Investigating the modulation of cognition and event-related potentials relating to visual attention, working memory, and executive control in habitual videogame players

Thesis submitted for the degree of Doctor of Philosophy

By

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University of Hull, April 2016

This work was carried out under the primary supervision of Dr. William J. McGeown, Dr. Paul Skarratt, and secondary supervision of Professor Paul Wilson.

I, Alexander James Spence, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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Abstract

The overall objective of this thesis was to produce a document that investigated whether habitual videogame playing modulated cognitive processes related to visual processing and where in the processing stream these modulations occur. In this thesis, the term ‘cognitive modulation’ refers to any neurological differences (as identified through ERP) between videogame players and non-videogame players that theoretically may have been a result of videogame playing. Using this method, I am able to ascertain whether differences between the two groups are observed in early sensory ERPs, in which case VGPs might possess an advantage in bottom-up visual processing, later selective attention which might indicate alterations in top-down attentional processing, motor-response waveforms that may indicate difference in stimulus response mappings, and finally any differences in working memory capacity that might be the underlying cause of supposed attentional differences. An example of cognitive modulation was observed by Wu et al., (2012) and discussed in more detail in the introduction of this thesis. Indeed these modulations should also be accompanied by a behavioural difference between the two groups. As ERP was the primary source of neurophysiological recordings in this thesis, modulations could occur in the amplitude, mean activity, or peak latency of ERP waveforms.

The paradigms employed in this thesis were chosen and designed so that in combination they provide a measure of potential cognitive modulation across the entire processing stream. That is, from early sensory ERPs, through selective attentional ERPs, including executive control ERPs and concluding at ERPs related to motor response priming. As these studies primarily focused on attentional

processes, an ERP chapter towards the end of this thesis was included to identify whether any modulations in attentional ERPs were an indirect result of modulated working memory.

Chapters 2 and 3 in this thesis focus on attentional control, resources, and the inhibitory processes of attention. Specifically, these chapters related to the attentional control each group employed when being presented with distracting items. Indeed, I observed modulated cognitive processes in chapter 3 related inhibitory processing in both attention and executive control related processes. In addition to this, the flanker task in Chapter 3 also allowed me to measure and modulation in motor priming between videogame players and non-videogame players.

Chapters 4 and 5 looked more closely at ERPs related to selective attention such as the N2pc and P3, alongside early sensory ERPs (N1, P1, etc.). In response to observing differences in how each group processed distractors (related to the N2pc in Chapter 4), Chapter 5 employed a very specific test in order to split the N2pc into its component parts to further investigate whether any cognitive modulation between groups was a result of altered priority on processing targets or inhibiting distractors.

Chapter 6 in this thesis sought to identify whether any differences observed in the attentional processing stream was actually the result of modulations in working memory, a cognitive process theoretically closely related to selective attention. Chapter 6 measured the contralateral delay activity, a neurological waveform that correlates with items held in visual working memory.

Chapter 7 provided further exploratory psychophysical testing to identify whether any potential behavioural between-group differences extend beyond the usual visual field our groups would play videogames in. This involved testing the crowding phenomenon whereby participants are unable to identify a stimulus when closely flanked by distractors.

This these concludes with Chapter 8, an overall discussion of each chapters results and how these theoretically synthesise with one another in relation to the two objectives of this thesis; does videogame playing modulate cognitive, and where in the attentional processing stream does this occur.

Acknowledgements

The last three (and a bit) years would have been impossible without the support of my supervisors, friends and family. Many thanks go to Will McGeown for accepting me as his student, giving me the opportunity to research this topic, and providing direction and advice whenever I needed it; I owe him far more than I can articulate here in these words, thank you. Thank you to Paul Skarratt for taking me on as his student without question and always being there for a chat when things felt tough, it meant a great deal to me. I would like to thank Mary-Ellen Large for entrusting me with her EEG lab, a place I spent so much time over the past few years.

A brief thank-you to my fellow PhD students who helped share the load during the more difficult periods of postgraduate life; Iveta, Matt, Richard, Steve, Kat, Erin, Joanna, Olivia, Margarita, Jade, Eszter, Manon, Lydia, Natalia, Michael, and Jamey. To those of you that were unfortunate enough to pilot my experiments, you deserve an additional thank you!

A huge thanks go to my Mum, Dad and beautiful Antoinette for putting up with all my grief over the past few years. No matter how difficult it got, or how stressed I was, you always supported me, and always encouraged me to continue forwards. Thank you all.

Contents

Chapter 1. General Introduction

The modern prevalence of videogaming

The digital entertainment industry has continued to grow and surpass that of traditional entertainment media (film, television, music) over the past several years. Between 2011 and 2014 in the UK alone, 14.3 million units of hardware were sold such as games consoles and handheld gaming systems, whilst in the same time period 156.5 million units of software were sold, i.e. videogames (UK yearly videogame chart, 2014). For perspective, as of 2013, the UK has 26.4 million households (United Nations Economic Commission for Europe, Statistical Database); that is enough consoles for approximately 54% of UK homes, with each one owning just short of six videogames.

The U.S. market appears to be equally strong, with total sales of videogames software, hardware and accessories reaching $21.53 billion in 2013 alone (Essential Facts 2014 Sales, Demographic and Usage Data; entertainment software association). U.S. Demographic information indicated 59% of all Americans play videogames, and that 51% of households own an average of two videogame playing devices. Interestingly, the perception of videogame users as young and male appears to be false, with the average videogame player being 31 years of age, and males comprising only 52% of videogame players surveyed. The average number of years videogame players have been playing games is 14 years, with adult males averaging 18 years and females 13 years, indicating this even gender split is a more recent occurrence. The greatest change in videogame playing behaviours between 2012 and 2013 was a 55% increase in casual and social gaming on mobile devices, an example of this being 2013’s most downloaded iOS app Candy Crush Saga, with 408 million active monthly users (Cox, 2014).

Videogaming and real-world impact

In recent years, videogames have been used for a variety of applications in the real world. Indeed, as recently as 2014, news agencies reported that the U.S. and UK sought videogame players ahead of experienced pilots when recruiting for new drone pilots (Subbaraman, 2013). Additionally, the U.S. military uses over 50 videogames as training tools including games such as *Virtual Battlespace 2* and *America’s Army*, both funded by the US military with the former used as a training tool to simulate various land, sea and air battlefield scenarios; the latter originally used for recruitment purposes but newer iterations include virtual weapons training and strategic communication practice (Prensky, 2003). Gopher, Well and Bareket (1994) tested the transfer of skills from the complex videogame Space Fortress to flight performance of Israeli Air Force cadets. Cadets that played the game for 10 hours showed significantly higher scores on subsequent test flights than did non-trained cadets.

However, not all applications revolve around the military. Surgical residents and physicians that were trained on videogames or had past videogame playing experience were found to perform laparoscopic surgery faster and with fewer errors than non-videogame playing participants (Rosser, Lynch, Cuddihy, Gentile, Klonsky, & Merrel, 2007). More recent research aims to create videogame platforms to improve clinical decision making and detection skills in nurses (Petit dit Dariel, Raby, Ravaut, & Rothan-Tondeur, 2013).

Videogaming and aggression

Despite these rather isolated and/or anecdotal benefits of videogame training being transferred to real-world scenarios, certain videogaming research has indicated extensive playing can have negative effects. The effect of videogame playing on aggressive behaviour has been well researched. Most meta-analyses find a positive correlation between violent videogame playing and aggressive traits and physical arousal, while it is inversely related to pro-social behaviour (Sherry, 2001; Anderson, 2001; 2010; Polman, Orobio de Castro & van Aken, 2008). More recent research has identified "wishful identification", i.e. identification with a violent videogame character, as an important factor when increased aggression. Indeed, adolescent boys that showed the highest identification ratings were significantly more likely to administer loud (hearing damaging) noise to another individual (Konijn, Bijvank, & Bushman, 2007). This effect has also been observed in longitudinal studies and across cultures in young adults, with habitual violent videogame playing being a significant predictor of aggressive behaviour 3 to 6 months later (Anderson, Sakamoto, Gentile, Ihori, Shibuya, Yukawa, Naito, Kobayashi, 2008). Furthermore, research has observed the neural mechanisms responsible for this aggression. Habitual violent videogame players and non-violent videogame players played a violent videogame whilst undergoing functional magnetic resonance imaging (fMRI). Non-violent gamers demonstrated increased activity in regions associated with emotional response whereas violent videogame players demonstrated suppression of this area (Gentile, Swing, Anderson, & Rinker, 2016). Interestingly, the same non-violent videogame players elicited increased activity in areas associated with spatial attention, navigation and cognitive control.

Indeed the notion that violent videogames increase aggressive behaviours has been perpetuated in the media. During the aftermath of tragic school shootings such as Columbine in 1999, the perpetrators, Eric Harris and Dylan Klebold were found to play *Doom* and *Quake*, violent first person shooter games set in a future science fiction setting (“Columbine families sue computer game makers”, 2001). Seung-Hui Cho, the man responsible for killings at Virginia Tech College in 2007 regularly played *Counterstrike*, a tactical first person shooter game in a modern military setting (Benedetti, 2007). Most recently Adam Lanza, the man responsible for the Sandy Hook massacre in 2012 was found to spend hours playing violent videogames such as *Call of Duty*, a modern military first person shooter game (Swaine, 2013). These incidents are not isolated to the US. Anders Behring Breivik responsible for killing 77 people in 2011 spoke of his use of videogames as part of his training when planning the massacre in Norway, specifically *Call of Duty: Modern Warfare 2*, a military style first person shooter game (Sutter, 2012).

However, recent research has brought potential methodological issues and biases to the forefront of past aggression literature, and the theory that violent videogames cause aggressive behaviour may not be as definitive as previous meta-analyses suggest (Anderson, 2001; Sherry, 2001). A recent meta-analysis found significant publication bias for violent videogame and aggressive behaviour literature, and once this bias was corrected for the relationship between violent videogames and aggression drops to the point where the confidence interval crosses zero. Interestingly, a similar publication bias pattern appears for enhanced visuospatial attention in video game players, however this effect remains robust after being corrected, with a confidence interval that does not cross zero (Ferguson, 2007). Additional research by Markey, Markey and French (2014) sought to identify whether violent videogames could be linked to actual violent acts such as aggressive assaults and homicide as opposed to minor and benign forms of laboratory observed aggression as previously studied (e.g. Konijn, Bijvank, & Bushman, 2007). Videogame sales and crime data provided by the FBI were examined over a 33 year time period, and used longitudinal analytical techniques that took concurrent and lagged effects into account. Surprisingly, monthly videogame sales were associated with decreases in aggravated assaults, and in the months following mature content-related game releases, homicides were found to decrease, not increase. Some theorize this is a cathartic response and have found adolescent males choose violent videogames to control aggressive feelings (Olson, Kutner & Warner, 2008). As a further point, most studies on videogaming and aggression rarely take into account that violent videogames have the potential to affect specific individuals that may already be predisposed to aggressive behaviours due to mental illness or personality traits (Markey & Markey, 2010; Markey & Scherer, 2009).

In summary, the notion that violent videogames can increase aggressive behaviours and reduce pro-social behaviours is debateable. Most importantly, these studies often contain methodological issues and frequently fail to assess the longitudinal effects videogames might have on violent behaviours, the individual differences of the participants they test and their mental predispositions towards violent behaviours in the first place.

Videogames and cognitive enhancement

Despite the prominence of videogames being linked to aggression in the media, decades of research has sought to identify potential positive effects videogames may have on individuals. Psychological research has toyed with the application of videogames within different domains since shortly after their inception and entrance into the home market in the early 80s. For example, as early as 1981, researchers noted the similarities between some commercially available videogames and behavioural tests such as the compensatory tracking task (Jex, 1967) in that results between the conventional tracking task and videogame correlated so strongly it was suggested as a low-cost alternative to expensive laboratory studies (Kennedy, Bittner, & Jones, 1981). Early research indicated videogame players displayed enhanced hand-eye motor coordination (Griffith, Voloschin, Gibb, & Bailey, 1983; Gagnon, 1985) and visual tracking (Gagnon, 1985). Hand-eye coordination alongside Purdue Pegboard scores (fine motor skills), and Verbal and Performance scale scores of the Wechsler Adults Intelligence Scale (WAIS) were observed in elderly participants after two months of training on an arcade-style videogame (Drew & Walters, 1986).

Clark, Lanphear and Riddick (1987) trained older adults using *Pac-Man* and *Donkey Kong*, two games requiring fast reaction times to be successful, in order to observe potential improvements in response selection processing. Training occurred in one of two groups between pre and post-testing of the paradigm. The paradigm consisted of two spatial compatibility conditions: compatible trials, in which participants were required to lift a finger off the button when the corresponding light was activated; and incompatible trials in which participants were required to lift the opposite finger. Results indicated those trained on videogames showed reduced reaction times in incompatible trials at the post-test stage, evidence for enhanced response selection. Importantly, this study observed enhancements generalising outside of the current task, a significant occurrence that was yet to be found at the time of writing (Hoyer, Labouvie, & Baltes, 1973). Indeed, early research had predicted videogames utilise abilities not previously tested by standard Factor-Referenced Cognitive Tests (Jones, Dunlap & Bilodeau, 1986).

Videogame research in the 1990s began to diverge away from attenuating cognitive decline and improving general wellbeing in the elderly and focusing on enhanced visual and spatial skills in younger participant populations. Practice on an action videogame in school children aged 10 to 11 years old was associated with improved spatial performance, being most effective for children with initially poor spatial skills, indicating the potential to reduce individual differences (Subrahmanyam & Greenfield, 1994). A causal relationship between videogame play and strategies of dividing attention in college age students has also been identified (Greenfield, DeWinstanley, Kilpatrick, & Kaye, 1994). Initially, participants (videogame players and novices) reaction times were measured identifying targets at low and high probability locations in a divided attention paradigm. Videogame players successfully identified targets at the low probability location faster. Novices then played a videogame for just five hours, which significantly decreased their response time at the low probability location in relation to previous performance on the task and successfully closed the gap between reaction times of novice and experts. A recent resurgence of videogame studies may be attributed to the finding of a broad spectrum of cognitive enhancements in videogame players by Green and Bavelier (2003). Enhancements observed in visuospatial and visual selective attention, temporal attention, distribution of attention and attentional capacity was observed in both cross-sectional and group training designs.

