VGPs and the NVGPs, and at the univariate level, trained NVGPs had significantly higher sensitivity levels, an indicator of better response accuracy. Thus, there is evidence to suggest that one month of action video game training is enough to improve NVGPs' sustained attention performance to be comparable to that of VGPs who have played video games for years. However, these results are not conclusive. In Study 1 there were 18 VGPs and 24 NVGPs, whilst in Study 2 (Chapter 4) there were only 6 trained NVGPs, thus the unequal sample size limits the generalisability of the findings. In addition, at the univariate level there are anomalies in the results. In the present study, the trained NVGPs had significantly higher sensitivity levels compared to the VGPs, despite there being no significant change in the sensitivity levels of the NVGPs from pre-test to the three-month follow-up test. Thus it is likely, that individual variability influenced the results, in that the trained NVGPs focussed on accuracy during the vigilance task. Further, it is also likely that participants were more motivated to perform well at the follow-up test as they had committed a substantial amount of time to participating in the study.

Similar results were also found in the multitasking performance. In Study 1 (Chapter 3), at the multivariate level, VGPs performed significantly better than NVGPs. However, in Study 2 (Chapter 4), there was no significant difference in performance between the VGPs and the trained NVGPs. Although this improvement in the performance of NVGPs may be attributed to action video game training, it is more likely the result of practice effects, as even at the three-month follow-up test, participants' performance on the MATB-II continued to improve.

# Chapter 5: Study 3 - Cognitive Fatigue, Video Games, & Driving

The previous two studies have shown that action video game players, and those who receive action video game training demonstrate improved sustained attention and multitasking skills. However, these skills have been demonstrated on relatively simple computer tasks within the laboratory that have little similarity to real-world tasks.

Despite the many studies investigating the visuospatial cognitive benefits of action video games, there is a lack of research taking the next step of investigating the practical real-world benefits of these effects (Ferguson, 2014; Latham et al., 2013b). There is emerging evidence however, that VGPs are able to apply their superior attentional skills to real-world tasks. For example, VGPs make fewer lane deviations whilst driving compared to NVGPs (Rupp, McConnell, & Smither, 2015). Motor vehicle driving is a complex task that involves executive control, multitasking, and sustaining attention (Desmond & Hancock, 2001; Donohue et al., 2012; Mäntylä, Karlsson, & Marklund, 2009; Rupp et al., 2015; Warm, Parasuraman, et al., 2008; Watson & Strayer, 2010). Therefore, to extend the results of the two previous studies (Chapter 3 & Chapter 4), the effect of video game experience on cognitive fatigue whilst driving was investigated.

## 5.1 Driving and Fatigue

It is well known that driving whilst fatigued is dangerous (Saxby et al., 2013). Cognitive fatigue occurs when attentional capability is reduced, and this can occur due to both active and passive fatigue (Desmond & Hancock, 2001). Passive fatigue is the result of under-stimulation, for example when driving on long stretches of straight road, and can lead to a decline in vehicle control (Desmond & Hancock, 2001). Active fatigue occurs when there is a constant demand on attention resulting in a drain on cognitive resources. Operators of all vehicles can be susceptible to active fatigue as they must make continuous adjustments to adequately control the vehicle. For example, Fancher (personal communication, 1997, as

cited in Desmond & Hancock, 2001) estimated that over 1000 accelerator adjustments are made during one hour of driving on a freeway. When taken in combination with other adjustments, for example steering wheel control, it is clear that driving for long periods of time places a high demand on a driver's cognitive resources. Over time, attention is reduced and fewer vehicle speed and control adjustments are made, potentially resulting in the vehicle leaving the road (Desmond & Hancock, 2001).

**5.2 Driving and Video games**

Motor vehicle driving is a complex task that is often investigated when examining the real-world consequences of fatigue (Desmond & Hancock, 2001). It places high demands on a range of cognitive processes (Mäntylä et al., 2009), and requires individuals to multitask and sustain attention for extended periods of time (Larue et al., 2010). As discussed in Chapter 2, playing action video games can increase visual attention (C. S. Green & Bavelier, 2003), speed of visual processing (Dye et al., 2009b), and improves decision making and cognitive control (Bailey, West, & Anderson, 2010), all of which are skills and abilities that are crucial when driving (Ciceri & Ruscio, 2014).

One example of this is the finding that VGPs often outperform NVGPs on the Useful Field of View (UFOV) task (Feng et al., 2007; C. S. Green & Bavelier, 2006b). As discussed in Section 2.1.1, the UFOV task is a common task for assessing selective attention. Participants must identify the location of a target that was previously presented and then hidden. This task measures the ability to quickly and accurately direct attention towards target areas, and it has been shown that those who perform better in the task are less likely to have a driving accident (Myers et al., 2000).

Vehicle driving tasks are also similar to sustained attention tasks and thus findings obtained from these studies may be beneficial in understanding driver fatigue (Thiffault & Bergeron, 2003). For example, participants that perform well on vigilance tasks may also

perform well in long driving situations. Further, identifying individuals that are resilient to cognitive fatigue and the vigilance decrement will have practical implications for the selection and training of professional drivers (Thiffault & Bergeron, 2003). Therefore, it is possible that as VGPs in Study 1 (Chapter 3) demonstrated improved sustained attention performance, that they too will also demonstrate improved driving performance when compared to NVGPs.

Despite the complex processes involved in driving, most studies have focussed on driving performance in relation to low-level attentional factors, such as visual search, and ignored the higher-order cognitive processes of executive functioning (Mäntylä et al., 2009). As discussed in Section 1.3, executive functioning involves monitoring and maintaining complex goal-directed behaviour through organising and controlling lower-level functions, in addition to ignoring irrelevant stimuli, switching attention between multiple locations and sensory modalities, all of which are crucial for safe driving (Mäntylä et al., 2009; van der Linden, 2011).

Mäntylä et al. (2009) investigated the simulator driving performance of teenage novice drivers and explored whether performance was related to executive functioning and video game experience. It was found that individuals with lower executive functioning made more errors on the driving simulator task. In addition, their results suggest that skills learned from video games can be used to compensate for less efficient working memory functions. These findings provide preliminary evidence that video game experience may facilitate improvements in driving performance however the authors suggest that future research continue to explore the connection between executive control and its relation to video games and driving simulator performance (Mäntylä et al., 2009).

### 5.3 Measuring Driver Fatigue

Fatigue is often operationalised as a decline in performance over time (Earle et al.,

2015; Lorist & Faber, 2011; Lorist et al., 2000; van der Linden, 2011; van der Linden et al., 2003). However, a linear relationship between task performance and time is not often found, and the same is true for driving performance (Gawron et al., 2001). Error patterns may change with varying levels of fatigue, and are also affected by other factors such as age, sex, and personality (Lal & Craig, 2001; Schleicher, Galley, Briest, & Galley, 2008). Thus, it is difficult to use general performance measures as indicators of driver fatigue (Schleicher et al., 2008). Therefore, in the present study, traffic violations during a simulated drive were recorded, in addition to eye-tracking data collected during the drive, and two self-report measures of fatigue.

**5.3.1 Traffic violations.**

There are a number of measures of driving performance, for example braking response time and accelerator and steering wheel movements. These do not provide the whole picture of driver performance, however, as an individual could brake softly and early or brake hard and late, with the end result being the same. In addition, there are no agreed-upon definitions of the statistics, measures, and values used to assess driving performance. As previously mentioned, thousands of accelerator adjustments are made during an hour of driving so distinguishing between an adjustment and an overt change is difficult (P. A. Green, 2012). Further, definitions of changes in behaviour and performance are highly contextual. For example, deviation from a lane can be considered to occur when the front tyre touches the lane boundary, or when the widest part of the vehicle is over the lane boundary, however, issues in measurement arise when lane and vehicle widths vary. In the present study, instead of using laboratory measures such as reaction times and accelerator adjustments, more realistic measures of performance, that is, the number and severity of traffic violations, were used to measure driving performance.

The software used for the driving simulation was *City Car Driving* (Enterprise

Edition, version 2.1.0; Forward Development, 2012). In this program, driving performance is measured by recording traffic violations. Each violation is assigned a score according to its severity, for example, a score of 1 (the lowest) is given for driving 10 km/h over the speed limit, whilst a score of 10 (the highest) is given for hitting another car or a pedestrian (see Appendix G for the full list of violations and scores).

**5.3.2 Eye-tracking.**

Visual scanning is a vital part of driving (Lansdown, 2001), and is negatively affected by fatigue (May & Baldwin, 2009), with the lack of visual attention being responsible for a large proportion of accidents (Chapman & Underwood, 1998). When individuals become fatigued, their visual perception is reduced, and their gaze narrows (Ji, Zhu, & Lan, 2004), resulting in reduced peripheral vision (Liu & Wu, 2009). In addition, the number eye-movements and scanning patterns are reduced (May & Baldwin, 2009). Reduced visual scanning may result in important roadside information (e.g. traffic signs, obstacles) being missed or their distance from the driver to be miscalculated, resulting in accidents (Liu & Wu, 2009). Fortunately, however, visual scanning can be improved with driving experience.

The visual search strategies of novice drivers are not as flexible or efficient as those of experts (Paxion, Galy, & Berthelon, 2014). Novices tend to focus solely on the vehicle ahead of them (Crundall, Underwood, & Chapman, 1998), and remain focused on it regardless of the driving situation. In addition, the lack of experience also means that novice drivers have a lower level of task automation and thus experience a higher mental workload whilst driving (Patten, Kircher, Östlund, Nilsson, & Svenson, 2006; Paxion et al., 2014). In contrast, experienced drivers exhibit flexible and adaptive search behaviour. This is primarily achieved through the widening of their horizontal search (Crundall et al., 1998; Patten et al., 2006), allowing them to gather and process more information about the situation and to adjust their driving behaviour accordingly, resulting in better driving performance (Paxion et al.,

2014).

In the present study, participants' eye-movements were recorded whilst completing the driving task. The number of fixations and the length of the fixations on areas of the road during the simulated driver were measured. Four areas of interest were selected for investigation, close and far, and centre and wide (see Figures 5.1 and 5.2 respectively).

*Figure 5.1.* Close (green) and far (red) areas of the road.

*Figure 5.2.* Centre (green) and wide (red) areas of the road.

**5.4 The present study**

This compared simulator driving performance of action VGPs and NVGPs over two driving sessions, which took approximately two hours to complete. Driving performance was measured by the total number of traffic violations made and the total score of those violations, and this was compared between the two driving sessions. It was hypothesised that because the driving simulator is similar to a video game, VGPs would perform better overall, compared to NVGPs. In addition, since VGPs are used to playing video games for long periods of time, it was hypothesised that their performance would not decline over time as much as that of the NVGPs.

Participants' eye-movements were recorded and compared between each driving

session. The number of fixations and total duration length of fixations was compared between the close and far road areas, and between the centre and wide road areas. Previous research on the UFOV shows that VGPs demonstrate an increased visual search area, and it was hypothesised that the eye-movement patterns of VGPs would match those of experienced drivers. That is, they should look at the far and wide areas of the road more than the close and centre areas. In addition, it was hypothesised that the eye-movements of NVGPs would become less frequent and narrower over time, as they become fatigued, whilst the eye-movements of VGPs would not.

The Samn-Perelli Fatigue Checklist was completed prior to the first driving session and after the second driving session to provide a subjective measure of fatigue. It was hypothesised that both groups would experience an increase in fatigue from pre-drive to post-drive, and that NVGPs would report a higher level of fatigue in the post-test. In addition, the Driving Fatigue Scale was provided after the second driving session to assess the type and severity of fatigue experienced during the driving sessions. It was hypothesised that NVGPs would experience greater levels of driver fatigue overall, compared to VGPs, however it is unknown whether the different groups would experience different types of fatigue.

## 5.5 Method

This study received approval from the Edith Cowan University Human Research Ethics Committee.

### 5.5.1 Participants.

Twenty-two individuals were recruited to partake in the study. One participant withdrew due to experiencing motion sickness during the practice phase of the experiment. Of the remaining 21 participants, 11 were classified as VGPs (9 males, $M_{age}$ = 22.72 years, $SD$ = 2.05), and 10 were classified as NVGPS (2 males, $M_{age}$ = 29.60 years, $SD$ = 13.27), according to the methods used in Study 1 (Chapter 3). Due to the difficulty of recruiting

VGPs who primarily played FPS games, the criterion for being classed as a VGP was expanded to include all action video games consistent with Study 1. In addition, as the results of Study 1 demonstrated that self-report measures of video game experience was sufficient to classify participants as either VGPs or NVGPs, participants' video game performance was not assessed.

All participants who completed the study received a $20 gift card. They also went into the draw to win one of two $50 gift cards (provided by the ECU Cognition Research Group), and into the draw to win one $500 gift card.

**5.5.2 Measures.**

In addition to the measures presented in Section 5.3, video game experience, driving experience, and two measures of fatigue were analysed. Video game experience was measured using a questionnaire similar to that used in Study 1 (Chapter 3; Appendix H). Driving experience was measured by the number of years since participants received their car licence.

***5.5.2.1 Fatigue checklist.***

The Samn-Perelli Fatigue Checklist (Samn & Perelli, 1982) was presented to participants before and after the driving simulation task to determine whether participants became fatigued during the task. The scale contains one 7-point item asking participants to rate their current mental fatigue (1 = fully alert, wide awake; 2 = very lively, responsive, but not at peak; 3 = okay, somewhat fresh; 4 = a little tired, less than fresh; 5 = moderately tired, let down; 6 = extremely tired, very difficult to concentrate; 7 = completely exhausted, unable to function effectively).

***5.5.2.2 Driving Fatigue Scale.***

The Driving Fatigue Scale (Matthews, Saxby, & Hitchcock, 2008) was used to assess how participants felt during the driving task. The scale is a 42-item questionnaire, measuring

four categories of fatigue (sub-categories are presented in parentheses); physical fatigue (muscular fatigue); tiredness-demotivation (exhaustion-sleepiness, boredom-demotivation); cognitive-attentional (confusion/distractibility, performance worries); coping/fatigue management (comfort-seeking, self-arousal). Items are rated on a 5-point scale (0 = not very much, 5 = very much).

**5.5.3 Materials.**

Eye-movement data was recorded using *Tobii Studio* (ver 3.2.3) and an X2-60 Tobii eye-tracking camera. The software used for the driving simulation was *City Car Driving* (Enterprise Edition, version 2.1.0; Forward Development, 2012). The hardware for the driving simulator consisted of a Logitech G27 Force feedback wheel and pedal set that were mounted to a *Playseat Evolution* gaming seat. The driving simulator program was presented on three BenQ 23” frameless monitors, with the speakers sitting behind the centre monitor (see Figure 5.3).


*Figure 5.3.* Set-up of the driving simulator and computer monitors.

#### 5.5.4 Procedure.

Upon arrival at the lab, participants read an information letter (Appendix I), and signed a consent form (Appendix J). Participants completed the pre-drive Samn-Perelli Fatigue Checklist and sat in the driving simulator chair. The experimenter than calibrated the eye-tracker to the participant and initiated the driving simulator software. After the experimenter explained the controls and the rules of the simulation software, participants completed a practice drive along a pre-determined route through the virtual environment that was designed to take approximately 30 minutes to complete. This included driving along a track to practice slow speed turning and manoeuvring along a narrow, winding lane. In addition, the route included the range of driving environments (e.g. highway, city, country roads), and was also populated by the same percentage of motor vehicles and pedestrians, that would be on the route in the testing phases.

After the practice route, participants completed two pre-determined driving routes. To create two routes that were of similar length and included similar amounts of time driving in different environments, the second route was the reverse of the first route. However, due to the design and layout of the roads in the virtual environment, the two routes were not perfect mirror copies of each other. For instance, due to one-way streets, some alterations to the route were required. Each route took approximately 50 minutes to complete, however it took longer if participants drove cautiously or deviated from the route. The order in which the two routes were completed was counter-balanced amongst participants. After completing the second route, participants filled in the post-drive Samn-Perelli Fatigue Checklist, the Driving Fatigue Scale, and the participant questionnaire (Appendix H).

### 5.6 Results

#### 5.6.1 Missing data.

Fatigue questionnaire data (Samn-Perelli Fatigue Checklist and Driving Fatigue

Scale) for one participant (female NVGP) was lost due to a technological issue. However, all other data collected (driving performance and eye-movements) were available for analysis. Driving performance for one participant (female NVGP) was also missing due to a technological issue. However, all other data collected (fatigue questionnaires and eye-movements) were available for analysis.

Eye-tracking data for two participants (2 female VGPs) were removed from the analysis due to low quality of the eye-tracking recording. All other data (fatigue questionnaires and driving performance) were available for analysis. Quality of eye-tracking recording is calculated by dividing the number of eye-tracking samples that were correctly identified by the number of attempts. When both eyes were found during the entire recording, quality is 100%, when one eye is found for the entire recording, or both eyes are found for half the time, quality is 50%. The quality for both participants was less than 50% (Tobii Technology 2012), possibly due to poor calibration or the participant adjusting their sitting position beyond the range of the eye-tracker. Of the remaining participants, quality ranged from 78% to 94% ($M$ = 88.68%, $SD$ = 4.57).

**5.6.2 Driving experience.**

To ensure that driving experience was not a confound, a between-group t-test was conducted on the number of years of driving experience that each group had. Levene's test for equality of variances was significant ($p$ = .002). There was no significant difference in the number of years of driving experience between the VGPs ($M$ = 4.76 years, $SD$ = 2.63) and the NVGPs ($M$ = 11.73 years, $SD$ = 13.22), $t(9.65) = 1.64$, $p$ = .134.

**5.6.3 Samn-Perelli Fatigue Checklist.**

A 2 (video game experience group) x 2 (pre- and post-drive) mixed design ANOVA was conducted on the Samn-Perelli Fatigue Checklist (Samn & Perelli, 1982). Levene's test of equality of variances was not significant for either pre-drive or post-drive ($p$s > .05). There

was a significant difference in self-reported fatigue ratings between pre-drive (*M* = 2.59, *SE* = 0.24) and post-drive (*M* = 4.67, *SE* = 0.22) , $F(1, 18) = 61.55$, $p < .001$, partial $\eta^2 = .77$. There was no significant difference in self-reported fatigue ratings between VGPs (*M* = 3.32, *SE* = 0.25) and NVGPs (*M* = 3.94, *SE* = 0.28), $F(1, 18) = 2.83$, $p = .110$, partial $\eta^2 = .14$. There was no significant interaction, $F(1, 18) = 0.52$, $p = .479$, partial $\eta^2 = .03$ (see Figure 5.4).

Post hoc analyses were conducted to determine if there was a significant difference between VGPs and NVGPs prior to driving in the simulator, as this would have introduced a potential confound. The results of the between-group t-test revealed that there was no significant difference in fatigue ratings between the VGPs (*M* = 2.18, *SD* = 0.87), and the NVGPs, (*M* = 3.00, *SD* = 1.22) prior to driving, $t(18) = 1.74$, $p = .098$. In addition, there was no significant difference in fatigue ratings between VGPs (*M* = 4.46, *SD* = 1.04) and NVGPs (*M* = 4.89, *SD* = 0.93) after driving, $t(18) = 0.98$, $p = .336$.