Research by Green and Bavelier (2003) is cited throughout videogame literature for a number of important reasons. It was the first study to use a comprehensive battery of well-established computerised paradigms in an effort to specifically measure modulation in a particular cognitive domain – visual attention. Moreover, the study successfully utilized a combination of methodologies established by previous research (e.g. Greenfield et al., 1994), consisting of both cross-sectional studies to initially identify differences, and training studies in order to support causality. Green and Bavelier (2003) observed significant differences in flanker compatibility, enumeration, attentional blink and useful-field-of-view tasks (UFOV) between seasoned videogame players and non-players. The flanker compatibility task measures participants’ capability to inhibit distracting items that are congruent or incongruent with task goals. Enumeration requires participants to identify the number of stimuli presented in the visual field of a briefly presented display. The attentional blink paradigm measures temporal attention and requires participants to identify target stimuli displayed in rapid serial visual presentations. Finally, the UFOV, tests deployment of attention across wider peripheral visual eccentricities compared to more traditional visual searches typically presented at narrower visual angles. This was further supported by an experiment showing significant improvements across all the previously mentioned tasks in novices trained after 10 hours of action videogame play; the game in question (*Medal of Honor*) requiring the participant to move throughout a highly salient virtual environment and rapidly attend to dynamic targets to be successful.

The following paragraphs aim to introduce the reader to the broad spectrum of cognitive domains in which enhancements occur. Studies utilizing cross-sectional designs shall be reviewed before studies using training designs or a combination of both, as the latter methodological types can infer causality with more support than cross-sectional designs. This will be followed by a review of the small body of literature that has not identified significant differences between videogame players and novices before a detailed description of modulated neurological differences that have been reported between groups.

Videogames and children

Dye and Bavelier (2004) undertook a similar study to Green and Bavelier (2003) using children instead of adult participants. The study used 114 participants who were identified post-hoc as video game players or non-video game players dependant on whether they had played first person action games or ball games in the 12 months prior to testing. Video game players were significantly faster and more accurate in a visual search task, had greater flanker compatibility effects (measured using the attentional network test (ANT), enhanced performance on the Useful Field of View paradigm (UFOV) and were able to attend to more targets (ball tracking task). The results indicated that video game playing can facilitate enhanced visual cognitions in a variety of fields, and not only that attention is determined by maturational factors but displays high rates of plasticity when individuals experience high salience, high tempo visual environments such as first person action games and ball sports gaming.

Trick, Jaspers-Fayer and Sethi (2005) administered a child-friendly multiple object tracking paradigm to several age groups of young, middle and adolescent children. As to be expected, a main effect of age noted significantly improved tracking performance as children were older. However, surveys also measured videogame playing behaviours amongst participants and found abilities to track multiple objects significantly differed between videogame players (VGPs) and non-videogame players (NVGPs), with VGPs able to track larger target numbers. Despite this finding, the authors acknowledged methodological limitations regarding its cross-sectional nature and stipulate further research is required.

Li and Atkins (2004) explored the association between early computer experience and exposure with cognitive and psychomotor development in children. The researchers used surveys to discover the participant's level of exposure to computers and socioeconomic status. Several measures were used to assess the participant's visuomotor, psychomotor and cognitive abilities including the Wechsler Preschool and Primary Scale of Intelligence-Revised (WPPSI-R). Results indicated children who had access to computers outperformed those without access on measures of school readiness and cognitive development after controlling for developmental stage and socioeconomic status. However, no relationship was found between computer experience and visuomotor or gross motor skills. This result remained consistent in later studies (Colzato, van Leeuwen, Wery, van den Wildenberg, & Hommel, 2010).

The following study used a training design, involving a pre/post test design whereby children played videogames between the two sessions in order to identify causality. A full review on these types of studies appears later in this introduction.

Subrahmanyam and Greenfield (1994) used a pre-test, post-test design where participants were trained between being tested on a computerized spatial skills battery. Participants were boys and girls all in the fifth grade (between 10.5 and 11.5 years of age). Their study used two different games, an action game called *Marble Madness* where players were required to guide a marble down a path using a joystick, while trying to avoid enemies and falling off the grid. The second game used was a word game called *Conjecture*; it contained no visual spatial stimuli and involved filling in the blanks in words and other similar puzzles. Prior to training, a strong gender bias was found towards boys in both spatial performance scores and average number of hours per week spent playing video games. After training, action video game practice was found to be more beneficial than was the word game (which showed no improvement). In addition to this, it was observed that those with initially low spatial performance showed greater enhancement after training than those who had higher spatial skills spatial skills to begin with. Given the clear ethical issues of using (often violent) action video games in training studies, such a study demonstrates enhancement in spatial performance of both genders using a non-violent videogame, a notable ethical issue in the application of research to real-world scenarios.

In summary, children and young adults appear to display improvements when exposed to regular videogame playing behaviours in attention (Dye & Bavelier, 2004), visual spatial performance (Subrahmanyam & Greenfield, 1994) and executive control (Dunbar et al., 2001) but not in motor skills (Li & Atkins, 2004). One might expect such results when considering age-based plasticity theories and that children may be more susceptible to cognitive modulation due to continuing development as opposed to adults with less plastic brain structures (Webster, Ungerleider, & Bachevalier, 1991).

Cross-sectional design studies

Selective and Spatial Attention

Chrisholm, Hickey, Theeuwes & Kingstone (2010) aimed to investigate further the differences in exogenous (reflexive, bottom-up attention) and endogenous attention (goal directed, top-down attention) between action VGPs and NVGPs. The authors used an attentional capture task in which participants were required to identify the orientation of a line within single target arrays and in the presence of a salient irrelevant distractor. VGPs were quicker to respond in both array types with no significant accuracy trade-off, and also showed a reduced capture effect of the irrelevant salient distractor compared to NVGPs. This reduced capture effect (illustrated by faster response times to the target) was indicative of better endogenous control, whereas increased attentional capture (slower response times) would have supported increased sensitivity to salience (exogenous attention). The authors postulated two different strategies to explain these findings. The first, VGPs have improved inhibition due to increased attentional resources as supported by Green and Bavelier (2006a). The second theory is that VGPs have better recovery from attentional capture, this is consistent with endogenous attention literature, supported by Green and Bavelier (2003, 2006a) and mirrors well the commonly used aspect of videogame play in which players are required to assess target relevance and reorient attention rapidly. This theory indicates that VGPs may have enhanced 'top-down' attentional control which in turn may modulate the more negative aspects of 'bottom-up' attentional capture.

Clark, Fleck and Mitroff (2011) aimed to explore whether top-down strategies are at least partially responsible for VGPs improved abilities. The experiment involved VGPs and NVGPs selected covertly via questionnaire (i.e. VGPs and NVGPs were unaware of the true, videogame related purpose of the study), and these individuals were then tasked with undergoing a 'flicker' paradigm. This paradigm involves constant switching between an image and its modified version counterpart, with a frame of visual noise intervening between the two. Participants are required to identify if the pictures are the same or different, and in this case using the computer mouse to select in which quadrant the picture differs followed by stating whether this selection was a guess or not. VGPs required significantly fewer cycles of the two images to correctly identify differences between the two. VGPs also clicked further distances from previous clicks whilst having the same number of ‘guess’ trials as NVGPs, indicating broader search patterns than NVGPs at reduced exposure to the stimuli. The authors propose these findings are indicative of a top-down broader search strategy as opposed to being able to process more visual details from a single fixation (bottom-up).

The second experiment conducted by (West, Stevens, Pun & Pratt, 2008) used a signal detection model to measure VGP and NVGP target detection ability amongst background noise, for example abrupt changes in motion. The current paradigm used a dynamic display of moving stimuli representing swimmers. Stimuli were presented in circles at 10, 20 and 30 degree eccentricities. Participants were required to identify abnormal swimming motion amongst a background of ‘normal’ swimming motion. The current paradigm also used high and low load conditions, consisting of 30 and 15 swimmers respectively. VGPs significantly showed increased signal sensitivity over NVGPs at all eccentricities bar 10 degrees in the low load condition, and 30 degrees of visual angle in the high load condition indicating modulation to selective attention does not just occur in foveal and parafoveal vision.

Additional research extending visual cognition measures into the periphery by Dye and Bavelier (2010) observed differential development of visual attention skills in school age children. The authors used children aged 7-17 years of age and adults 18-22 years of age. Visual selective attention was tested using the UFOV paradigm, alongside a temporal attention paradigm (attentional blink) and multiple object tracking tests. The authors noted that spatial, temporal and object tracking aspects of attention develop at different rates indicating different neural mechanisms behind each component. Once testing was completed, participants were surveyed as to the number of hours of video games they played per week. Participants who played action video games significantly outperformed those that did not on all aspects of attention tested. The researchers make two very good points for further research, the first being the importance of understanding that the majority of action video games are marketed to males whom already seem to have some (debatable see, Voyer, Voyer, & Bryden, 1995) advantages in visuo-spatial attention; secondly, the ethical issue of finding a suitable action game (not graphically violent) for children when undergoing ‘training’ designed studies.

Further research by Dye, Green and Bavelier (2009) aimed to characterize the plastic changes in video game players with ages ranging from 7 to 22 years of age, and also indicates differences in parietal attentional networks. Participants were split into two groups, VGPs and NVGPs by using a questionnaire prior to the experiment beginning. All participants were administered a child friendly version of the Attentional Network Test (ANT) that measures selection, orienting and executive control. As found with past research, video game players were found to have significantly faster reaction times with no decrease in accuracy. In addition to this, video game players showed increased flanker compatibility effects, indicating additional available attentional resources. It is this shift in ability to orientate that indicates potential between-group differences in fronto-parietal networks (Corbetta & Shylman, 1998). No effect of age was found on cognitive enhancements after baseline reaction times were controlled. The researchers note two main issues, the first being that ANT only measures one specific area of visual cognition, specifically endogenous attention as cues are always valid and stimuli remain on screen until a response is made. Secondly, for video game playing to be shown to be causally responsible for cognitive enhancement requires a training-type study.

In summary, cross-sectional designs appear to be powerful in identifying differences in selective attention between VGPs and NVGPs. VGPs appear to possess greater attentional resources across a wide visual angle in comparison to their non-videogame playing counterparts. Not only does this appear to be evident in faster response times, but in attentional resources spilling over and capturing nearby distracting stimuli. Despite this theory of attentional spill-over (bottom up), VGPs (under certain circumstances) may have greater attentional control and show enhancements in inhibiting the processing of distracting items (top down).

Temporal Attention

Research investigating the effects of videogame experience on attentional capture found VGPs displayed greater sensitivity to exogenous events in visual space (West, Stevens, Pun & Pratt, 2008). The first experiment reported by Stevens et al., (2008) used a visual temporal order judgement (TOJ) paradigm requiring participants to identify which of two stimuli were presented first. This experiment implemented a peripheral pre-cue to one of two locations in order to investigate differences between VGP and NVGP's ability to capture exogenous peripheral cues. Typically, stimuli that are attended due to visual pre-cuing are perceived as earlier than the unattended stimuli – a phenomenon known as 'visual prior entry'. This occurs due to accelerated processing of sensory stimuli, thus decreasing the time between physical onset of a stimulus and its further entry into conscious awareness. This phenomenon is measured by calculating the *point of subjective simultaneity*

(PSS), which is the amount of time the uncued stimulus must precede the cued stimulus both to be perceived as occurring simultaneously. Overall, VGPs had significantly greater PSS scores, indicating VGPs display greater degrees of attentional capture.

Both experiments by West et al., (2008) (including the experiment mentioned in the above section) suggest experience with videogames modulates sensory abilities at the level of attentional capture. However without a training study, population bias cannot be ruled out. Despite this, as neither paradigm focused on reaction times, enhanced motor control does not appear to be responsible for the observed results. The authors note that habitual players could experience changes in subcortical striatal dopaminergic systems and cortical posterior parietal attentional networks. Such systems have been implicated in error monitoring (Schultz, Dayan, & Montague, 1997), and responses to unpredicted salient events (Jensen, McIntosh, Crawley, Mikulis, Remington, & Kapur, 2003). Additionally, the posterior parietal attentional network, a group of structures including the posterior parietal lobe, lateral pulvinar nucleus, dorsal frontal cortex and superior colliculus have been thought responsible for shifting and engaging in involuntary and voluntary attention (Hopfinger, Buoncore, & Mangun, 2000; Posner &Peterson, 1989). Further recruited structures such as limbic structures during orientation to salient stimuli (Downar, Crawley, Mikulis, & Davis, 2002) may also be responsible for modulation through long term action video game play. Such further investigation requires the use of neuroimaging equipment; such studies will be reviewed later in the thesis introduction and experimental chapters.

Temporal order judgement in multiple modalities (visual and auditory) was further investigated by Donohue, Woldorff and Mitroff (2010). Two experiments investigated whether VGP's ability to judge the simultaneity of multi-sensory information and temporal order of multi-sensory information differed to that of NVGPs. Results indicated VGPs showed significantly higher accuracy across both tasks, indicating videogame playing experience not only enhances various cognitive abilities in the visual modality but to multi-sensory stimuli also. Indeed, complex action videogames often utilize auditory stimuli and cues to provide the player with information, whether footsteps of enemy players or distant gunfire. A very important note is that Donohue et al., (2010) appear to be the first authors to incorporate a covert recruitment design, as participants completed their videogame questionnaire post-experiment, removing any potential demand characteristics that may arise during overt recruitment.

In summary, the playing of videogames may induce modulation in temporal attention such that VGPs are sensitive in multiple modalities to the synchrony of stimulus onsets.

Response Mappings

Castel, Pratt and Drummond (2005) investigated the difference in the time course of inhibition of return (IOR) and the efficiency of visual search between videogame players and non-videogame players. IOR is the slowing of response times to a location that has been attended more than 300ms earlier (Posner & Cohen, 1984), and is interpreted as a bias of visuomotor resources away from previously inspected spatial locations. The study aimed to investigate the specific mechanisms responsible for IOR and visual search; and whether they differ between VGPs and NVGPs. A standard IOR paradigm was used which typically shows facilitated target detection at shorter SOAs for cued locations, the effect reversing, facilitating the uncued location at longer SOAs (>200 ms). Experimenters were interested to note any difference in times of onset or magnitude of IOR between VGPs and NVGPs. Both groups showed a similar magnitude of IOR effect and similar timings, the only significant difference being VGPs displayed faster reaction times than NVGPs indicating they are faster at detecting and responding to stimuli in the visual environment. The authors criticised this first experiment for being too simple as the target stimulus could be presented in one of only two positions. The second experiment used a visual search task with two different difficulties. The easy condition involved searching for a letter amongst an array of the same distractor letter, whereas the difficult condition used different letters as distractors. The position of the target stimuli was random. The results indicated that playing action games results in faster response times to targets in the visual environment. As no evidence was found indicating different search strategies of VGPs relative to NVGPs during IOR, any difference in response time is most likely to be attributed to faster stimulus response mappings. Although the enhanced stimulus-response mappings of the IOR task would translate and continue to be beneficial throughout the non-cued 'free-viewing' nature of the visual search, it cannot be ruled out that processes such as enhanced executive control mechanisms and control of attentional resources, as posited by Green and Bavelier (2003), may be present.

Task Switching and Executive control

Colzato, van Leeuwen, van den Wildenberg & Hommel (2010) investigated the differences in cognitive flexibility between VGPs and NVGPs using a task-switching paradigm. Participants were tasked to identify whether a shape made up of smaller shapes was rectangular or square or to identify the smaller shape (square or rectangle) that made up the larger shapes depending on the goal that was cued on each trial. The participant would be cued prior to each trial as to identify the larger (global) shape (square or rectangle), or the smaller (local) shapes (squares or rectangles). No significant difference in reaction times or accuracy was observed, and thus performance of VGPs and NVGPs are arguably comparable overall. However, VGPs had significantly better performance on switch trials (trials which switched between global and local identification) than NVGPs, thus displaying reduced switch-costs. The absence of interactions between group and congruency, and group and precedence indicates no improved visual attention in VGPs. This led the authors to suggest that some earlier literature (e.g. West, Stevens, Pun & Pratt, 2008) may have found ‘low-level’ improvements which were actually due to enhanced executive control functions.

In summary, cross-sectional designs give us a good indication of what may be possible with videogame playing and subsequent cognitive modulation. Differences in both bottom-up (exogenous) and top-down attention (endogenous) were observed by Chrisholm et al., (2010). These differences remained fairly consistent and were observed by others (Clark et al., 2011) but not all (Castel et al., 2005) who put differences down to enhanced stimulus-response mappings. VGPs also displayed enhanced temporal attention, not only in the visual domain but in multiple modalities (West et al., 2008; Donohue et al., 2010). Differences outside of attention were also observed by Colzato et al. (2010), who noted VGPs were able to switch between two tasks easier than their non-videogame playing counterparts. Although important to note that little information was gathered on the software types children used (Dye & Bavelier, 2010), it is equally important to note that not all cross-sectional studies completely support the notion that videogame playing enhances cognitive functions such as visual attention. Through the use of EEG, I seek to determine which of the two possibilities is correct, that is whether videogames cause attentional modulation (Chrisholm et al., 2010) or these alterations are simply due to enhanced stimulus-response mappings (Castel et al., 2005).

Training studies

Spatial Attention

Despite predominantly consistent findings amongst cross-sectional studies, such methodology suffers from several problems including selection biases and an inability to assess causality. More time consuming ‘training studies’ employing a pre/post test design whereby NVGPs trained themselves using videogames between testing sessions have been used to address these methodological concerns. An early example of such a training study by Okagaki and Frensch (1994) observed effects of video game playing on spatial attention, focusing on late adolescence and gender differences. This experiment used a pre-test, post-test design where participants were given paper and pencil measures of spatial ability, and computerized measures of mental rotation and visualization skills. Participants in the experimental group completed these tests both before and after playing six hours of the game *Tetris,* whereas the control group refrained from videogame play between the pre and post testing phases. Subsequent to six hours of play, mental rotation time and visualization time decreased for both males and females (these improvements were in similar amounts). However, one might not be surprised at such findings due to very similar skills being utilized in both Tetris and the measures used, not fully demonstrating the transferability of skills that previous studies have done.

Research by Green and Bavelier (2006b) observed the effect of action videogames on the spatial distribution of visual attention by manipulating perceptual load and salient flanking distractors varying in compatibility (as used in Green & Bavelier, 2003). The Load Theory of Attention and Cognitive Control (Lavie, 2005) posits that attentional distribution is automatic (although not distributed in the same manner in all people) and resources left over during a low perceptual load trial will ‘spill over’ leading to compatibility effects. Tasks with higher perceptual loads will have little or no remaining attentional resources remaining to process extraneous distractors, showing little or no distractor effects. Results of such a paradigm found clear compatibility effects for VGPs under high perceptual load conditions where NVGPs did not, reflecting an increased amount of attentional resources in VGP populations. Previous literature have noted a bias for central vision, with compatibility effects in central vision decreasing less sharply than peripheral distractors, indicating greater attentional resources in central vision (Beck & Lavie, 2005). An interaction between videogame playing groups, compatibility effects and perceptual load suggests enhanced attentional capacities in VGPs are not limited to the periphery but are present in central vision also (VGPs continued to process distractors at the highest load regardless of distractor positioning).

The second of Green and Bavelier’s experiments used the UFOV paradigm, measuring the ability to locate targets as a function of eccentricity in addition to distracting elements and an added central task. The UFOV paradigm allows VGP’s attention to be tested at the centre, border and beyond the field of view videogames are typically played. VGPs displayed enhanced attention through improved target localization under all conditions tested in comparison to NVGPs. VGPs were able to detect changes in the visual field with a stimulus display time of <15ms and maintained this ability in distractor-present trials reflecting a greater ability to select targets among distracting stimuli. VGPs displayed near perfect accuracy during this task, suggesting the load of both tasks did not reach VGP limit for dual-task performance. NVGPs performed worse than VGPs indicating a lower dual-task performance limit. The final study of the research used a Pre/Post test training design in order to identify videogame playing as the causal factor in enhanced visual selective attention. Participants completed four conditions of the UFOV task from experiment 2 before and after 30 hours of videogame training on a fast paced first person shooter action game (*Unreal Tournament 2004*) or a single item-focused game strongly dependent on visuomotor control (*Tetris*). Action videogame players improved more than did the control game players at the UFOV, thus indicating improvements cannot be attributed to practice effects or videogame training facilitating visuomotor control alone. Furthermore, the action VGPs improved at all eccentricities, including 30 degrees, suggesting videogame training effects generalize to untrained locations in the visual environment. Improvement at peripheral locations even in the presence of a central task indicates not only enhancements in the periphery, but that any enhancements are not detrimental to central attention.

Green and Bavelier (2007) demonstrated how action videogame experience can alter spatial resolution. The authors tested the ‘crowding phenomenon’ which refers to a substantial increase in difficulty when attempting to identify a target object with distracting objects in its immediate vicinity. Typically participant performance decreases when both the number of distractors increases and when the distance between targets and distractors are reduced (Leat, Li & Epp, 1999). Several theoretical explanations have been postulated to explain this phenomenon, most notable of which proposes that the crowding region can offer a measure of the resolution of visual attention (Intriligator & Cavanagh, 2001). Experiment 1 investigated differences between VGPs and NVGPs using a crowding paradigm requiring participants to discriminate between up-side down and right-side up T-Shapes at varying eccentricities in the visual field flanked by distractors. VGPs displayed smaller crowding regions than NVGPs; this effect did not interact with eccentricity, indicating similar levels of improvement across all eccentricities, including eccentricities outside of normal videogame playing behaviour, displaying a transfer of learning across visual eccentricities. Higher performance at more central eccentricities was regarded as surprising as foveal vision is believed to be near optimal (Neville & Bavelier, 2002). Results also indicated VGPs have better visual acuity thresholds than NVGPs.

Experiment 2 used a Pre/Post-test training design using identical apparatus and paradigm to experiment 1 to observe a causal role of action videogame play. An experimental group played 30 hours of Unreal Tournament 2004 whereas the control group played Tetris for the same time. Tetris was believed to be heavily dependent on visuomotor control, thus the control group was used to control for test-retest effects, improved visuomotor effects and the Hawthorne effect (enhanced performance due to experimenters “paying attention” to them). Results of experiment 2 confirmed the causal role of action videogame play; participants trained using the action game showed reduced crowding thresholds from Pre to Post-test sessions with no interaction of eccentricity, indicating training had similar effects across all eccentricities. In conclusion, as VGPs could tolerate smaller spacing between target and distractors. This may very well be a result of action videogame training, and these results transfer to areas outside of the standard visual field of typical videogame experience.

Feng, Spence and Pratt (2007) investigated attentional processes which are likely to contribute to gender differences of spatial cognition. Functional imaging research has linked higher level abilities such as mental rotation with the posterior parietal cortex (Cohen et al., 1996) which is also activated during other attentional tasks (Behrman, Geng & Shomstein, 2004). Baenninger and Newcombe (1989) note the importance of recreational activities as a major cause of gender differences in adult cognition. As such the authors noted that boys have always played different games to girls, and that first person shooter action games are appealing to boys but not to the opposite sex (Quaiser-Pohl, Geiser & Lehmann, 2006). The first experiment used the Useful Field of View (UFOV) paradigm and attempted to understand gender differences in spatial attention. VGPs made more correct responses than NVGPs, as males did when compared to females. The second experiment aimed to modify or eliminate the difference observed in experiment one through the use of videogames. Participants completed the UFOV and a mental rotation task (MRT) in a Pre/Post Test design separated by 10 hours of videogame training. The experimental group trained using a first person action game, the control group trained on a 3D puzzle game. Participants in the experimental group improved substantially on the UFOV whereas no significant difference was observed Pre/Post Test in the control group. Females in the experimental group showed greater improvements than the males and reduced the gender gap greatly. Similarly, both males and females in the experimental group improved on the MRT while again, no significant difference between Pre/Post Test was found in the control group. Likewise, the improvement observed in the experimental group was larger for females than males, resulting in means equal to the males of the control group. Interestingly, not only do videogames appear to improve spatial attentional capacity, but also spatial function may be improved simultaneously. Longitudinal testing indicated these changes in performance between pre and post testing lasted four months after the original experiment had concluded.

Additional research by Spence, Feng, Yu and Marshman (2009) used a matched pair, two wave longitudinal design to identify whether any differing rates in learning a spatial skill existed between males and females. All participants were screened prior to the experiment beginning using an attentional visual field task (similar to UFOV), which allowed for female and male matched pairs to be created. After 10 hours of videogame training, both males and females in their respective pairs appeared to improve equally. Retesting an average of 4 months later also indicated these improvements had persisted in accordance with results obtained by Feng et al. (2007). This study not only supports theories that males and females acquire spatial skills at the same rate, but that they persist equally over time.

In summary, relatively short periods of videogame training may be responsible for improved performance over several tasks requiring visuospatial attention. Perhaps unsurprisingly, videogames similar to the experimental task (i.e. Tetris and mental rotation tasks) appear to provide improved performance on the task at hand. On the other hand, commercially available videogames that require consistent and varied cognitive demands appear to increase and/or make the deployment of attentional resources more efficient (Green & Bavelier, 2006b), including in the periphery (Green & Bavelier, 2006b, 2007; Feng et al., 2007; Spence et al., 2009), and also reduce the crowding phenomenon found in the visual periphery (Green & Bavelier, 2007).

Attention and Memory

In 2006, Green and Bavelier (2006a) published a series of experiments to identify differences between VGP's and NGP's ability to rapidly apprehend items displayed in the visual field. The first three experiments used an enumeration paradigm to assess differences in parallel and serial apprehension of information, believed to be a bilinear function. Past enumeration research has noted an 'elbow' discontinuity, believed to reflect a switch from subitizing to serial (counting) apprehension. The initial experiment used a standard enumeration task with two conditions, a central field of view and wide field of view. VGPs were found to enumerate more accurately than NVGPs by approximately two items before the accuracy breakpoint was reached. No effect of field of view visual angle was found at low numerosities, although increased errors, underestimation and faster reaction times were associated with increasing number of squares in the wide field of view condition.

The first experiment used a cross-sectional design, and thus to assess causality, experiment 2 used a pre/post test training design. Participants in the experimental group played 10 hours of a first person action game, Medal of Honour: Allied Assault, a game requiring heavy use of visual selective attention across a wide field of view. A control group trained for an equal amount of time on Tetris, a game requiring visuo-motor control and attentional focus on a single item. Participants in the experimental condition displayed a shift in accuracy breakpoint, enhanced estimation and greater accuracy whereas those in the control condition showed little modulation in performance. No gender effects were noted, indicating consequences of playing action video games are not sex specific.

Experiment 3 used the same design as experiment 1, using participants placed into groups dependent on self-report criteria. This experiment employed backward masking between trials to reduce the effect of after-images and participants gave vocal responses, eliminating variables associated with faster visuomotor control, and so giving a better indication of reaction time. Differences in accuracy breakpoints between the two groups despite similar reaction time breakpoints indicate VGPs can successfully access more items in visual short term memory when NVGPs fail to do so and that videogame playing does not necessarily improve the ability to subitize, but improves serial apprehension (counting). Experiment 4 used a Multiple Object Tracking (MOT) paradigm to measure the number of items that videogame players can simultaneously track in comparison to NVGPs. Results indicate VGPs and NVGPs show the same performance attributes for low numbers of times, with differences becoming apparent only after a critical threshold is exceeded, where VGPs begin to outperform NVGPs. Similar to experiment 2, experiment 5 used a Pre/Post test design to identify a causative effect of videogame playing responsible for the observed results in experiment 4. This time, participants completed 30 hours of training, on either Unreal Tournament 2004 (first person action game) or Tetris. Using the same experimental paradigm as experiment 4, participants trained on an action video game showed improved performance whilst control participants' (who played Tetris) performance remained consistent between pre and post-testing, indicating little videogame playing experience is required to improve multiple object tracking skills.