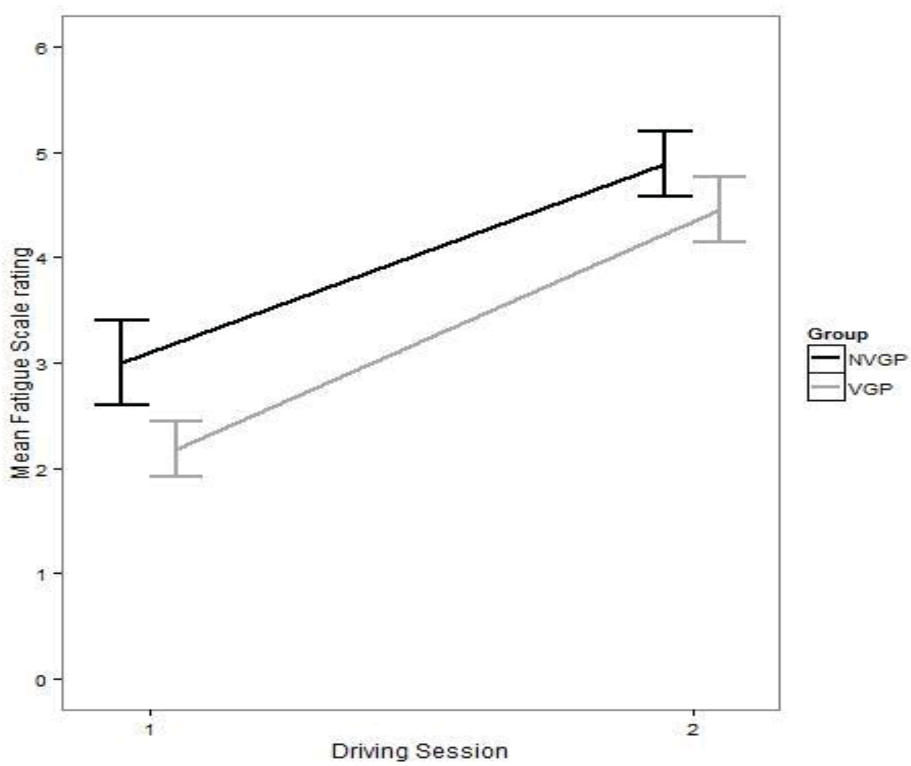


*Figure 5.4.* Mean fatigue rating on the Samn-Perelli Fatigue checklist. Error bars represent ± 1 standard error.

**5.6.4 Driving Fatigue Scale.**

A MANOVA was conducted on the seven sub-categories of the Driving Fatigue Scale (Matthews et al., 2008). Box's test of equality of covariance was significant ($p$ = .001). Levene's test of equality of variances was significant for the *confusion* and the *comfort* categories (*p*s < .05).

At the multivariate level, there was no significant difference between the two groups, $V$ = 0.35, $F$(7, 12) = 0.91, $p$ = .533, partial $\eta^2$ = .35. Results were also analysed at the univariate level to determine if groups differed in the type of fatigue experienced whilst driving. There were no significant differences between the two groups in any of the seven categories (see Table 5.1). Results were also analysed by grouping the sub-categories into the four broader categories (physical fatigue, tiredness-demotivation, cognitive-attentional, coping/fatigue management), however as with the previous analysis, there was no significant difference between the groups, and are therefore not reported here.

Table 5.1.

*Driving Fatigue Scale self-report measures*

| Sub-category | VGP (SD) | NVGP (SD) | ANOVA |
|---|---|---|---|
| Muscular | 9.27 (3.80) | 9.56 (6.50) | $F$(1, 18) = 0.02, $p$ = .905 |
| Exhaustion | 10.55 (6.41) | 11.44 (7.52) | $F$(1, 18) = 0.08, $p$ = .776 |
| Boredom | 16.82 (8.66) | 17.33 (9.18) | $F$(1, 18) = 0.02, $p$ = .899 |
| Confusion | 15.09 (4.89) | 16.22 (8.61) | $F$(1, 18) = 0.14, $p$ = .716 |
| Performance | 15.00 (5.85) | 16.00 (6.98) | $F$(1, 18) = 0.12, $p$ = .731 |
| Comfort | 17.82 (4.09) | 12.89 (8.36) | $F$(1, 18) = 2.98, $p$ = .101 |
| Arousal | 19.91 (3.81) | 17.33 (7.04) | $F$(1, 18) = 1.09, $p$ = .310 |

**5.6.5 Driving Performance.**

Driving performance was assessed by measuring the number of traffic violations made in each driving session, as well as the total number of points acquired in each session, as it is possible to make fewer traffic violations but for these to be of greater severity or to have a greater number of minor traffic violations.

A 2 (video game experience) x 2 (driving session) mixed design ANOVA was conducted on the number of traffic violations made by VGPs and NVGPs in each of the two driving sessions. Levene's test of equality of variances was not significant for either session (*p*s > .05). There was a significant difference between the first session (*M* = 54.75, *SE* = 4.06) and the second session (*M* = 70.02, *SE* = 9.02), *F*(1, 18) = 6.31, *p* = .022, partial $\eta^2$ = .26. The difference between the VGPs (*M* = 50.55, *SE* = 8.45) and the NVGPs (*M* = 74.22, *SE* = 9.34) was not significant *F*(1, 18) = 3.53, *p* = .077, partial $\eta^2$ = .16. There was no significant interaction *F*(1, 18) = 0.61, *p* = .447, partial $\eta^2$ = .03 (see Figure 5.5).

Post hoc analyses were conducted to determine if there were differences in the number of traffic violations between the two groups during individual driving sessions. Two between-group t-tests were conducted, one for each driving session. In the first driving session, VGPs (*M* = 45.27, *SD* = 15.74) made significantly fewer violations than the NVGPs (*M* = 64.22, *SD* = 20.57), *t*(18) = 2.34, *p* = .031. However, in the second sessions there was no significant difference between VGPs (*M* = 55.82, *SD* = 28.81) and NVGPs (*M* = 84.22, *SD* = 50.89), *t*(18) = 1.57, *p* = .133.

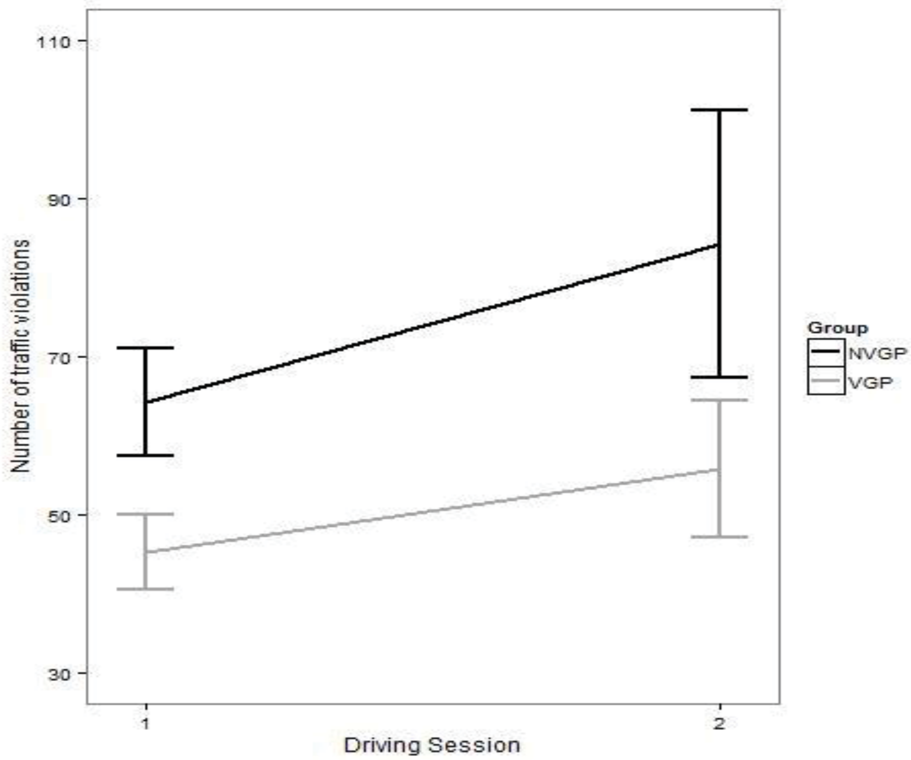


*Figure 5.5.* Number of traffic violations over driving sessions. Error bars represent ±1 standard error.

A 2 (video game experience) x 2 (driving session) mixed design ANOVA was conducted on the total violation score of VGPs and NVGPs in each of the two driving sessions. Levene's test of equality of variances was not significant for either session ($p$s > .05). There was a significant difference between the first session ($M$ = 223.02, $SE$ = 16.09) and the second session ($M$ = 287.81, $SE$ = 37.79), $F(1, 18) = 5.68$, $p = .028$, partial $\eta^2 = .24$. The difference between the VGPs ($M$ = 206.05, $SE$ = 34.43) and the NVGPs ($M$ = 304.78, $SE$ = 38.06) was not significant $F(1, 18) = 3.70$, $p = .070$, partial $\eta^2 = .17$. There was no significant interaction $F(1, 18) = 0.74$, $p = .400$, partial $\eta^2 = .04$. (see Figure 5.6).

Post hoc analyses were conducted to determine if there were differences in the total violation scores between the two groups during individual driving sessions. Two between-group t-tests were conducted, one for each driving session. In the first driving session, VGPs ($M$ = 185.36, $SD$ = 72.88) had a significantly lower total violation score than the NVGPs ($M$

= 260.67, *SD* = 69.93), *t*(18) = 2.34, *p* = .031. However, in the second sessions there was no significant difference between VGPs (*M* = 226.73, *SD* = 125.30) and NVGPs (*M* = 348.89, *SD* = 209.75), *t*(18) = 1.62, *p* = .123.

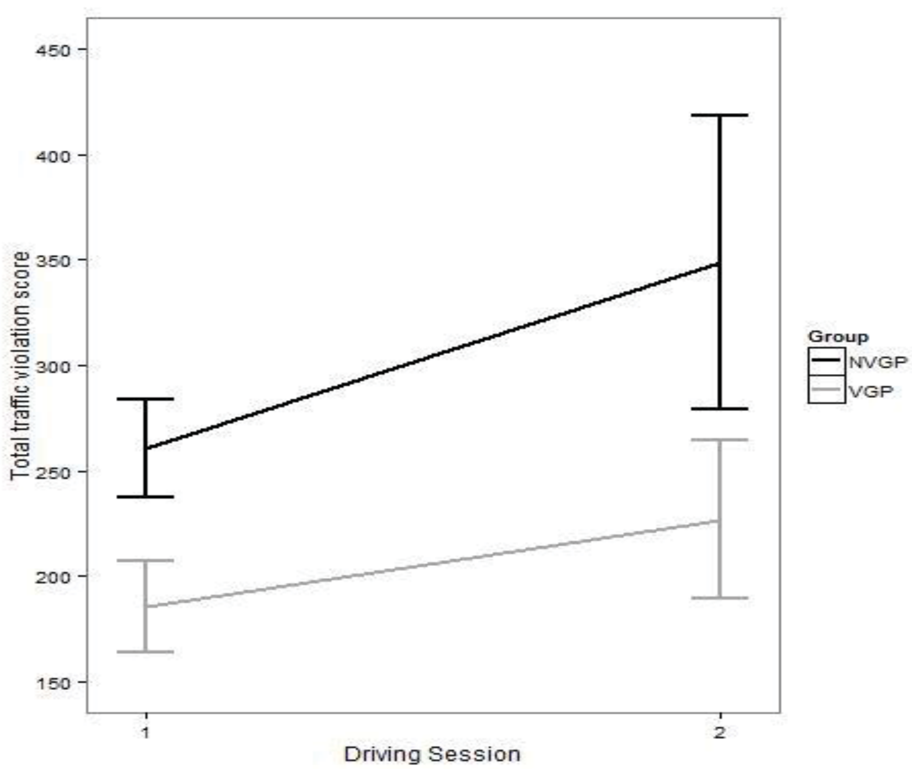


*Figure 5.6.* Total violation score over driving sessions. Error bars represent ±1 standard error.

**5.6.6 Eye-tracking.**

Eye-movements of VGPs and NVGPs during the driving the two driving sessions were compared. The number of fixations to an area, and the total amount of time fixated in that area during each driving session was measured. Two analyses were conducted, one compared eye-movements to close and distant areas of the road, and the other compared eye-movements to the centre and wide areas of the road.

***5.6.6.1 Close vs. Distant.***

A MANOVA was conducted on the total number and total duration of eye-movements (seconds) of VGPs and NVGPs to close and distant areas of the road between the

two driving sessions. Box's test of equality of covariances was significant ($p < .001$). Levene's test of equality of variances was not significant (*p*s > .05). There was no significant difference between the two groups, $V = 0.14$, $F(2, 16) = 1.26$, $p = .309$, partial $\eta^2 = .14$. There was a significant difference between the two areas of the road, $V = 0.61$, $F(2, 16) = 12.61$, $p = .001$, partial $\eta^2 = .61$. There was no significant difference between the two driving sessions $V = 0.13$, $F(2, 16) = 1.17$, $p = .337$, partial $\eta^2 = .13$. There was no significant interaction between road areas and groups, $V = 0.26$, $F(2, 16) = 2.78$, $p = .092$, partial $\eta^2 = .26$. There was no significant interaction between driving sessions and groups, $V = 0.07$, $F(2, 16) = 0.61$, $p = .555$, partial $\eta^2 = .07$. There was no significant interaction between road area and driving session, $V = 0.18$, $F(2, 16) = 1.81$, $p = .196$, partial $\eta^2 = .18$. The three-way interaction between road area, driving session, and group was not significant, $V = 0.29$, $F(2, 16) = 3.33$, $p = .062$, partial $\eta^2 = .29$.

Univariate tests revealed that the difference in the number of fixations between the close ($M = 282.49$, $SE = 44.64$) and distant ($M = 419.84$, $SE = 64.36$) road areas was not significant, $F(1, 17) = 4.30$, $p = .054$, partial $\eta^2 = .20$. The difference in the total duration of fixations between the close ($M = 123.90$s, $SE = 17.19$) and distant ($M = 219.49$s, $SE = 27.67$) areas was significant, $F(1, 17) = 8.30$, $p = .001$, partial $\eta^2 = .33$. The three-way interaction between road area, driving session, and group was significant for both number of fixations, $F(1, 17) = 5.52$, $p = .031$, partial $\eta^2 = .25$, and total fixation duration, $F(1, 17) = 7.05$, $p = .017$, partial $\eta^2 = .29$. No other effects or interactions were significant (see Figures 5.7 and 5.8).

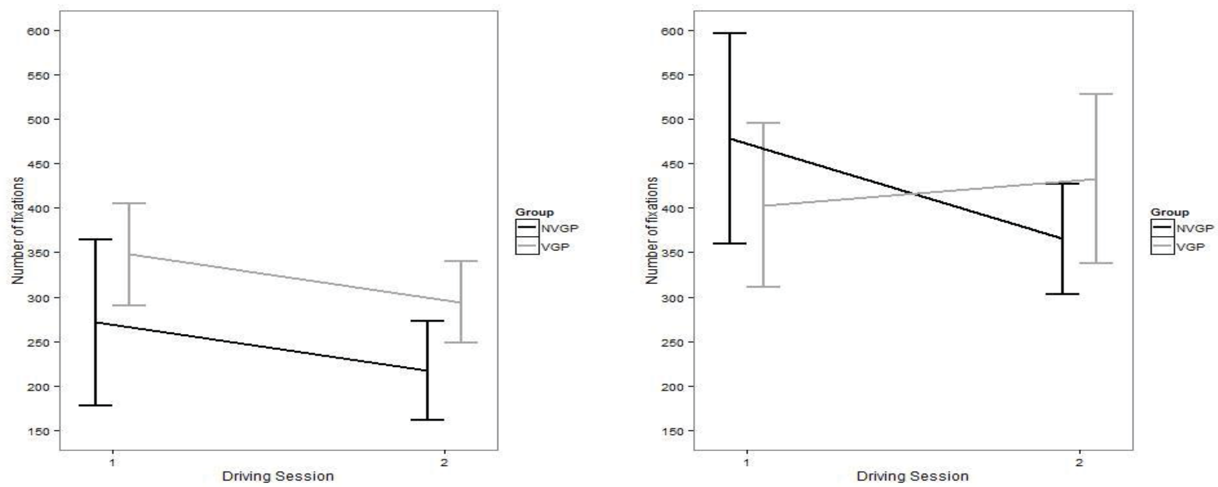


*Figure 5.7.* Number of fixations to close area (left) and distant area (right) of road. Error bars represent ±1 standard error.

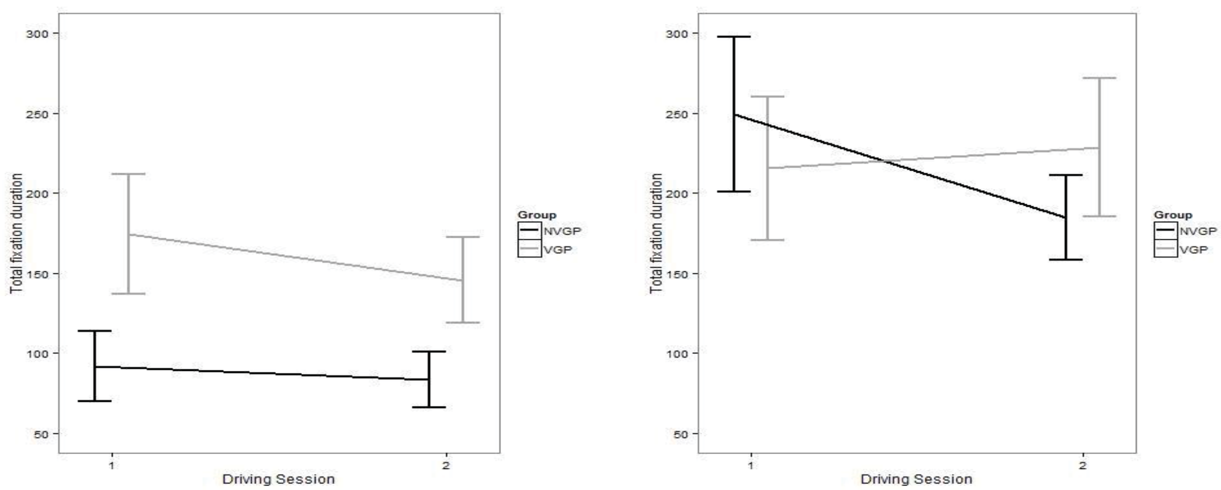


*Figure 5.8.* Total length of fixations to close area (left) and distant area (right) of road. Error bars represent ±1 standard error.

***5.6.6.2 Wide vs. Centre.***

A MANOVA was conducted on the total number and total duration of eye-movements of VGPs and NVGPs to wide and centre areas of the road between the two driving sessions. Box's test of equality of covariances was significant ($p$ = .001). Levene's test of equality of variances was not significant ($p$s > .05). There was no significant difference between the two groups, $V$ = 0.01, $F$(2, 16) = 0.10, $p$ = .905, partial $\eta^2$ = .01. There was a significant difference between the two areas of the road, $V$ = 0.80, $F$(2, 16) = 32.60, $p$ < .001, partial $\eta^2$ = .80. There was no significant difference between the two driving sessions $V$ = 0.15, $F$(2, 16) = 1.38, $p$ = .281, partial $\eta^2$ = .15. There was no significant interaction between road areas and groups, $V$ = 0.08, $F$(2, 16) = 0.74, $p$ = .495, partial $\eta^2$ = .08. There was no significant interaction between driving sessions and groups, $V$ = 0.09, $F$(2, 16) = 0.83, $p$ = .456, partial $\eta^2$ = .09. There was no significant interaction between road area and driving session, $V$ = 0.02, $F$(2, 16) = 0.15, $p$ = .863, partial $\eta^2$ = .02. The three-way interaction between road area, driving session, and group was not significant, $V$ = 0.07, $F$(2, 16) = 0.60, $p$ = .559, partial $\eta^2$ = .07.