Training studies and the real-world

Abnormal visual experiences in early development can cause various abnormal visual functions including Amblyopia, more commonly known as 'lazy eye' syndrome. Li, Ngo, Nguyen and Levi (2011) observed the capacity for video games to induce plasticity in patients suffering from Amblyopia. Participants played an action video game, a non-action video game or no videogame (control) and underwent normal 'eye patching' therapy. Two hours a day of gameplay with both action and non-action games was sufficient to induce substantial improvements over a wide range of fundamental visual functions including visual acuity, positional acuity, spatial attention and stereopsis. Positional noise was used to identify the neural mechanisms underlying these enhancements, indicating increased sampling efficiency and recalibrated distributed retinal topographical maps of Amblyopic visual fields.

In summary, training studies have provided substantial evidence that videogame playing improves both spatial and selective attention. Importantly, this methodology allows us to make a causal link between videogames and performance as opposed to cross-sectional designs. Not only did videogames enhance spatial attention in the form of more efficient attentional allocation to visual space (Green & Bavelier 2006b), but altered the spatial resolution of vision. Post training, individuals also displayed improved enumeration capabilities, although this may reflect enhanced attention and processing as opposed to any differences in working memory capacity (Green & Bavelier, 2006a). Differences in multiple object tracking were also observed, indicating not only enhanced attention but perhaps more efficient strategy usage/executive control in the form of attentional allocation (Feng et al., 2007). One of the most important factors in this study is that differences were found to persist up to four months after the experiment, providing some evidence of the permanence of videogame effects (Feng et al., 2009).

Null effect research

Despite predominantly consistent findings of differences between VGPs and NVGPs in visual cognition, some studies have noted no differences on paradigms where differences have been found previously (Boot, Kramer, Simons, Fabiani & Gratton, 2008). An extensive cognitive battery of tests was used in a combined cross-sectional and training designed study in order to identify whether videogame playing experience modulates cognitive abilities, including attention but also further afield. Expert videogame players displayed significantly superior memory storage, multiple object tracking and task switching capabilities. Interestingly, no significant improvements were observed in the functional field of view task (UFOV), attentional blink and enumeration tasks, paradigms that have previously observed between group differences (e.g. Green & Bavelier, 2003, 2006b, Feng et al., 2007). Boot et al., (2008) noted that videogame players may alter learned strategies as much as enhance low-level cognitive abilities, and these strategic alterations change the ways which gamers complete tasks. With constantly changing objectives in high tempo, highly salient visual environments in modern videogames, improved strategies centred on dynamically shifting visual attention may prove incredibly important, although difficult to test. Despite the potential importance of learning and altered strategy use, mixed results are indicative that research has yet to robustly identify which factors may or may not modulate cognitive abilities.

Irons, Remington and MacLean (2011) also failed to replicate previously established results when comparing VGP and NVGP performance on an Eriksen Flanker Task. Results indicated no significant differences in compatibility effects between groups including during a second experiment when flanker proximity was varied. Research previously discussed by Castel et al., (2005) failed to observe significant between-group differences in search strategy, although differences in response time were observed and attributed to stimulus response mappings. Between group differences in attentional distribution, capacity and processing ability were not observed during a cross-sectional study by Murphy and Spencer (2009). A recent training study using a perceptual discrimination task to measure information processing speed found no significant between group differences between individuals trained on action games, cognitive games and no games for a total of 10 hours over 4 separate sessions (van Ravenzwaajj, Boekel, Forstmann, Ratcliff, & Wagenmakers, 2014).

More recent research by Walter Boot and colleagues discuss common methodological flaws in the current literature, and conclude that although the overwhelming majority of studies suggest transferability of skills from video games to attention and other cognition, methodological flaws may be, at least in part, responsible for these findings (Boot, Blakely, & Simons, 2011). The authors note overt recruitment appears prominent in the current body of literature, actively seeking out experts and novices alike, thus potentially leading to differential demand characteristics between the two groups. Prior to this thesis, only two published studies (Donohue et al., 2010; Clark et al., 2011) had utilized covert recruitment to overcome this methodological issue and these successfully observed group differences favouring VGPs in temporal attention and change detection. Boot et al., (2011) maintains a point made previously: that to causally infer that videogames enhance cognitive abilities, specific experimental designs must be adhered to, specifically that of the training design. Despite this, problems may still arise from the type of training intervention used; differential demand characteristics (labelled by Boot et al., 2011, as ‘placebo effects’, expectations may differ depending on whether an improvement is likely) stemming from different types of intervention may affect task performance (e.g. participants trained using fast paced video game play, may display expect enhanced performance on a fast paced visual search, but on a task requiring the recruitment of other cognitive domains such as mental rotation, no improvement is likely to be observed). Another problem yet to be addressed by the current body of literature is a lack of testing the perceived similarities between training interventions and tasks used to test changes in various cognitive functions.

When studies have controlled some of the methodological issues identified by Boot et al. (2008; 2011), they have failed to replicate a number of previous findings. No differences found in enumeration tasks and frequently used paradigms such as the UFOV provides an interesting predicament in videogame literature. Studies finding no significant differences in processing speed (van Ravenzwaajj et al., 2014) directly contradict meta-analyses (of studies using overt recruitment techniques) overwhelmingly indicating videogames do increase processing speed (Dye et al., 2009). Such disparity in results provides a platform for the usage of neuroimaging studies in order to test underlying brain network alterations that behavioural studies are unable to isolate.

Neuroimaging studies

Neuroimaging techniques provide the current body of literature with a methodology capable of addressing many of the issues described by Boot et al. (2011). Although no studies (at the time of writing) have yet utilised covert recruitment to avoid demand characteristics and placebo effects, neuroimaging techniques afford experimenters the ability to identify cortical areas in the processing stream, potential differences in strategy usage via differences in neural network recruitment, and identify how networks are modulated after training. Early research investigating the underlying neural mechanisms of video game players observed reduced regional glucose metabolic rate using positron emission tomography in a pre/post test of participants performing both visuospatial and motor tasks. Participants underwent training daily on Tetris and displayed reduced glucose metabolic rates (GMR) despite significant performance increases (Haier, Siegel, MacLachlan, Soderling, Lottenberg, & Buchsbaum, 1992). The authors suggest this modulation in GMR may reflect modulation of learning strategy.

A study by Koepp et al. (1998) examined striatal dopamine release in videogame players. Participants were scanned using positron emission tomography (PET) before (baseline) and during videogame play. Participants were required to guide a tank through a visual environment whilst destroying other tanks and maintaining their life points. The binding of C-labelled raclopride to dopamine receptors was measured in the ventral and dorsal striate and the cerebellum. Significant reductions of raclopride binding in the striatum were found to positively correlate with improved performance during the task; this may be indicative of greater dopaminergic transmission and binding to receptors. Indeed, the dopaminergic system in the dorsal striatum has been associated with sensorimotor co-ordination and developing motor responses for difficult tasks (Robbins & Everitt, 1992).

Nagamitsu, Nagano, Yamashita, Takashima, and Matsuishi (2006) used near-infrared spectroscopy (NIRS) that emits a light which reflection is inversely related to the concentration of non-oxygenated haemoglobin in brain tissue. This allows for measuring of haemoglobin in response to neural activation as a function of regional cerebral blood volume. Six children and six adults took part in the experiment, two of the children were already habitual videogame players, and all other participants had little or no videogame experience. Participants played 15 seconds of the Gameboy game *Donkey Kong*, followed by a 15 second relaxation period. This sequence was preceded by a 10 second pre-scan period and in total, the sequence was repeated nine times for each participant. The patterns of deoxygenated haemoglobin change varied greatly among all subjects. Children’s total haemoglobin and oxygenated haemoglobin were far lower than adult concentrations in pre-frontal areas. Videogame playing induced increased bilateral pre-frontal haemoglobin oxygenation in adults and significant decreases in the same area of children. Two possible explanations for the observed results indicate a potential influence of game performance, interest and attention devoted to the task, however the task period was very short in-order to maintain attention and interest levels. A second, more likely explanation is due to differences in age-dependant utilization of different neural circuits during the task, affecting prefrontal cerebral blood volume.

Bavelier, Achtman, Mani and Föcker (2011) used brain imaging to elucidate the underlying neural mechanisms of alterations in allocation of attentional resources and efficiency of resource distribution when comparing VGPs to NVGPs. This research used a visual search task of high and low difficulty with central and peripheral distractors. In addition to this, the distractors that were present either moved or stayed stationary. fMRI scans indicated that moving distractors elicited less activation in the motion sensitive cortex in gamers than in non-gamers. Fronto-parietal areas associated with top down processing of allocation of attentional resources showed greater activation in NVGPs as task difficulty increased, however this network was barely engaged in VGPs. The current study is a good example of using varied task difficulties to elicit a range of responses from both VGPs and NVGPs.

In summary, neuroimaging studies have demonstrated significant differences between groups. The combined results of increased dopaminergic secretion and uptake (Koepp et al., 1998), differential BOLD signals in the prefrontal cortex and motor areas (Nagamitsu et al., 2006) and reduced activation in the motion sensitive cortex in gamers when displaying dynamic distractors (Bavelier, et al., 2011) all indicate VGP brains work differently; whether this is by utilizing different strategies, enhanced neurotransmitter systems or reducing unnecessary activity. Despite this, the use of PET and fMRI do not provide the temporal resolution of electroencephalography (EEG), an imaging technique more apt at capturing differences in processing speed if these differences do indeed exist.

Electrophysiology

Mishra, Zinni, Bavelier and Hillyard (2011) used Steady State Visual Evoked Potentials (SSVEPs) recordings while participants completed an attentionally demanding task involving rapid stimuli presentation sequences presented in visual locations. Consistent with previous studies, VGPs outperformed NVGPs players in both reaction time scores and accuracy. VGPs elicited increased suppression of SSVEPs associated with irrelevant peripheral presentation sequences when compared to NVGPs, whereas SSVEPs of attended stimuli remained comparable between groups. Differences in SSVEPs alongside increased amplitude of the P300 potential in VGPs associated with target stimuli are indicative of video game players’ superiority in target acquisition, at least partially attributable to their ability to suppress the cortical processing of irrelevant stimuli.

Additional research by Wu, Cheng, Feng, D’Angelo, Alain & Spence (2012) provides support of brain plasticity caused by videogame playing. Whereas Mishra et al., (2011) used seasoned VGPs, this study provided evidence of brain plasticity after only 10 hours of videogame playing. Participants underwent EEG recordings during completion of an attentional visual field paradigm (similar to the UFOV) before and after 10 hours of videogame practice. High performing videogame players showed both behavioural improvement and modulated neural correlates of spatial selective attention; P300 amplitude, in this case, thought to correlate with enhancements in attentional resource allocation (Luck, Woodman, & Vogel, 2000). The study noted no significant differences between groups for neurological waveforms earlier than the P300, and therefore postulated videogame playing improved top-down attentional allocation as opposed to earlier bottom up processes. Wu et al., (2012) also observed increased early selective attention correlates such as the P2 amplitude in videogamers that possessed improved performance on the attentional visual field paradigm. The authors felt this reflected modulation of attention to the task demands, and perhaps sensitivity to the saliency of the target stimulus.

EEG experiments have been successful in observing differences in the processing of visual stimuli in VGPs and NVGPs. Thus far, EEG research has focused on later top-down attentional processes, and has observed significant differences in the P3 and P2 components responsible for attentional allocation and target identification. The present thesis will aim to utilise EEG methodology for the purpose of measuring differences across the entire processing stream, including these later attentional ERPs observed already.

Summary

The following experimental chapters aim to address a number of questions in the current literature. Firstly, to provide ERP measures for the full duration of the attentional processing stream, to identify if habitual videogame playing (i.e. high levels of exposure to visually salient and high tempo visual stimuli) does cause cognitive modulation, and where in the processing stream this modulation might occur. Also, whether any identifiable cognitive modulation between videogame players and non-videogame players are also partnered with observable behavioural differences – the primary measure of previous literature. In addition to identifying whether videogame playing causes cognitive modulation, the following experimental chapters will attempt to remedy some methodological issues described by Boot et al. (2008), most specifically through the employment of covert recruitment techniques in order to control for demand characteristics that may be prevalent in the current literature.

Chapter 2. Attentional Resources and Control

The initial experimental chapter in this thesis aims to repeat and extend upon the perceptual load paradigm used by Green and Bavelier (2003).The paradigm manipulates cognitive load on a central task while simultaneously presenting highly salient distractors. Importantly, when videogames were assessed using this task, they were found to elicit strong compatibility effects (that is, they processed the distractor item at multiple eccentricities) at the highest cognitive load when attentional resources would usually be exhausted indicating VGPs possessed greater attentional resources than NVGPs. The following chapter repeats this study while extending distracting items further into the periphery in order to both assess the role of selective attention in the processing stream (specifically relating to distractor inhibition) and identify how far into the periphery videogame players attentional modulation may occur.

Perceptual Load paradigms first became popular when used by Lavie (1995) in an effort to resolve the early versus late selective attention debate. In the late 1950's Broadbent (1958) postulated an attentional theory dubbed 'Filter Theory', an idea stemming from previous auditory work suggesting that external sensory information is filtered in the very early stages of information processing, and only part of it is selected for further processing. Broadbent (1958) touched upon the differences in bottom-up and top-down processing when describing how task instructions initially drive the participant however these internal filters have their own biases towards certain stimuli. Specifically, with regards to vigilance tasks, this bias is likely to occur after constant stimulation from a single source/type of information. Filter theory is based on the notion that we have a limited capacity of information we can take in, and a limited number of channels to do this with. Although rare and different stimuli should activate channels not previously activated (and therefore biased towards), these rare signals, alongside the constant information stream may saturate capacity and cause brief moments in which attention is shifted away from the task. In addition to this, other non-task relevant stimuli may also yield irrelevant information up-take and further create saturated channels causing gaps in focused attention on the task.

Through a series of dichotic listening experiments, Treisman and Geffen (1967) proposed minor alterations to 'Filter Theory' as proposed by Broadbent (1958). These studies, and that by Lawson (1966), note the importance of information load in that performance vary greatly between identification of words and low level signals such a pips and tones. The largest difference is that where Broadbent theorizes complete elimination of the irrelevant stream, it is more likely to be attenuated. Treisman et al. (1967) argued this point from an evolutionary perspective, suggesting there would be a selection pressure for attentional mechanisms that retain some sensitivity to unattended stimuli, as these signals might indicate a threat to the organism's survival. More importantly, empirical observations of shadowing tasks showed that unattended streams could be recalled on occasion, a finding incompatible with the notion that unattended information is filtered out early on. In summary, this argument of early selection consists of filter channels that either allow or attenuate external information from reaching the perceptual stage, and the efficacy of these filter channels are heavily dependent on the information required to be processed.

Deutch and Deutch (1963) discuss challenges to Broadbent’s Filter theory (1958), specifically in its poor explanation where complex discriminations are required between two objects (Moray, 1959; Howarth & Ellis, 1961) and of findings that appear to show attending to multiple streams of information is possible (Peters, 1954). They postulate that rather than a single signal being picked based on a simple discrimination and the remainder being filtered (Broadbent, 1958), multiple signals are instead processed and weighted or prioritized based on task relevance. The signal(s) that reach the required level to be processed further then move onto memory storage, motor output, etc. Deutch and Deutch (1963) discuss the ability of this theory to explain lesser weighted signals ‘breaking in’ for further processing if their importance is raised, giving late selection theory (where all information is processed to a further stage before being selected) a more dynamic basis than filter theory.

Over the past decade, researchers have commonly observed that videogame players (VGPs) display enhanced visual attention in a variety of tasks when compared to non-videogame players (Green & Bavelier, 2003, 2006a, 2006b, 2007; West, Stevens, Pun, & Pratt, 2008; Feng, Spence, Pratt, 2007; Subrahmanyam & Greenfield, 1994). Moreover, neural correlates have been observed in concordance with these enhancements, specifically observing enhanced inhibition of irrelevant distracting stimuli (Wu et al., 2012). An aspect of visual attention left relatively un-researched has been whether these enhancements, specifically the ability to inhibit irrelevant items, transfers outside of central vision.

Green and Bavelier (2003, 2006) have previously used a perceptual load with facilitatory or inhibitory flanking distractors task in an effort to determine attentional differences between VGPs and NVGPs. In their original study (Green & Bavelier, 2003), VGPs processed distracting stimuli during both low load and high load trials, indicating VGPs possessed a greater number of attentional resources that ‘spilled-over’ and processed highly salient distractors. On the other hand, NVGPs showed no processing of distracting stimuli during difficult trials as their attentional resources had been exhausted. This paradigm was further extended (Green & Bavelier, 2006) by manipulating the placement of the external distractor, which was presented in either central (0.5 visual degrees from fixation) or parafoveal vision (4.2 visual degrees). The congruency effect in these experiments was calculated in order to determine the level of distractor processing that occurred. Again, VGPs elicited slower reaction times during high load incongruent distractor conditions, indicating VGPs were processing these distractors during high load conditions. Interestingly, no main effect of group or interaction between group and distractor eccentricity was observed, indicating the spatial distribution of attention up to 4.2 visual degrees was similar between VGPs and NVGPs.

Despite this, more recent research using a spatial orienting task showed VGPs elicited a reduced capture effect of irrelevant distractor stimuli compared to NVGPs (Chrisholm, Hickey, Theeuwes, & Kingstone, 2010). Whereas results from Green and Bavelier (2003) would rely on exogenous attention of VGPs being unable to inhibit processing of salient distractors, the study from Chrisholm et al., (2010) appears to show the opposite. One explanation offered suggests VGPs show greater control of endogenous attention, specifically that VGPs still process irrelevant stimuli but are able to recover faster from such processing. Top down processing reflecting the task demands may be responsible for the difference in results from Green & Bavelier (2003) and Chrisholme et al., (2010). Whereas the distracting stimuli used by Green & Bavelier (2003) had a 50% chance of being facilitatory and thus beneficial for rapid processing, the distracting stimuli used by Chrishome et al., (2010) was always the opposite shape and colour of the target stimulus. It is likely that the more efficient recovery of irrelevant stimulus processing in the study by Chrisholm et al., (2010) is a result of participants learning that the distracting item is always irrelevant and attention is deployed differently than in the task by Green & Bavelier (2003).

The present study replicates that by Green and Bavelier (2006) while also extending distractors further into the periphery. As other paradigms have identified significant between-group differences when identifying targets at 10 visual degrees (Green &Bavelier, 2006, 2007), the current experiment was designed to investigate the efficiency with which VGPs process distractor information in a more peripheral visual field location when under high load. For this purpose, distractor stimuli were also supplied at 6.3 visual degrees into the periphery. I predicted VGPs would continue to process distractors at the furthest eccentricity, whereas NVGPs' ability to attend to distracting items far from the locus of attention would be diminished due to reduced attentional resources in the furthest peripheral location. However, it is important to note the opposite result may be found if VGPs possess greater control over the deployment of their attentional resources.

Method

Participants

Forty-three male undergraduate or postgraduate students were recruited from the University of Hull to take part in a study. A measure of videogame play was taken after experiment completion in the form of an extensive questionnaire on past and immediate videogame usage; this included details of game play session duration, session frequency, average weekly play, number of years played, and screen size information. Psychology undergraduates were awarded course credit for participation and non-psychology participants received fiscal compensation. VGPs were classified in the same style as previous videogame studies in literature, on the basis of spending an average of 6 or more hours of action videogaming per week, whereas NVGPs played less than 2 hours per week of non-action games over the past 6 months. In total, five participants were removed due to not fitting either the videogame player or non-videogame player criteria. The 38 males included 11 non-videogame players (M age: 23.18, SD: 2.4) and 27 videogame players (M age: 21.04, SD: 2.3). All had normal/corrected vision and were free from medical ailments (as assessed by self-report).

Stimuli and Procedure

The following stimuli and procedure were based on the task used by Bavelier and Proksch (2002), and Green and Bavelier (2003, 2006). Participants were seated and positioned with a chin rest 60cm from a 24 inch Samsung LCD monitor displaying at 60Hz. Participants were required to identify a square or diamond stimulus presented in one of six circular placeholders surrounding the central fixation cross. Circular placeholders were 0.7 visual degrees in diameter, coloured black with 2 pixel thicknesses. Each placeholder was 2.1 visual degrees from the central fixation cross, with one circular placeholder placed directly above and below, with two in each hemifield equidistant from one another. Both target and distractor stimuli approximately subtended 0.6 x .04 visual degrees within the placeholders. Trials had equal probability of containing 0, 1, 3 or 5 distractors ($p = 0.25$) alongside the square or diamond target shape ($p = 0.5$). The distractor stimuli consisted of trapezium, triangle, and house shapes at varying orientations, with each trial not repeating the same stimuli arrangement throughout the experiment. Each trial also contained a single flanking stimulus, presented either 0.5 (central), 4.2 or 6.3 visual degrees from a central fixation cross. The size of flanking stimuli were adjusted to account for cortical magnification, 0.3 x 0.2 visual degrees for the central condition, and 0.9 x 0.5 and 1.1 x 0.6 visual degrees, respectively. The flanking stimulus could be a black square or diamond shape and was equally probable to be positioned at one of the three positions; in addition to this each flanker was equally probable to be congruent or incongruent with the target stimulus.

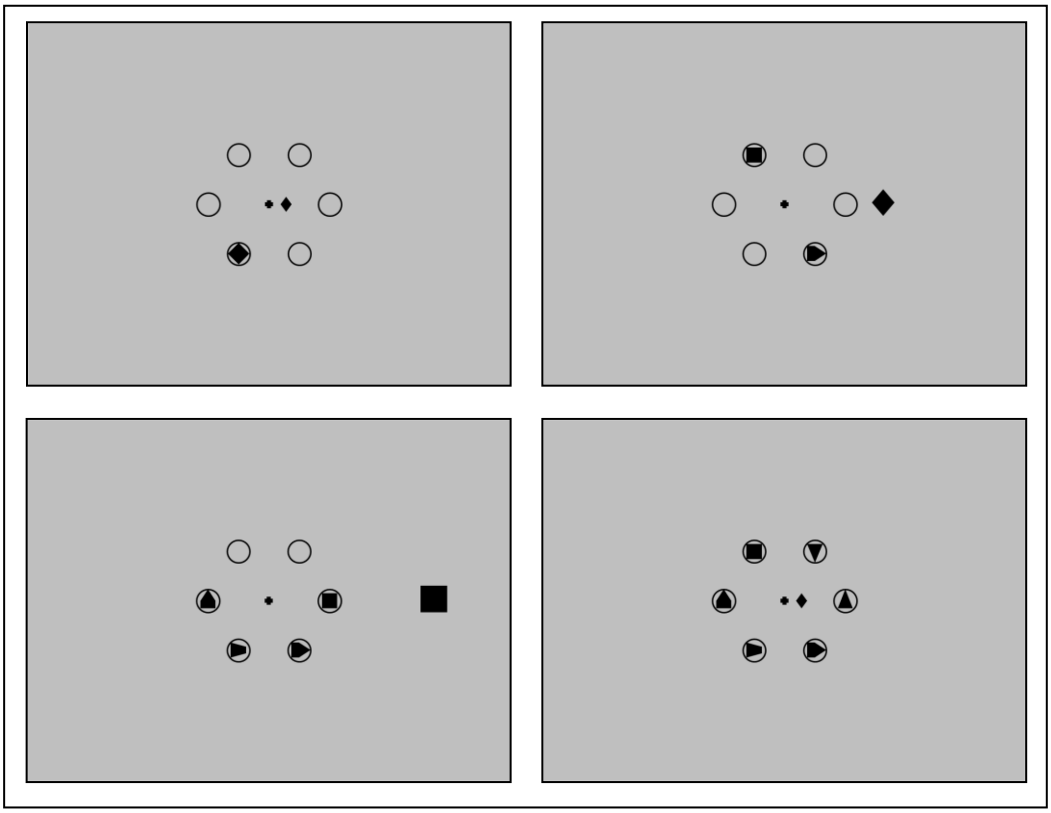


Figure 1. Example trials of the flanker compatibility task. From top-left to bottom-right: Low load, diamond target, compatible central flanker; low load square target incompatible parafoveal flanker; high load square target compatible peripheral flanker; high load square target incompatible central flanker.

Participants were instructed to answer as quickly and accurately as possible using the relevant keys, diamond responses were mapped to the ‘m’ key and required a right handed response while square responses mapped to the ‘z’ key and required a left hand response on a typical QWERTY keyboard situated in front of the participant. Throughout the experiment, participants kept the index finger of both hands on the corresponding response keys.

Trials were presented using E-Prime (V.1.1 Service Pack 3) at a resolution of 640x480 (Monitor at 1920x1080) on standard desktop PC (Intel i5 processor @ 3.2Ghz, 3GB RAM). Each trial began with a black central fixation cross presented for a variable amount of time ranging from 500-1500ms on a grey background. Each array was presented for 100ms before a grey response screen for 2000ms. The target stimulus was equally likely to be presented in one of the six circular placeholders. If no response was recorded in this time frame an incorrect result was coded before the trial process was repeated.

The experiment began with a brief set of both verbal and written directions instructing the participant to focus on the fixation cross between trials and maintain fast and accurate responses. Participants began by completing a practice block of 32 trials, during this time the experimenter remained in the room to observe the participants understanding of the task. After the practice trial the participant was allowed to ask any questions about the task. If the participant understood the task, they were allowed to continue, if not, the practice run was started again. Practice block data was excluded from further analysis. The experiment consisted of 12 blocks consisting of 144 trials each, thus a total of 1728 trials were administered. Each block used a randomized sequence of congruent and incongruent trials, central, near and far flanker placement, and 0, 1, 3, 5 distractors; ensuring equal probabilities of each trial type was achieved after completion of the 12 blocks. A break between each block allowed participants to rest; the length of each break was decided by the participant with a 10 minute mandatory break at the half way point.

Data Analysis

Only correct trials with responses between 300 and 1800ms were entered into the subsequent analyses. For analytical purposes, trials using 0 and 1 distractors were grouped into a low perceptual load group, and trials containing 3 and 5 into high perceptual load. Reaction time and accuracy data was entered separately into two mixed-design ANOVAs with flanker congruency (congruent, incongruent), flanker position (central, near, far), perceptual load (low, high) as within subject variables, and videogame playing behaviour (VGP, NVGP) as the between subject variable. Interactions were further broken down with one-way ANOVAs and paired t-tests were appropriate.

Results

Reaction time data was entered into a mixed-design ANOVA as previously described in the method section. A main effect of flanker position (F(2,72) = 9.205, $p < .001$) was observed. Paired t-tests indicated flankers presented in the near distance elicited significantly later reaction times when compared to central (t(37) = 3.299, $p < .005$) and far (t(37) = 3.612, $p < .005$) flanker positions. A main effect of perceptual load (F(1, 36) = 239.316, $p < .001$) indicated participants responded significantly faster to low load trials.

A congruency × perceptual load interaction on reaction time (F(1, 36) = 5.319, $p < .05$) was broken down to reveal low perceptual load trials to elicit significantly earlier responses for both congruent (t(37) = -17.398, $p < .001$) and incongruent (t(37) = -16.815, $p < .001$) trial types. Paired samples t-tests indicated low perceptual load trials did not differ significantly between congruent and incongruent flanker stimuli ($p > .6$), however contrary to expectations congruent trials elicited significantly delayed responses during high perceptual load trials compared to incongruent trials (t(37) = 2.719, $p < .05$).

Finally, a flanker position × videogame group interaction was observed on reaction time (F(2, 72) = 5.432, $p < .05$). Independent t-tests yielded no significant between group differences. To explore the interaction further, ANOVAs were computed for each group individually. Both VGPs and NVGPs elicited significant main effects of flanker position (F(2, 52) = 6.454, $p < .005$; F(2, 20) = 6.198, $p < .05$, respectively). VGPs near flanker positions elicited significantly later responses than both central (t(26) = 3.945, $p < .005$) and far (t(26) = 2.322, $p < .05$) flanker positions. Whereas NVGPs far flanker positions yielded significantly faster responses when compared to central (t(10) = 2.526, $p < .05$) and near (t(10) = 3.087, $p < .05$) flanker positions. No other interactions with group were present.

Table 1. Reaction time descriptive statistics for VGPs and NVGPs at high and low cognitive load for both congruent and incongruent distractors at each distractor positioning.

Distractor Positioning	Low - VGP	Low - NVGP	High - VGP	High - NVGP
Congruent - Centre	507.3 ±76.17	486.1 ±59.88	614.8 ±109.03	579.3 ±62.97
Congruent - Near	513.5 ±75.37	484.5 ±55.66	617.6 ±100.34	584.5 ±36.78
Congruent - Far	511.6 ±77.19	476.2 ±51.01	617.6 ±100.22	572.5 ±67.04
Incongruent - Centre	507.8 ±74.28	483.8 ±58.20	611.3 ±102.16	579.3 ±63.53
Incongruent - Near	516.0 ±73.01	487.4 ±59.60	615.5 ±103.13	574.2 ±65.33
Incongruent - Far	510.2 ±82.83	479.9 ±56.41	607.6 ±100.53	565.6 ±56.64

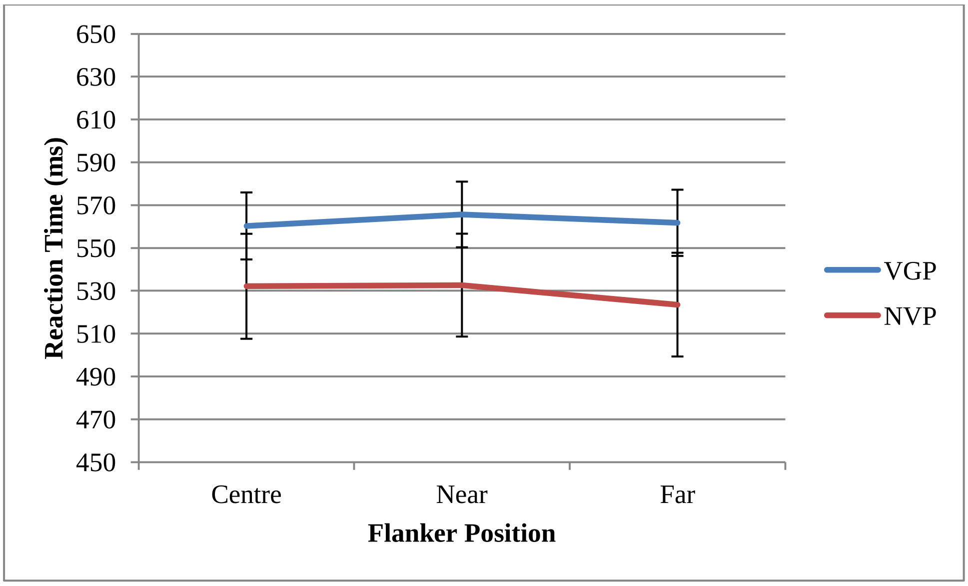


Figure 2. Reaction time data for each flanker position as a function of videogame playing group.

Accuracy data (number of correct responses) was then entered into an identical mixed-design ANOVA to that used for reaction time data. A significant main effect of perceptual load indicated high loads elicited significantly more errors than low load (F(1, 36) = 22.767, *p*< .001). The only other observed main effect indicated VGPs made significantly fewer errors than did NVGPs (F(1, 36) = 5.049, *p*< .05).

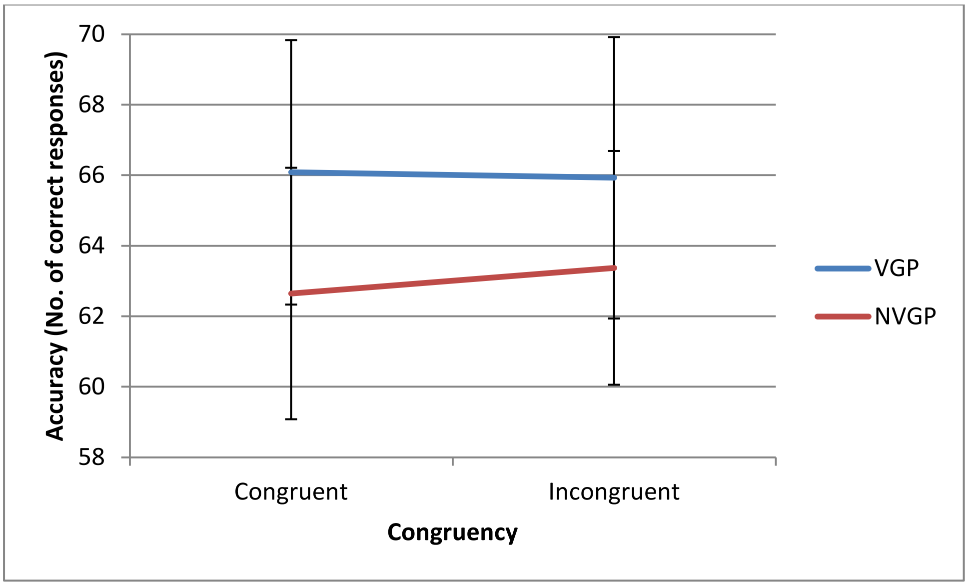


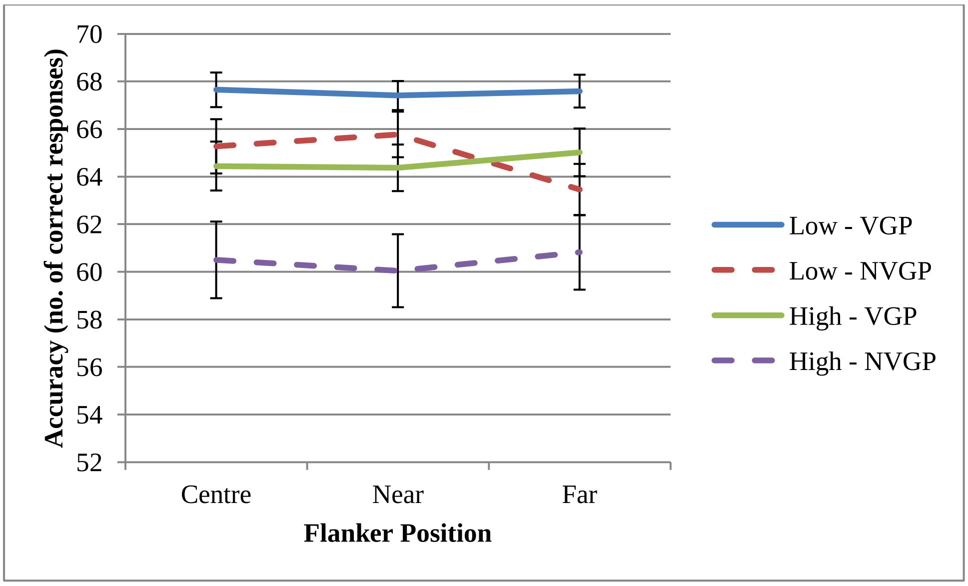
Figure 3. Accuracy data for each congruency type as a function of videogame playing group.

A flanker position × congruency × perceptual load interaction (F(2,72) = 8.325, *p*< .005) and flanker position × congruency × perceptual load × videogame playing group (F(2, 72) = 7.250 *p*< .005) was observed.

Table 2. Accuracy data for VGPs and NVGPs during high and low load trials for both congruent and incongruent distractors at each distractor positioning.

Distractor Positioning	Low - VGP	Low - NVGP	High - VGP	High - NVGP
Congruent - Centre	67.65 ±0.728	65.27 ±1.14	64.44 ±1.02	60.50 ±1.61
Congruent - Near	67.41 ±0.611	65.77 ±0.95	64.37 ±0.97	60.05 ±1.53
Congruent - Far	67.59 ±0.689	63.46 ±1.08	65.02 ±1.00	60.82 ±1.57
Incongruent - Centre	67.06 ±0.693	65.27 ±1.08	64.22 ±1.09	60.96 ±1.70
Incongruent - Near	67.30 ±0.673	63.86 ±1.05	64.59 ±1.04	62.64 ±1.64
Incongruent - Far	67.44 ±0.703	66.23 ±1.10	64.94 ±0.93	61.27 ±1.46

A)



B)

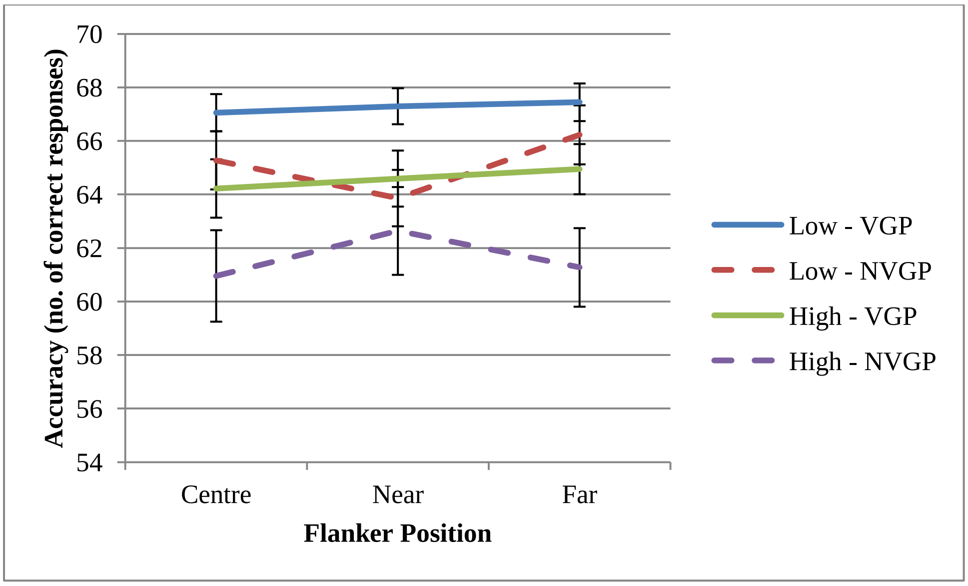


Figure 4. Accuracy data for each flanker position as a function of perceptual load and videogame playing group (A: Congruent; B: Incongruent).

To further investigate the flanker position × congruency × perceptual load × videogame playing group interaction, a one-way ANOVA results indicated VGPs yielded significantly higher accuracy during several different trial types. At central flanker positions only congruent trials with a high perceptual load showed VGPs significant advantage (F(36) = 4.262, *p* =<.05). Near flanker positions showed VGP improvements during congruent trials at high perceptual load, and incongruent trials at low perceptual load (F(36) = 5.650, *p*<.05; F(36) = 7.541, *p*< .05; respectively). VGPs also showed significant increased accuracy during far flanker positions for both high and low load congruent trials (F(36) = 10.434, *p*< .05; F(36) = 5.087, *p*< .05, respectively) and high load incongruent trials (F(36) = 4.448, *p*< .05).

Discussion

The current experiment demonstrates differences in the manner in which seasoned videogame players complete the perceptual load flanker compatibility task when compared to non-videogame players. The dominant finding indicated VGPs superior accuracy at no cost to reaction time, although NVGPs showed a trend for more rapid responses overall. Reaction times indicate VGPs processed near (4.2 visual degrees) flankers more so than central and far distractors. On the other hand, NVGPs reaction times appeared to show central and near distractors took longer to process than the furthest distractors. Despite this, accuracy scores appear to show VGPs were more successful at inhibiting distractors, during many of the conditions and especially during the furthest flanker position.

VGPs showed no reaction time accuracy trade-off; however this time VGPs displayed enhanced accuracy over reaction time (Dye et al., 2009). Unlike Castel et al’s. (2005) findings, of faster stimulus-response mappings and faster motor processing in VGPs, VGPs in the current study appear to display enhanced perceptual discrimination skills either through more efficient target prioritization or distractor inhibition. This discrepancy is further investigated in the following chapter, using ERP measures such as the lateralized readiness potential (LRP) to further assess which process, if not both, is responsible for these enhancements in task performance. Unlike Green and Bavelier (2006b) no significant interaction with videogame playing behaviour and congruency or perceptual load was observed for reaction times, therefore target prioritization may be the best explanation. Despite this, past research has indicated VGPs successfully inhibit distractors more efficiently than NVGPs (Mishra et al., 2011, Wu et al., 2012). This enhanced processing however does not appear to speed up response times during the current task.

With regards to flanker position, the results amongst VGPs and NVGPs appear inconsistent. VGPs appear to process flanking distractors at all distances; and consequently, VGPs appear to possess either increased attentional resources or enhanced resource management to both process these flankers and outperform NVGPs on accuracy. Fast response times may be expected to indicate a lack of processing of the flanking distractor, therefore making the task easier and increasing accuracy on the part of NVGPs. This did not occur in VGPs who displayed increased accuracy and a trend for slower reaction times indicating attending to the flanker and its subsequent processing. A second explanation might be that NVGPs simply did not process the furthest distractor as it may have been presented outside of their attentional focus. Despite this, the most likely interpretation of these results may stem from increased difficulty of the task for NVGPs, i.e. NVGPs may have processed the flanking stimuli, but struggled to revert attention back to the central task as easily as VGPs and compensated for this with a faster less accurate response.

VGP response times appear to show greater interference from flanker stimuli in the near distance, whereby distractors at the near distance are processed slower than far and central distractors. This is a pattern we might expect due stimulus-distractor proximity, but that should hold true for central distractors also. My overall suggestion is that these differences between distractor locations are due to statistical anomalies within the data. Additionally, processing of the furthest distractor appeared reduced in both groups; again VGPs appear to show a benefit from this due to increased accuracy scores in VGPs. In summary, VGPs appear to show more control over the allocation of central attentional resources, a conclusion found previously in videogame playing literature (Green & Bavelier, 2003).

As mentioned in the reaction time data above, the lack of between subject interaction with congruency or perceptual load was unexpected. One explanation is that the task was not difficult enough and required more salient distractors and greater perceptual load to detect these types of processing differences between groups. The significance that VGPs produced more correct results than NVGPs is especially telling when past studies noted no such difference (Green & Bavelier, 2003, 2006). Previous studies postulated the saturation of attentional resources was responsible for NVGPs inability to process the additional flanker stimulus (Green & Bavelier, 2006). A lack of congruency effects may indicate distractor stimuli saliency did not reach a threshold to influence processing despite previous studies using the same paradigm successfully observing these differences (Green & Bavelier, 2003, 2006).