Univariate tests revealed that the difference in the number of fixations between the wide ($M$ = 1606.82, $SE$ = 67.63) and centre ($M$ = 697.91, $SE$ = 88.15) road areas was significant, $F$(1, 17) = 68.75, $p$ < .001, partial $\eta^2$ = .80. The difference in the total duration of fixations between the wide ($M$ = 922.20s, $SE$ = 65.54) and centre ($M$ = 341.24s, $SE$ = 31.90) areas was significant, $F$(1, 17) = 53.17, $p$ < .001, partial $\eta^2$ = .76. No other effects or interactions were significant (see Figures 5.9 and 5.10).

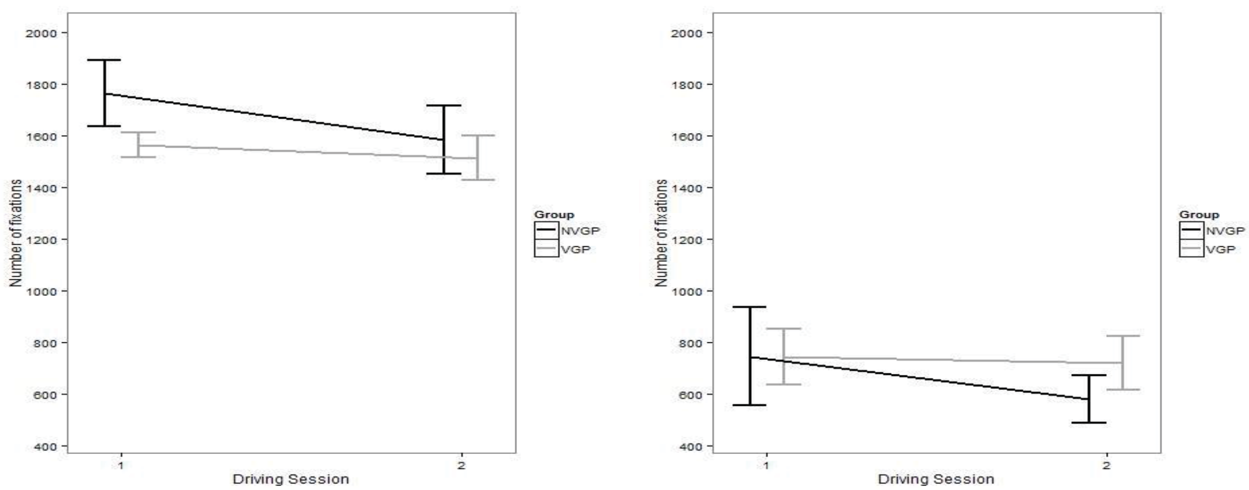


*Figure 5.9.* Number of fixations to wide area (left) and centre area (right) of road. Error bars represent ±1 standard error.

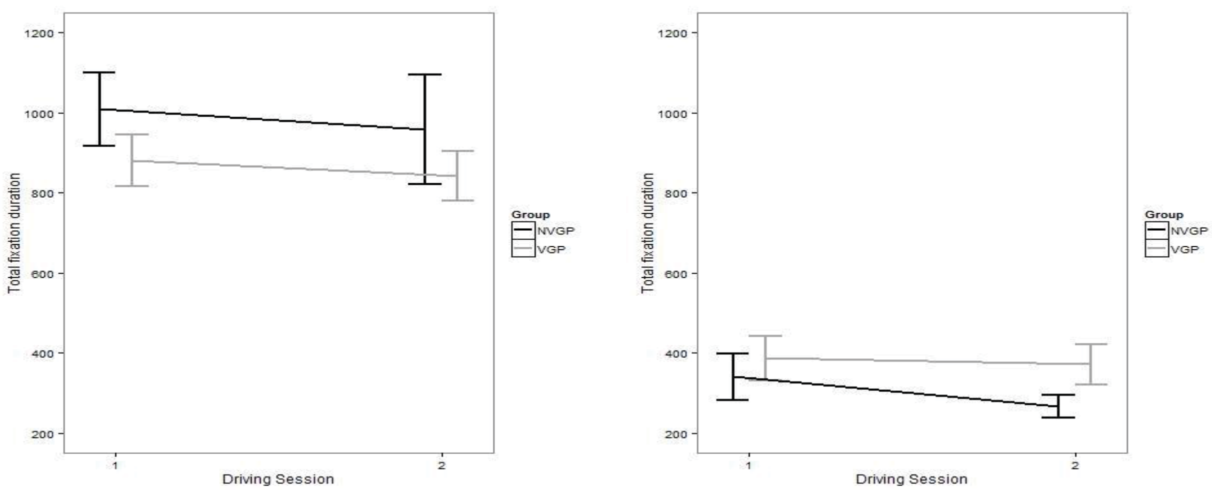


*Figure 5.10.* Total length of fixations to wide area (left) and centre area (right) of road. Error bars represent ±1 standard error.

**5.7 Discussion**

Overall, the results of the present study demonstrate the real-world benefits of regularly playing action video games. With regards to driving simulator performance, VGPs performed significantly better than NVGPs in the initial driving session when they were not cognitively fatigued. However, the performance of both groups declined over time due to fatigue, so that there was no significant difference between the groups. Driving experience was also assessed as this could have been a potential confound affecting performance, however, there was no significant difference between the groups. Thus, the significant difference in driving performance between the groups in the first driving session can be attributed to the differences in action video game experience. The results of the Samn-Perelli Fatigue Checklist confirmed that both groups experienced cognitive fatigue as there was a significant increase in fatigue ratings from pre-drive to post-drive, however there was no significant difference between the groups, indicating that both groups subjectively experienced similar levels of fatigue. In addition, there was no difference between the groups on the Driving Fatigue Scale, further indicating that both groups experienced similar levels of fatigue.

Driving performance was measured by the number of traffic violations and the total violation score in each driving session. The pattern of results was similar for both measures indicating that the number and severity of violations was proportional between sessions and groups, that is, participants did not make more violations of lesser severity or fewer violations of greater severity between sessions. Video game players made fewer violations and had lower violation scores in the first session compared to the NVGPs. However, this difference was reduced when participants were fatigued in the second driving session. Thus, there is evidence to suggest that both VGPs and NVGPs experience the effects of cognitive fatigue similarly. The results of the driving simulator performance in the first session are consistent

with that of previous research finding that VGPs are better drivers than NVGPs (Rupp et al., 2015). Regularly playing action video games improves a range of cognitive abilities such as visual attention (C. S. Green & Bavelier, 2003), speed of visual processing (Dye et al., 2009b), and decision making and cognitive control (Bailey et al., 2010), and this is one of the first studies to demonstrate that action video game players can transfer these abilities to real-world tasks, as demonstrated by superior driving simulator performance compared to NVGPs.

The results of the present study confirm the findings from Study 1 (Chapter 3), both VGPs and NVGPS experience similar performance decrements due to cognitive fatigue. At the multivariate level, VGPs had superior sustained attention performance compared to NVGPs, however their performance declined over time, similar to the performance of the NVGPs. In the present study, the driving performance of the VGPs was significantly better than that of the NVGPs when they were not fatigued, however, in the second driving session, there was no difference between the two groups. Thus, the results demonstrate that although action video game experience can improve driving performance, it does not assist with resisting the effects of cognitive fatigue.

As identified in the previous studies (Chapter 3 and 4), when measuring cognitive fatigue, only tasks on which optimal performance can be achieved in a short period of time, or in which all participants are already proficient, should be used, as learning effects can masks fatigue effects (Ackerman, 2011). The results of the present study demonstrate that the driving simulator is an ideal task for measuring multitasking and executive control in relation to fatigue. On average, participants had 5 to 10 years of driving experience and therefore the practice driving session could focus on the participants becoming familiar with the driving simulator rather than on driving skills and road rules. Further, the decline in performance between the two driving sessions reveals that there was no learning effect, or that participants

reached their optimal performance in the practice or first driving session and then experienced the effects of fatigue after that.

In addition to driving performance, eye-movements were also recorded. The number of fixations, and total fixation length was measured when participants looked at either the close or distant areas of the road, or the wide or centre areas. Both VGPs and NVGPs demonstrated eye-movement characteristics of experienced drivers (Crundall et al., 1998; Patten et al., 2006), in that there were more fixations on, and longer time spent viewing the distant and wide areas of the road, compared to the close and centre areas. Viewing a wider area of the road, and looking further ahead allows drivers to process more information and to adjust their driving behaviour accordingly, resulting in better driving performance (Paxion et al., 2014). Although it was predicted that VGPs would demonstrate this behaviour, it is not surprising that NVGPs demonstrated this behaviour too, given the number of years of driving experience they had. Further, neither group experienced tunnel vision as a result of fatigue. There was no significant change in the number of fixations or time spent looking at either the wide or centre areas of the road between the two driving sessions. However, there was a significant change over time in the number of fixations and total length of fixations to the close and distant areas of the road, and a significant three-way interaction between video game experience group, driving session, and road area. Over time, NVGPs looked at the close and distant areas of the road less and for shorter periods. Thus, NVGPs were directing their attention to other off-road areas as they became fatigued, which is likely the cause of their poorer driving performance in the second driving session, as inadequate visual scanning inevitably leads to traffic accidents (Underwood, Crundall, & Chapman, 2011).

Interestingly however, whilst VGPs also looked at the close area of the road less and for shorter as they became fatigued, they differed to NVGPs, in that there was an increase in the number of fixations and duration of time spent looking at the distant area of the road.

Again, this is indicative of experienced driving behaviour, as looking further ahead along the road allows the driver to see potential hazards and adapt their behaviour (Paxion et al., 2014).

Although the results of the current study are encouraging, more research is still needed. The present study is only one of a few that have investigated the real-world benefits of regular action video game playing, and the only one that has investigated cognitive fatigue. However, a causal relationship between action video game playing, driving performance, and cognitive fatigue cannot be established from the current results. Future studies should attempt to replicate and build on the current study by investigating the effect of action video game training on simulated driving performance.

In conclusion, the results of the present study demonstrate that regular action video game players perform better on a driving simulator compared to NVGPs. Regularly playing action video games has previously been shown to improve cognitive processes that are essential for safe driving (Bailey et al., 2010; Dye et al., 2009b; C. S. Green & Bavelier, 2003), and the current results demonstrate that these can be transferred to real-world tasks. However, VGPs remain as susceptible to the effects of cognitive fatigue as NVGPs.

## Chapter 6: Summary

The purpose of this thesis was to examine the relationship between action video game experience and cognitive fatigue. Cognitive fatigue results in increased difficulty in maintaining task performance and increases the likelihood of human error (Ackerman, 2011; Guastello et al., 2013; Lal & Craig, 2001; Van Dongen et al., 2011), which can become fatal when performing certain tasks or occupations, for example motor vehicle or aircraft control. It has previously been found that individuals who regularly play action video games perform better than non-video game players on tasks related to sustained and divided attention (Boot et al., 2008; Castel et al., 2005; C. S. Green & Bavelier, 2003, 2006b, 2007; Hubert-Wallander, Green, Sugarman, et al., 2011; T. N. Schmidt et al., 2012), however there has been little research investigating this directly. Further, research on the cognitive benefits of action video games has been limited by the use of only one training technique. In the field of skill acquisition, it is well known that training that is variable and that emphasises cognitive flexibility can lead to greater learning (Baniqued et al., 2013; Kramer et al., 1995; R. A. Schmidt & Bjork, 1992), however this has not yet been explored with the use of modern action video games. Lastly, there are few studies examining the everyday benefits of action video game playing and how cognitive fatigue may affect performance on real-world tasks.

The main findings of this thesis reveal that VGPs experience similar levels of cognitive fatigue as NVGPs. In Study 1 (Chapter 3), VGPs and NVGPs were indistinguishable by their performance on the vigilance task. Over the 60-minute task, the performance of both groups declined by similar amounts, with increases in reaction time variability, and decreases in sensitivity and criterion levels. In addition, in Study 3 (Chapter 5), when driving in a simulator, the performance of both groups declined significantly over time, as indicated by more traffic violations and having a higher total violation score. Combined, these results demonstrate that both VGPs and NVGPs are equally susceptible to

the effects of cognitive fatigue. This is further supported by participants' self-report measures of fatigue, in that both groups experienced similar increases in fatigue after driving in the simulator, and both groups reported experiencing similar types of fatigue whilst driving.

Although VGPs experience similar levels of cognitive fatigue as NVGPs, there remain advantages to regularly playing action video games. In Study 1 (Chapter 3), VGPs were significantly better at multitasking than the NVGPs. The results revealed that the VGPs performed significantly better on the secondary tasks of the MATB-II compared to the NVGPs, indicating that VGPs could perform these tasks without sacrificing performance on the primary tasks. Although MATB-II performance could not be used to assess the effect of cognitive fatigue on multitasking due to practice effects, the results do demonstrate that VGPs learned how to perform the MATB-II faster than the NVGPs. In the first MATB-II session, there was no significant difference in performance at the multivariate level, however in the second session, despite both groups improving, VGPs performed significantly better than the NVGPs. Video game players' superior multitasking skill was also evidenced in better driving performance. In Study 3 (Chapter 5), when not fatigued, the driving performance of the VGPs was significantly better than that of the NVGPs. The number of years of driving experience was also assessed as this may have been a potential confound, however, there was no significant difference between the groups, and in fact on average, NVGPs had twice as many years' experience as the VGPs. Thus, the superior driving performance of VGPs can be attributed to their experience playing action video games.

When people are fatigued, visual perception is reduced, gaze narrows (Ji et al., 2004), and the peripheral field of view, the number of eye-movements and scanning patterns are reduced (Liu & Wu, 2009; May & Baldwin, 2009), potentially leading to hazardous consequences when driving. In Study 3 (Chapter 5), participants' eye-movements were recorded to examine whether VGPs and NVGPs had different search patterns and if these

changed as they became fatigued. As the NVGPs became fatigued, they looked at the close and distant areas of the road less. The VGPs also looked at the close area of the road less as they became fatigued, however, the amount of time spent looking at the distant area of the road increased. Previous research has shown that VGPs have increased visual attention (C. S. Green & Bavelier, 2003), speed of visual processing (Dye et al., 2009b), and increased field of view (Feng et al., 2007; C. S. Green & Bavelier, 2006b). Looking further ahead along the road is characteristic of experienced driver's eye-movements, as it allows the driver to process more information, adjust their driving behaviour, and avoid potential hazards (Paxion et al., 2014). However, this did not result in any difference in performance between the two groups when they were fatigued. Thus regularly playing action video games may allow individuals to develop visual scanning patterns similar to those of experienced drivers, however this does not affect their performance when they are fatigued.

The above results demonstrate that individuals with a greater amount of action video game experience perform better on sustained attention and divided attention tasks. However, there remains the possibility that individuals who have superior sustained and divided attention skills are attracted to action video games and therefore perform well at them, and so these skills are not improved by action video game playing (Adams & Mayer, 2012). Therefore, in Study 2 (Chapter 4), the effect of video game training on these measures was also investigated. In addition, two types of training were compared, variable priority training and fixed emphasis training, to determine which was most effective at improving sustained and divided attention performance. Overall, there was no advantage of using one training technique over the other when learning to play the video game. Further, there was no difference between training techniques on any of the sustained and divided attention measures. However, overall there is some evidence to suggest a positive effect of video game training. For the vigilance task, the multilevel modelling analyses found an interaction

between period of watch and testing session. This revealed that in the pre-training test there were increases in reaction times and reaction time variability as time-on-task increased. However, in the post-training test, and at the three-month follow-up there was little to no increase in reaction times or reaction time variability over time. Thus, participants experienced the effects of cognitive fatigue to a lesser extent after video game training than compared to before training. In addition, there was a significant improvement in multitasking performance after video game training, however, as participants continued to improve on the MATB-II even at the three-month follow up test, it is unknown whether the improved performance was due to video game training or simply due to practice effects on the test.

## 6.1 Implications

Many occupations require sustained and divided attention where the effects of cognitive fatigue can have fatal consequences (e.g. pilots, power plant operators, long-distance drivers, security surveillance operators, and unmanned aircraft vehicle operators) (Chiappe et al., 2013; Durso & Sethumadhavan, 2008; Feltman, 2014; Finomore et al., 2009; Gartenberg et al., 2013; Hubal et al., 2010; Warm, Matthews, et al., 2008; Warm, Parasuraman, et al., 2008). Therefore, understanding the factors involved in attaining optimum human performance, and the ability to maintain this in the face of cognitive fatigue is beneficial when implementing personnel screening, assessment, and training for such occupations. For example, the MATB-II was designed to replicate the tasks performed by aircraft operators (Santiago-Espada, Myer, Latorella, & Comstock, 2011), and has previously been used to assess the suitability of VGPs as potential unmanned aerial vehicle (UAV) operators (Feltman, 2014). Operators of unmanned-aerial vehicles need to sustain their attention for hours at a time (Cummings et al., 2013), as well as operate multiple UAVs simultaneously, all of which requires a high level of cognitive skills and the ability to resist the effects of cognitive fatigue. Understanding the effects of cognitive fatigue on UAV

control has been highlighted as an important issue, as the use of UAVs increases (Wilson, Caldwell, & Russell, 2007). The results of the studies reported in this thesis have practical implications in this area. Individuals with action video game experience, whether from past experience or through training, may be suitable UAV operators, as they demonstrate superior multitasking abilities, however, caution must be taken, as they are as susceptible to the effects of cognitive fatigue as individuals without video game experience

The results of this project also have theoretical implications pertaining to the role of executive control in cognitive fatigue. Cognitive fatigue is an adaptive mechanism that controls and manages motivation and behaviour, and is closely related to executive control (Hockey, 2013). The executive functions organise and control lower-level cognitive functions according to the individual's goals. They are particularly involved in sustained attention and divided attention tasks, as executive control is needed when goals need to be prioritised, when irrelevant stimuli need to be ignored, and when automatic responses need to be overruled (van der Linden, 2011). However, performing complex tasks for long durations taxes executive control, resulting in a reduction in performance (Earle et al., 2015; Lorist & Faber, 2011; Lorist et al., 2000; van der Linden, 2011; van der Linden et al., 2003). Therefore, in the present project, it was hypothesised that those with greater executive control, that is, the VGPs, would be able to resist the effect of cognitive fatigue. The results presented are consistent with previous work (Appelbaum et al., 2013; Strobach et al., 2012), demonstrating that VGPs have greater executive control compared to NVGPs, as demonstrated by their superior sustained and divided attention performance. However, there was limited support for the executive control hypothesis, as the advantage of superior executive control did not always transfer to an increased resistance to the effects of cognitive fatigue. In Study 1 (Chapter 3), the performance of VGPs and NVGPs declined at a similar rate in the vigilance task. These results are consistent with the previous research on the

effects of fatigue however they do not support the hypothesis that those with greater executive functions will be less affected by cognitive fatigue. Further evidence was provided for this in Study 3 (Chapter 5). When participants were not fatigued, VGPs performed significantly better than NVGPs. However, the performance of both groups declined over time due to fatigue, so that there was no significant difference between the groups.