One final explanation for our results differing from past findings could be a reflection of the recruitment process used in the current study. At the time of writing, this is the only study to make use of covert recruitment to avoid potential demand characteristic influences as described by Boot et al., (2011). One could postulate that being aware of the gaming related purpose a study may induce faster reaction times on the part of gamers, perhaps at the partial expense of accurate perceptual decision making. Therefore the current study may paint a more representative picture of the altered cognitive processes VGPs may possess. Despite this, it is important to note the perceptual load manipulation in the current study appears to have been insufficient in detecting between group changes, as was the congruency manipulation of the flanker stimulus. Therefore further investigation is still required with a more salient set of stimuli in order to increase task difficulty and power.

In conclusion, VGPs and NVGPs appeared to process the flanking distractors at varying visual eccentricities differently. Previous research has shown an advantage to VGPs in localization (Green & Bavelier, 2006) and identification (Green & Bavelier, 2007) of visual stimuli in the periphery. The accuracy scores of the current study appear to mimic this, again supporting enhanced visual attentional resources extending from the fovea to such a level that distractors still appear to be processed yet fail to interfere with accuracy. These distractor items extending further into the periphery appear to be processed and disengaged even more efficiently, especially when compared to NVGPs. Therefore the current study suggests VGPs ability to process and inhibit distracting items extends further into the periphery than first suggested, regardless of central task difficulty. From this one might suggest that VGPs possess greater control of their attentional resources.

However, there appears to be some uncertainty as to whether VGPs enhancements are due to improved distractor inhibition, target prioritization/acquisition, or even earlier or later stages of the processing stream. These different possibilities are investigated using electrophysiological methods in Chapters 3 and 5.

Chapter 3. Incorrect Response Priming and Inhibition

Surprisingly, the previous experimental chapter failed to reproduce the results of Green and Bavelier (2003). I found no significant flanker compatibility effects across any condition, indicating that either VGP possessed no cognitive modulation in relation to selective attention mechanisms of the processing stream, or a methodological confound was present. To further investigate the role of selective attention, specifically that of distractor processing and inhibition, I employed a modified Eriksen flanker task in combination with event-related potentials. The following experimental paradigm provides a behavioural measure of distractor inhibition in a more difficult setting through the inclusion of a stimulus onset asynchrony but also important neurophysiological event-related potentials on several mechanisms within the processing stream, such as; selective attention (P3), executive control (N2c), and motor control (LRP).

Typically, the study of visual information processing uses visual search tasks, often using an array of letters with a target letter embedded within it requiring rapid identification from the participant. As well as the processes that lead to selection of the target, it is equally important to investigate the inhibitory process afforded to suppression of the distractors. Past research has found probability of target detection and reaction times to be dependent upon noise/target similarity (McIntyre, Fox, & Neale, 1970; Estes, 1972) and the number of distracting elements within the display (Estes, 1972). Research from Eriksen and colleagues (Eriksen & Hoffman, 1972, 1973; Colegate) noted even when subjects received an indicator of target location prior to the display of noise stimuli, they were unable to completely ignore the effects of extraneous variables. Additionally, a spatial proximity effect was found in that distracting stimuli within half a visual degree of the target impaired reaction times more so than those further removed.

Such findings by Eriksen et al., (1972, 1973) not only indicates a minimal channel capacity for target selectivity, but a single target letter is not enough to exceed such a capacity; that is, spare attentional resources remain after target processing. As this unused capacity cannot be disabled in any way, a number of extraneous stimuli within the display are also processed simultaneously with the target. During any trial the subject is processing (at approximately the same time) the target stimulus and a number of distracting stimuli. Subsequently a selection and inhibitory process occur simultaneously, the vocalisation of the correct stimulus must be selected during inhibition of the distracting stimuli. It is this selection and inhibition stage that is believed to affect reaction times during visual search tasks.

This process of selection and inhibition forms the basis of the *continuous flow model* (Eriksen & Schultz, 1979). This model posits that responses begin at the time of visual presentation and as the information thus far is related to a number of responses, all of these are activated. Initially, flanker-triggered responses gain precedent, as more flanker information than target information has been accumulated at this point. During an incompatible trial a response conflict is produced. Response priming narrows down on the probability of alternative responses; and as the target stimulus becomes more localized the coinciding response begins to receive stronger activation. It is the response competition between the initial incorrect activated response and the subsequently activated response that affects reaction times in the task.

The continuous flow model adequately describes early processing of the flanker task, however does not satisfactorily account for triggered incorrect responses. However, parallel processing models fit closely with the continuous flow model, bridging the gap between early visual processing and stimulus response associations. In an effort to conceptualize the dynamics of parallel processing, two processing streams were labelled direct and deliberate (Kornblum, Hasbroucq, & Osman, 1990). The target is processed along the deliberate route, ensuring correct translation of the stimulus-response. Conversely, the direct route is dominated by the target and flankers, and is responsible for rapid automatic response. The power of the direct route is based heavily on the strength of the stimulus-response association, for example, the direct route response would favour the flanking stimuli in an array with multiple flankers and a single target (Bashore, 1990). Both paths then converge at the response activation level, requiring the direct route to often be inhibited to prevent an incongruent response. This inhibition is time consuming and contributes to the flanker effect (increased reaction time) (Wylie, 2007).

In an attempt to further the understanding of noise (distractors) on target identification in visual search tasks Eriksen and Eriksen (1974) modified the classic visual search task involving letters to create the Eriksen Flanker Task (1974). Unlike a standard visual search task, whether it is a circular array or random presentation of noise letters and a target letter, the Eriksen Flanker Task (1974) used a horizontal chain of stimuli. The target letter remains in the same location for every trial and is flanked by noise stimuli. In the original experiment, the target could be one of four letters, a C or S coded to a left-handed response, and an H and K to a right handed response. Six trial conditions formulated the original experiment; the target could be the same as the flanking noise letters (e.g. HHHHHHH), the target could be different to the flanking stimuli but still response compatible (e.g. HHHKHHH), the target response could be incompatible to the noise in both feature and hand mapping (e.g. SSSKSSS), the target may be flanked by heterogeneous noise letters with similar features to the target (e.g. NWZHNWZ) or dissimilar features (e.g. GJQHGJQ) and the final condition was the target presented alone.

Several modifications of the original Eriksen Flanker Task have been used to examine selective attention and cognitive control. Kopp, Rist & Mattler (1996) presented their stimuli in a vertical chain as opposed to horizontally. Additionally, arrow stimuli replaced the classic letter stimuli; arrows could point either left or right and were coded to a response from the corresponding hand. Advantageously, this meant the participants were not required to learn associations between target letters and a certain response prior to the experiment (Kornblum, Hasbroucq & Osman, 1990). Another example would be the task used by Wylie, Ridderinkhof, Eckerle and Manning (2007), similar to Kopp et al. (1996) whereby letter stimuli were substituted for arrow stimuli in a horizontal chain format similar to the original task by Eriksen and Eriksen (1974). Ridderinkhof, Scheres, Oosterlaan and Sergeant (2005) combined letter and symbol stimuli such that in this version of the flanker task participants were required to identify the direction of an arrow (target stimulus) amongst distracting letter stimuli. Van'tEnt (2002) altered the task further, symbol stimuli were set out in a three-by-three grid with the target placed at the centre. Furthermore the colour of the central stimulus indicated whether participants should make a response with the correct or opposite hand. Some past research has used combinations of letter and number digits (Proctor & Fober, 1985) or just number digits (Flowers & Wilcox, 1982). Shaffer and LaBerge (1979) even found flanker effects using full words; participants were tasked with identifying a target noun belonging to a specific category with one hand, or belonging to another category with the opposite hand whilst being surrounded by distracting nouns.

The predominant theory behind these flanker task alterations remains around the concept that the stimuli are required to share similar aspects if they are to be congruent and different aspects if they are incongruent. The original experiment by Eriksen and Eriksen (1974) controlled for this by using the Gibson System (Gibson, 1969 in Eriksen & Eriksen, 1974) to rate letter features, ensuring any feature analysis processing could be controlled for within trial types. More recent research investigating feature similarity and intrinsic response mapping used four different arrays; perceptually similar response compatible (e.g. HHH, >>>), perceptually different response compatible (e.g. HSH, />/), perceptually similar response incompatible (e.g. CSC, <><) and perceptually different response incompatible (e.g. NSN, \>\) (Fournier, Scheffers, Coles, Adamson & Abad, 1997). Both traditional letter and modified symbol arrays were used. Findings suggested both letter and symbol stimuli elicited compatibility effects with response reaction times being slower and less accurate during incompatible trials. Furthermore, results indicated the greater the feature similarity in target letter and noise stimuli, the greater the effect of noise stimuli. Due to the differing effectiveness of arrow and slash stimuli, with slash stimuli having an effect similar to letter stimuli, the two symbol stimuli were compared to measure intrinsic response mapping. Compatibility effects were found to be highest for arrow stimuli, indicating an important role of intrinsic response mapping. In conclusion, this research indicates compatibility effects are due to a combination of stimulus evaluation delays, response competition, all dependent on response mappings and feature similarity (Fournier, Scheffers, Coles, Adamson & Abad, 1997). As arrow stimuli have been found to elicit the greatest compatibility effects and intrinsically map to responses with less effort than letter stimuli, the current study employed arrow stimuli to test response inhibition in videogame players.

The spatial distance between targets and flankers to observe compatibility effects have been well documented in past research. A small variance of distance was tested in the original experiment; the authors used letter spacing's of .06, .5 and 1 visual degree finding a significant effect of spacing and significant noise condition by spacing interaction. The results indicated greater compatibility effects at smaller letter spacing, with participant reaction times getting faster as letters were presented further apart (Eriksen & Eriksen, 1974). Research using a narrow letter spacing of 0.9 and wide spacing 4.9 visual degrees found significant effects of flanker type at both eccentricities using separate ANOVAs for both conditions (Miller, 1991). Analysis of the combined data revealed significantly larger flanker compatibility effects using narrow letter spacing. Interestingly, no significant difference in accuracy was observed between spacing conditions. This effect of distance between flankers and target has also been observed in studies using numerical digits (Flowers & Wilcox, 1982) and vertical chain symbol stimuli (Kopp et al., 1996).

According to the continuous flow model (Eriksen & Schultz, 1979), Bjork and Murray (1977) theorized that flankers are processed at a slower speed than the target stimulus as they fall on a less sensitive area of the retina. However, any effects of this slowed processing could theoretically be offset using a stimulus onset asynchrony (SOA), allowing the flanking stimuli more time to be processed to an extent where response competition manifests (Flowers, 1980). SOA's are useful in determining the time course of facilitation and interference effects of noise stimuli, giving the additional ability of inferring coding and processing stages (Flowers &

Wilcox, 1982). Research manipulating SOA's whilst observing neutral, incongruent and congruent trial types at two different spatial eccentricities found flanker compatibility effects were greatest when noise stimuli were presented simultaneously (Flowers, 1980; Flowers, 1990) or shortly before the target stimulus (Flowers and Wilcox, 1982; Mattler, 2003; Wascher, Reinhard, Wauschkuhn, &Verleger 1999). However, most studies found this level of interference declines at longer SOA's, being virtually eliminated or becoming facilitatory at 300ms or more (Flowers, 1980; Flowers, 1990; Flowers & Wilcox, 1982).

The Eriksen flanker task is not without its potential confounds, the conflict monitoring theory (Botvinick, Braver, Barch, Carter, & Cohen, 2001) initially explains responses similarly to the parallel processing model described earlier; i.e. that correct and incorrect response channels compete at the response activation level and that resolving this competition takes time and thus produces an observable flanker effect. However, this is where similarities between the two theories end. Conflict monitoring theory posits that the amount of conflict in a trial is monitored, and is used to regulate top-down attentional control in the subsequent trial. This explains an interaction between trial types known as the Gratton effect (Gratton, Coles, & Donchin, 1992), that is, faster reaction time for congruent trials followed by congruent trials than congruent trials followed by incongruent trials, and for incongruent trials followed by incongruent trials compared to incongruent trials followed by congruent trials.

Electroencephalography (EEG) is often used to record waveforms during Eriksen flanker task completion (Kopp, Rist, & Mattler, 1996; Spencer & Banich, 2005). A series of components observable throughout individual trials are thought to correlate with stimulus coding and response making.

Aside from the N100 component (thought to reflect the orientation of attention, (Luck, Heinze, Mangun, & Hillyard, 1989) elicited by stimulus presentation in the absence of task demands (Luck, 2005), several N2 subcomponents, the P300 and Lateralized readiness potentials (LRP) are elicited during completion of the Eriksen Flanker task. Research by Kopp et al., (1996) noted larger N2b components in neutral flanker conditions, which remained unaffected by congruent and incongruent conditions, or different spatial distances. This component tends to be largest for infrequent items and is thought to correlate with stimulus categorization (Luck, 2005). The N2c appears to be confined to the incongruent condition; more specifically associated with the priming of erroneous responses due to response competition from flanking stimuli (Kopp et al., 1996). Gehring, Gratton, Coles and Donchin (1992) noted the N2c was elicited when these erroneously primed responses had to be interrupted. The N2 subcomponents are typically measured over central electrodes, Fz, Cz, Pz and to some extent Oz.

The positive P300 peak is usually associated with the probability of a stimulus, specifically larger P300 amplitudes during trials with infrequent stimuli (Luck, 2005). Past research has posited that P300 amplitude is sensitive to the manner in which the stimulus is delivered (Johnson 1988; Ruchkin, Johnson, Canoune, Ritter, Hammer, 1990) and the size of the peak correlates with the amount of attentional resources required to process the stimulus presented in the task (Wickens, Kramer, Vanasse, & Donchin, 1983; Polich, 1987). Furthermore P300 latency is inversely correlated with cognitive processing power, thus shorter latencies indicate greater cognitive processing power (Emmerson, Dustman, Shearer, & Turner, 1989). Recent research lends further support, showing smaller P300 amplitudes at shorter latencies in congruent trials of the Eriksen Flanker task, representing less attentional resources but faster processing abilities (Kopp et al,. 1996; Van ‘t Ent, 2002).