In addition to the real world and theoretical implications identified above, the present project has also highlighted a number if implications related to the study and analyses of the cognitive performance of VGPs. It has been consistently demonstrated that VGPs have improved cognitive abilities that are required in performing sustained attention tasks (Boot et al., 2008; Castel et al., 2005; Dye et al., 2009b; C. S. Green & Bavelier, 2003, 2006b, 2007; Hubert-Wallander, Green, Sugarman, et al., 2011; T. N. Schmidt et al., 2012), and it has been found that VGPs have faster reaction times than NVGPs on a vigilance task (Dye et al., 2009b). In Study 1 (Chapter 3), at the univariate level, there was no significant difference in reaction times, reaction time variability, measures of accuracy, or sustained attention performance between VGPs and NVGPs. However, it is important to consider all variables in the analysis, as at the multivariate level, there was a significant difference in sustained attention performance between the groups. This suggests that the difference in performance between VGPs and NVGPs is detectable only when a combination of the sustained attention performance measures are analysed together. Further evidence of this is provided by the results of Study 3 (Chapter 5) measuring driving performance. The driving simulator task required participants to sustain their attention for approximately two hours. Successful driving performance is the result of a combination of multiple variables as it consists of performing multiple sub-tasks simultaneously and places high demands on a range of cognitive processes (Desmond & Hancock, 2001; Mäntylä et al., 2009). In this task, VGPs performed significantly better than NVGPs in the first driving session, when fatigue was not

a factor. Thus, when a combination of factors and variables contribute to task performance, they must be analysed in combination. Doing so reveals that VGPs have superior sustained attention compared to NVGPs, which is consistent with previous research (Boot et al., 2008; Castel et al., 2005; Dye et al., 2009b; C. S. Green & Bavelier, 2003, 2006b, 2007; Hubert-Wallander, Green, Sugarman, et al., 2011; T. N. Schmidt et al., 2012).

In addition to the above, this project has also contributed to knowledge on the cognitive benefits of action video game playing through the methods used to classify participants as either NVGPs or VGPs. Many studies refer to their video game playing participants as experts, rather than as those with more experience (Andrews & Murphy, 2006; Boot et al., 2008; Karle et al., 2010; Zhang et al., 2009), and while the process of becoming an expert in a particular field often requires many hours of practice (VanDeventer & White, 2002), it is not sufficient criteria for being considered an expert. These studies also use self-report measures only to classify participants as either VGPs or NVGPs. Study 1 (Chapter 3) was the first in the literature to classify participants by using actual video game performance measured in the laboratory. The results provide statistical evidence to support the use of self-report measures in classifying individuals as either VGPs or NVGPs. Thus, the use of self-report measures of video game experience appears to be sufficient in classifying participants as either VGPs or NVGPs, on the proviso that VGPs are referred to as having more ‘video game experience’, rather than as ‘video game experts’.

This project was also the first to investigate the effectiveness of different training techniques in improving the cognitive skills associated with action video game playing. Practicing a task will undoubtedly result in improved performance, however, specific training strategies can be more effective at increasing learning, improving retention of newly learned skills, and broadening the transfer of training (Gopher et al., 2007; Lee, Boot, et al., 2012; R. A. Schmidt & Bjork, 1992). Variable priority training was chosen in comparison to the

conventional fixed emphasis training, as training techniques that are variable, promote cognitive flexibility, and that avoid task-specific mastery can lead to greater levels of learning as well as broader transfer (Baniqued et al., 2013; Kramer et al., 1995; R. A. Schmidt & Bjork, 1992). However, the results of the Study 2 (Chapter 4) did not demonstrate an advantage for either training technique. There are a number of possible reasons as to why the collected results are inconsistent with those from previous research, and these are discussed in the following section.

**6.2 Limitations and future directions**

The results of the current project fill a gap in the literature pertaining to the experience of cognitive fatigue by VGPs and NVGPs, however it is not without its limitations. Firstly, it was difficult to recruit participants who solely played first-person shooter video games. There has been a great deal of interest in this particular genre of video game since the seminal paper by C. S. Green and Bavelier (2003), and subsequent work has continued this focus. However, in both Study 1 (Chapter 3) and Study 3 (Chapter 5) it was necessary to broaden the categorisation of VGPs to include all action video games. Thus when comparing findings between studies it is important to determine how VGPs are classified. Further, it is possible that not all action video games induce the same cognitive benefits as first-person shooter games, and may explain why, inconsistent with previous research, that there was no significant differences between VGPs and NVGPs on some measures of performance (e.g. initial multitasking performance in Study 1). Therefore, the results of Study 1 and Study 3 pertain to the effects of regularly playing action video games, not specifically to first-person shooter video games. It is suggested that future work investigate differences between the sub-types of action video games. Investigation of this is still in its early stages (Oei & Patterson, 2015), and in light of the present results it would be beneficial to direct the focus on the potential differences between genres of video games in

the development of sustained and divided attention abilities.

Secondly, Study 2 (Chapter 4) only involved six participants, all of whom were female, aged 29 to 58 years. Thus, the results cannot be generalised to the wider population, and are also heavily impacted by individual differences (see Section 4.5.4). The results of Study 2 are therefore only preliminary with regards to investigating the benefits of different training techniques with video games in improving sustained and divided attention. It was also highlighted in Study 2 that the efficiency of training improves when it is highly variable. By including a range of action video games for participants to train on, instead of just one, task variability is increased which may in turn increase the transfer of improvements in video game performance to sustained and divided attention tasks (Chiappe et al., 2013; C. S. Green et al., 2009). It is therefore suggested for future studies that multiple action video games be used when investigating the benefits of variable priority training.

Thirdly, as with Study 1 (Chapter 3), the results of Study 3 (Chapter 5) do not provide evidence for a causal relationship between video game experience and improved driving performance. Therefore, future work should train NVGPs on one or more action video games to determine whether driving performance can be improved through action video game experience. In addition, it has previously been suggested that complex real-world tasks such as driving may benefit from variable priority training (Boot et al., 2010). Therefore the investigation of the effectiveness of different training techniques with video games, aimed at improving sustained and divided attention should be expanded to also include simulator task performance in addition to laboratory task measures. Further, it would be interesting to investigate whether the visual search patterns of the NVGPs change due to playing these video games. The results of Study 3 provide evidence that there are differences in search patterns between VGPs and NVGPs, however it is still unclear whether this is due to action video game experience or other factors such as driving experience, and whether this can

affect driving performance.

**6.3 Conclusion**

The results of this project demonstrate that individuals who regularly play action video games have superior sustained attention and divided attention compared to non- video game players. These results were found by measuring performance not only in the laboratory using vigilance and multitasking tasks, but also through measuring driving performance in a simulator. However, despite the improved performance of VGPs compared to NVGPs, both groups were equally susceptible to the effects of cognitive fatigue. Over time, both groups experienced significant declines in sustained attention, divided attention, and driving performance. The results of this thesis also provide further evidence that training on an action video game can result in improved sustained and divided attention, and that these improvements can remain three months after training ceases.

The wide range of cognitive benefits of playing action video games, and the superior sustained and divided attention ability of VGPs suggests that playing these games improves executive functioning, which also controls the adaptive mechanisms associated with cognitive fatigue. However, this thesis presents evidence that improved executive control does not result in an increased ability to resist the effects of cognitive fatigue. Overall, these findings have practical implications for the recruitment and training of personnel in occupations that require high levels of cognitive performance and the need to divide and sustain attention for extended periods of time. However, whilst video game experience and training can improve sustained and divided attention performance, the results reported in this thesis demonstrate that it does not improve the ability to resist the effects of cognitive fatigue.

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## Appendix A

### Study 1 Questionnaire

Full name: ___________________________________

Age: _______________________________________

Sex: _______________________________________

Contact email: ______________________________

Contact phone: ______________________________

Please list any exercise/sport activities you partake in, and how often:

______________________________________________________________________

Do you play video games (including brain-training games)? **YES / NO**

If **<u>YES</u>**:

On average, have you played <u>first-person shooter games</u> at least 4 times per week for a minimum of 60 minutes each time, over the past 6 months?

**YES / NO**

How often, over the past 6 months, do you play video games (any genre, including brain-training games, and if you have Unreal Tournament experience)

| TITLE | GENRE | CONSOLE | Hours per week |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |

# Appendix B

## Study 1 Information Letter

JOONDALUP CAMPUS

270 Joondalup Drive,
Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: (08) 9300 1257
CRICOS 00279B

ABN 54 361 485 361

**Video Game Expertise:**
**Improving Cognitive Endurance through Action Video Game Play**

<u>Information letter</u>

My name is James Brooks, I am a PhD student in the School of Psychology and Social Science at Edith Cowan University, and this research project is being undertaken as part of the course requirements.

I am interested in finding new ways to improve people's cognitive performance, and cognitive endurance, i.e. the ability to maintain a high level of performance for long periods of time. The aim of this research is to determine whether video game playing can improve cognitive endurance. Participation in this project will involve completing a few computer-based tasks, and the completion of a short questionnaire. The total duration of this task is expected to take approximately 2 hours (you will be encouraged to take a break every 20-30 minutes). You will also go into the draw to win one of two $50 shopping vouchers and will receive a raffle ticket for every hour of participation.

This project has been approved by the ECU Human Research Ethics Committee. Any information recorded will remain confidential and identifiable information will only be available to myself and my supervisors, Prof. Craig Speelman and Dr. Guillermo Campitelli. The final results of this study will not include any personally identifiable information, and data may be used for future research. Participation in this study is voluntary, and you will be free to withdraw at any time with no explanation or justification needed.

Your participation in this study would be greatly appreciated. If you require any further information about the research project, please contact:

| | | |
|---|---|---|
| James Brooks | | Email: j.brooks@ecu.edu.au |
| Prof. Craig Speelman | Phone: 6304 5724 | Email: c.speelman@ecu.edu.au |

Regards,
James Brooks

If you have any concerns or complaints about the research and wish to talk to an independent person, you may contact:
Research Ethics Officer
Edith Cowan University
270 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 2170
Email: research.ethics@ecu.edu.au

## Appendix C

## Study 1 Consent Form

JOONDALUP CAMPUS
270 Joondalup Drive,
Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

**Video Game Expertise:**
**Improving Cognitive Endurance through Action Video Game Play**
**Informed Consent Form**

Contact Details:

| Primary Researcher: | Principal Supervisor: |
| --- | --- |
| James Brooks | Prof. Craig Speelman |
| | Ph. 6304 5724 |
| j.brooks@ecu.edu.au | c.speelman@ecu.edu.au |

I have been provided with a copy of the Information Letter explaining the research study. I have read and understood the information provided. I have been given the opportunity to ask questions and any questions I have asked have been answered to my satisfaction. I am aware that if I have any additional questions I can contact the research team.