The lateralized readiness potential (LRP) provides a cortical measure of response activation. The LRP is typically computed by subtracting waveforms recorded at C3 and C4 from one another to gain a measure of left and right-handed responses. Electrodes placed on the scalp at C3 and C4 are adjacent to the motor cortices. The LRP computed for each hand reflects the activation of the motor cortical areas for that responding hand, providing an accurate real time measure of response preparation prior to response. Research studies using LRPs have found they tend to lateralize earlier on congruent trials than on incongruent trials. Additionally LRPs of incongruent trials tend to display an early positive deflection indicating incorrect response activation preceding a slightly delayed negative deflection indicating a correct response (Kopp et al., 1996; Mattler, 2003; Beste, Saft, Andrich, Gold, & Falkenstein, 2008).

Green and Bavelier (2003) first included principles of the flanker compatibility task whilst investigating potential attentional modulation in experienced action videogame players. Perceptual load was manipulated alongside flanker compatibility in a task where participants were presented congruent or incongruent flanking stimuli alongside a central task. Videogame players were found to be more susceptible to flanking stimuli during low perceptual load (easier central task) and less susceptible during high perceptual load. This was believed to reflect videogame players’ additional attentional resources spilling over and capturing external flanking stimuli, or perhaps videogame players’ larger attentional spotlight including both target and flanking stimuli causing both to be processed. On the other hand, NVGPs appeared susceptible to flanking stimuli during low load trials, but no during high load trials, indicating NVGPs did not possess the attentional resources on high load trials to process flanking stimuli. Despite the central premise of compatible and incompatible flanking stimuli being present, between group differences cannot be directly attributed to the flanker task as created by Eriksen & Eriksen due to the addition of a central perceptual load task (1974).

The current task allows two avenues of investigation. The first concerns the investigation of peripheral attention and the size of the attentional spotlight in videogame players. Green & Bavelier (2003, 2006b) showed enhancements in videogame players' ability to localise target stimuli amongst distracters at visual eccentricities up to 30 visual degrees using both cross-sectional and training approaches. Participants familiar with action videogames showed significantly higher accuracy when compared to non-videogame players when searching for target stimuli amongst distracters at 10, 20 and 30 visual degrees. After a brief training session, non-videogame players that played action videogames improved significantly over those that did not train using action videogames. This not only appears to show increased or more efficient use of attentional resources, but a larger visual area over which they can be utilised.

Further investigation into videogame players and peripheral attention has noted differences in the spatial resolution of vision (Green & Bavelier, 2007). Crowding effects, whereby when targets and distractor stimuli are in close proximity cause difficulty in identification of the target in peripheral vision. Videogame players demonstrated significantly smaller target-distractor thresholds, meaning they were able to identify targets presented in the periphery in closer proximity to distracters than non-videogame players. Critically, when non-videogame players were trained, a similar effect was noted when compared to non-videogame players not trained on videogames.

The second avenue of investigation relies on the electrophysiological waveforms this task is able to elicit, and therefore the processes which can be measured. Thus far, videogame research has primarily aimed to identify whether videogame players' enhanced attentional abilities stem from modulated target prioritization or distractor inhibition. Previous research by Mishra, Zinni, Bavelier and Hillyard (2011) recorded steady-state visually evoked potentials (SSVEPs) while videogame players and non-videogame players monitored a multi-stimulus display presenting rapid sequences of alphanumeric stimuli. Videogame players elicited significantly suppressed SSVEPs to irrelevant peripheral sequences when compared to non-videogame players. In addition to this, ERP component analysis indicated videogame players elicited a significantly larger amplitude P300 component to target stimuli. Mishra et al., (2011) concluded behavioural enhancements between groups were, in part, a result of enhanced suppression of irrelevant stimuli in combination with increased perceptual decision processing. More recently, Wu, Cheng, Feng, D'Angelo, Alain and Spence (2012) supported the finding of Mishra et al., (2011) finding a modulated P300 component during completion of an attentional field of view task. Wu et al., (2012) attributed the P300 to enhanced spatial selective attention via increased distractor inhibition.

Indeed, the current chapter and task used allows us to further assess the processing stream of VGPs. Furthermore, I am able to investigate previously un-investigated ERP waveforms in VGPs, specifically the N2c and LRP. Analyses of the N2c, a component thought to correlate with erroneous response inhibition, may provide information regarding the differences in the inhibitory mechanisms VGPs may possess. Additionally, the elicitation of the LRP, a measure of motor response build-up, may provide information on whether habitual VGPs' cognitive enhancements also include modulated motor control.

Until now, videogame players have not been tested using a flanker compatibility task (as designed by Eriksen & Erikesn, 1974). As described above, the task examines the processing of both interfering and facilitating flanking stimuli when identifying a central target. The current study used geometrical shapes and is based on the methodology used by Kopp et al., (1996) with the spatial distance manipulation being extended to 1, 3 and 5 visual degrees in order to measure the extent of videogame players' distribution of attention in the visual field. Geometric shapes were used (left and right facing triangles, or arrows) to ensure responses were intrinsically coded (left-handed, right-handed) and had no semantic meaning. Using EEG, several individual ERPs allow the investigation of response priming, inhibition of incorrect response priming, target processing and motor priming. From a behavioural standpoint, I would hypothesize VGPs to display enhanced reaction time with no speed-accuracy trade-off and VGPs will continue to show a flanker compatibility effect at greater eccentricities due to greater attentional resources/more efficient use of attentional resources. A second hypothesis given previous findings would be to expect significant differences in the P300 between groups, supporting work by Wu et al., (2012) and Mishra et al., (2011). As Wu et al., (2012) concluded their finding represented enhanced perceptual decision making through inhibition of distractors; this may indicate potential differences in erroneous response inhibition (N2c). Finally, no study has yet tested motor priming in an ERP setting on videogame players. Although a difference in latency of the LRP might not be expected, any modulation on the peak amplitude may reflect a difference in processing requirements at the motor stage.

Method

Participants

A sample of 47 undergraduate and postgraduate students was recruited from the University of Hull to take part in a study under the pseudonym, 'Investigating the underlying neural correlates of attention'. A pseudonym was used to ensure participants were unaware that videogame playing behaviour was being measured, thus avoiding the issue of demand characteristics and placebo effects (cf. Boot et al., 2011). A measure of videogame play was covertly taken as part of a 'free time' questionnaire. Undergraduates were awarded course credit for participation and postgraduates received fiscal compensation. In total, eleven participants were removed due to poor accuracy (<80%) (n=2), poor EEG recordings (n=1) or not fitting either the videogame player or non-videogame player criteria as described below (n=6). The 36 participants included 21 non-videogame players (5 males; 16 females) (M age: 23.52, SD: 5.45) and 15 videogame players (12 males; 3 females) (M age: 22.4, SD: 3.96). All had normal/corrected vision, right hand dominance and were free from medical ailments (as assessed by self-report). VGPs were classified on the basis of spending an average of 6 or more hours of action videogaming per week over the past six months, whereas NVGPs played less than two hours per week.

Stimuli and Procedure

The following stimuli and procedure were based on the task used by Kopp et al. (1996). Participants were seated approximately 120cm from a 24 inch Samsung LCD monitor displaying at 60Hz. Subjects were required to identify the direction of a target stimulus presented in the centre of the screen surrounded by two distractor stimuli presented directly above and below the target. The target was a solid grey equilateral triangle with each side measuring 15mm. The distractor stimuli consisted of either a pair of triangles identical in size and colour to the target, or a pair of squares the same colour as the target. The target stimulus could point to either the left or right; a left facing target stimulus required a left-handed response, this response was mapped to the ‘z’ key on a typical QWERTY keyboard situated in front of the participant. Right facing targets were mapped to the ‘m’ key. Throughout the experiment, participants kept the index finger of the both hands on the corresponding response keys.

In congruent trials, two triangles pointing the same direction as the target stimulus, one above and below the target were presented. Incongruent trials consisted of triangles pointing in the opposite direction to that of the target stimulus. Neutral trials used square distractors above and below the target. All stimuli were presented on a black background. The current experiment consisted of three separate distance conditions; small, medium and large. The presented stimuli were 1 visual degree apart measured from point-to-point in incongruent trials in the 'small' condition, 3 visual degrees apart in the 'medium' condition and 5 visual degrees in the 'large' condition.

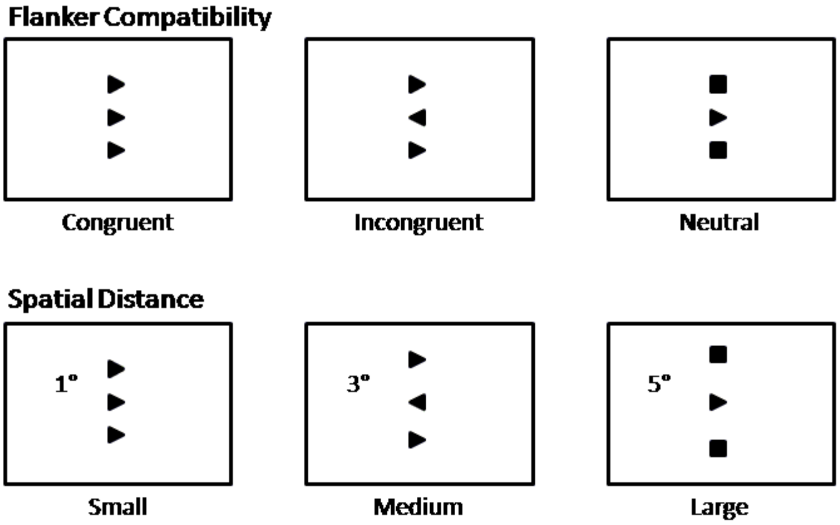


Figure 1. Examples of congruent, incongruent and neutral trial types alongside trials of small, medium and large spatial distances. These trial types were fully balanced and were of equal display probability. N.B. For the purpose of this report, trials have been displayed in black and white. The experiment proper used a black background and gray coloured stimuli.

Trials were presented using E-Prime (V.1.1 Service Pack 3) at a resolution of 640x480on standard desktop PC (Intel i5 processor @ 3.2Ghz, 3GB RAM). Each trial began with a grey central fixation cross presented for a variable amount of time ranging from 500-1500ms on a black background. Flanker stimuli were subsequently presented for 150ms without the central fixation cross or target stimulus. The target stimulus appeared between the upper and lower flanker stimuli for the last 100ms of the flanker display before both target and flanker stimuli simultaneously disappeared. A black blank screen was then presented for 2000ms where the participant was able to respond. If no response was recorded in this time frame an incorrect result was coded before the next trial was presented.

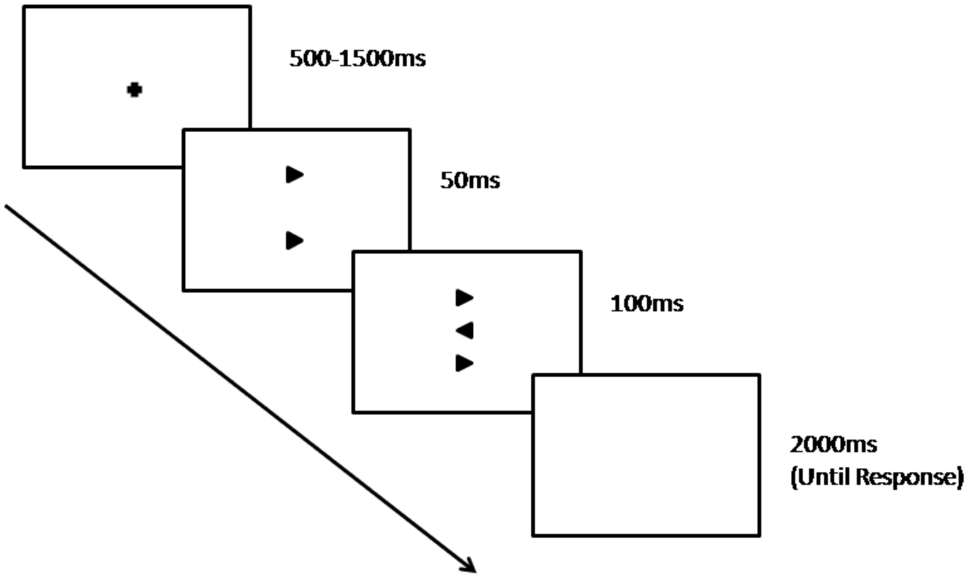


Figure 2. Example of an incongruent flanker trial. N.B. For the purpose of this report, trials have been displayed in black and white. The experiment proper used a black background and gray coloured stimuli.

The experiment began with a brief set of both verbal and written directions instructing the participant to focus on the fixation cross between trials and central stimulus during trials, ignoring the distractors. Further task instructions were given to complete each trial as fast and accurately as possible whilst keeping their fingers on the relevant response keys throughout the experiment. Participants began by completing a practice block of 60 trials. During this time the experimenter remained in the room to observe the participants understanding of the task. After the practice trial the participant was allowed to ask any questions about the task. If the participant understood the task, they were allowed to continue. If not, the practice trial was started again. Practice block data was excluded from further analysis. The experiment consisted of 9 blocks consisting of 90 trials each, thus a total of 810 trials were administered. Each block used a randomized sequence of congruent, incongruent and neutral trials types and a random selection of distance conditions (near, medium and far) with equal probabilities for each trial type and condition. A total of 90 trials for each stimulus combination were presented during the experiment (e.g. congruent at small spatial distance, congruent at medium spatial distance, etc.) A break between each block allowed participants to rest; the length of each break was decided by the participant.

Data Analysis

Due to gender imbalances between groups, and initial mixed design ANOVA with gender as the between subject variable and array type (congruent, incongruent, neutral) and flanker distance (small, medium, large) as the within subject variables was computed to identify potential confounds this imbalance may cause. Subsequent correlational analyses of the full sample prior to grouping into VGP and NVGP groups to determine whether relationships between the number of hours played weekly over the