I am aware that participation in this research project will involve completing some computer-based tasks, and completing a short questionnaire. I am aware that the total duration of the task is expected to take approximately 2 hours.

I am aware that information provided will be kept confidential, and that my identity will not be disclosed without consent. I understand that I am free to withdraw from further participation at any time, without explanation or penalty.

I am aware that any data collected may be used for future research. Access to this information will be distributed at the discretion of the primary researcher (James Brooks) and principal supervisor (Prof. Craig Speelman).

I agree that I am over 18 years of age.

I freely agree to participate in this project.
Name:

Date:

Signature:

## Appendix D

## Study 2 Information Letter

JOONDALUP CAMPUS
270 Joondalup Drive,
Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

**Video Game Expertise:**
**Improving Cognitive Endurance through Action Video Game Play**

Information letter

My name is James Brooks, I am a PhD student in the School of Psychology and Social Science at Edith Cowan University, and this research project is being undertaken as part of the course requirements.

I am interested in finding new ways to improve people's cognitive performance, and cognitive endurance, i.e. the ability to maintain a high level of performance for long periods of time. The aim of this research is to determine whether video game training can improve cognitive endurance. The research will involve the completion of a video game training program. This will involve playing a video game for 10 1-hour sessions over 4 weeks. After this, a post-training session will involve completing a few computer-based tasks, and the completion of a short questionnaire. This task is expected to take approximately 2.5 hours (you will be encouraged to take a break every 20-30 minutes). You will then be asked to return in 3 months' time for a follow-up session. You will also go into the draw to win one of two electronic tablet devices (or gift card of equivalent value) and will receive a $20 gift voucher at the 3-month follow-up.

This project has been approved by the ECU Human Research Ethics Committee. Any information recorded will remain confidential and identifiable information will only be available to myself and my supervisors, Prof. Craig Speelman and Dr. Guillermo Campitelli. The final results of this study will not include any personally identifiable information, and data may be used for future research. Participation in this study is voluntary, and you will be free to withdraw at any time with no explanation or justification needed.

Your participation in this study would be greatly appreciated. If you require any further information about the research project, please contact:

| | | |
|---|---|---|
| James Brooks | | Email: jbrooks2@our.ecu.edu.au |
| Prof. Craig Speelman | Phone: 6304 5724 | Email: c.speelman@ecu.edu.au |

Regards,
James Brooks

If you have any concerns or complaints about the research and wish to talk to an independent person, you may contact:
Research Ethics Officer
Edith Cowan University
270 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 2170 Email: research.ethics@ecu.edu.au

# Appendix E

## Study 2 Consent Form

JOONDALUP CAMPUS
270 Joondalup Drive,
Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

**Video Game Expertise:**
**Improving Cognitive Endurance through Action Video Game Play**
<u>Informed Consent Form</u>

Contact Details:

| Primary Researcher: | Principal Supervisor: |
|---|---|
| James Brooks | Prof. Craig Speelman |
| | Ph. 6304 5724 |
| j.brooks@ecu.edu.au | c.speelman@ecu.edu.au |

I have been provided with a copy of the Information Letter explaining the research study. I have read and understood the information provided. I have been given the opportunity to ask questions and any questions I have asked have been answered to my satisfaction. I am aware that if I have any additional questions I can contact the research team.

I am aware that participation in this research project will initially involve completing some computer-based tasks, and completing a short questionnaire. I am aware that the total duration of this task is expected to take approximately 2 hours.

I also agree to partake in the training program, requiring the completion of 10 60-minute sessions, over the following 4 weeks. I am aware that I will be asked to return for participation in a 2-hour session in 3 months' time

I am aware that information provided will be kept confidential, and that my identity will not be disclosed without consent. I understand that I am free to withdraw from further participation at any time, without explanation or penalty.

I am aware that any data collected may be used for future research. Access to this information will be distributed at the discretion of the primary researcher (James Brooks) and principal supervisor (Prof. Craig Speelman).

I agree that I am over 18 years of age.

I freely agree to participate in this project.
Name:

Date:

Signature:

**Appendix F**

**Study 2 Variable Priority Training Instructions**

| Task | Description |
|---|---|
| 1 | • Get full Health (199)<br>• Get full Shield (150)<br>• Find the double-damage pick-up |
| 2 | • Pick up all of the weapons<br>• Get full ammunition for each weapon<br>• Use the Primary fire (left click) and Secondary fire (right click) for each weapon |
| 3 | • Complete Task 1 and Task 2 whilst evading the enemy<br>• Try not to die (Pick up health, use dodge and jump) |
| 4 | • Complete Task 1 and Task 2 whilst attacking the enemy<br>• Try to kill the enemy as many times as possible (Use everything at your disposal, i.e. weapons, pick-ups ) |
| 5 | • Complete all tasks<br>• Gain full Adrenaline (100)<br>• Learn the 3 other secret key combos to unlock the Adrenaline bonus<br>• E.g. W,W,W,W = speed |

## Appendix G

### Study 3 Traffic Violations and Scores

| Violation Description | Score |
|---|---|
| You are driving more than 10 kph over the speed limit | 3 |
| Driving into the traffic lane without turning the left turn signal. | 3 |
| Driving into the traffic lane without turning the right turn signal. | 3 |
| Left turn signal not used when changing the lanes | 3 |
| Right turn signal not used when changing the lanes | 3 |
| The right turn signal was not on when turning | 3 |
| Turn signal not used | 3 |
| The exit from the ring is allowed only in the left outside lane | 3 |
| The left turn signal was not on when entering the ring. | 3 |
| The left turn signal was not on when leaving the ring. | 3 |
| Unnecessary crossing to the opposite lane | 3 |
| You are driving in the forbidden direction | 3 |
| You are driving more than 20 kph over the speed limit | 3 |
| You are driving in the opposite lane | 5 |
| You are driving more than 40 kph over the speed limit | 5 |
| You are driving on a red light | 5 |
| You have crossed the lane markings into the opposite lane | 5 |
| You haven't yielded to a pedestrian | 5 |
| You've pulled over the roadway | 5 |
| You are driving more than 60 kph over the speed limit | 10 |
| You are driving more than 80 kph over the speed limit | 10 |
| Pedestrian accident | 10 |
| You've had an accident | 10 |

# Appendix H

## Study 3 Questionnaire

Full name: ___________________________________

Age: _______________________________________

Sex: _______________________________________

Contact email: ______________________________

Contact phone: ______________________________

Please list which driver's licences you hold, how many years you have been driving & any other driving experience factors (e.g. work as a courier, taxi driver etc.)

_____________________________________________________________________________

Do you play video games (including brain-training games)? **YES / NO**

If **YES**:

On average, have you played first-person shooter games at least 4 times per week for a minimum of 60 minutes each time, over the past 6 months?

**YES / NO**

How often, over the past 6 months, do you play video games (any genre)?

| TITLE | GENRE | CONSOLE | Hours per week |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |

# Appendix I

## Study 3 Information Letter

**Comparing Simulated Driving Performance of Gamers and Non-Gamers**

JOONDALUP CAMPUS
270 Joondalup Drive,
Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

<u>Information letter</u>

My name is James Brooks, I am a PhD student in the School of Psychology and Social Science at Edith Cowan University, and this research project is being undertaken as part of the course requirements.

The aim of this research is to determine whether video game playing experience can affect simulated driving performance. Participation in this project will involve completing a driving course in a simulator, and the completion of a short questionnaire. The total duration of this task is expected to take approximately 2.5 hours. You will go into the draw to win one of two $50 shopping vouchers, and one $500 shopping voucher.

This project has been approved by the ECU Human Research Ethics Committee. Any information recorded will remain confidential and identifiable information will only be available to myself and my supervisor, Prof. Craig Speelman. The final results of this study will not include any personally identifiable information, and data may be used for future research under the supervision of Prof. Craig Speelman. Participation in this study is voluntary, and you will be free to withdraw at any time with no explanation or justification needed. Please be aware that the driving simulator may induce motion sickness.

Your participation in this study would be greatly appreciated. If you require any further information about the research project, please contact:

| | | |
|---|---|---|
| James Brooks | | Email: j.brooks@ecu.edu.au |
| Prof. Craig Speelman | Phone: 6304 5724 | Email: c.speelman@ecu.edu.au |

Regards,
James Brooks

If you have any concerns or complaints about the research and wish to talk to an independent person, you may contact:
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# Appendix J

## Study 3 Consent Form

**Comparing Simulated Driving Performance of Gamers and Non-Gamers**

JOONDALUP CAMPUS
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Informed Consent Form

Contact Details:

| Primary Researcher: | Principal Supervisor: |
|---|---|
| James Brooks | Prof. Craig Speelman |
| | Ph. 6304 5724 |
| j.brooks@ecu.edu.au | c.speelman@ecu.edu.au |

I have been provided with a copy of the Information Letter explaining the research study. I have read and understood the information provided. I have been given the opportunity to ask questions and any questions I have asked have been answered to my satisfaction. I am aware that if I have any additional questions I can contact the research team.

I am aware that participation in this research project will involve performing a driving course in a driving-simulator, and completing a short questionnaire. I am aware that the total duration of the task is expected to take approximately 2.5 hours.

I am aware that the driving simulator may induce motion sickness.

I am aware that any information provided will be kept confidential, and that my identity will not be disclosed without my consent. I understand that I am free to withdraw from further participation at any time, without explanation or penalty.

I am aware that any data collected may be used for future research. Access to this information may be distributed at the discretion of the primary researcher (James Brooks) and principal supervisor (Prof. Craig Speelman).

I confirm that I am over 18 years of age.

I freely agree to participate in this project.

Name:

Date:

Signature: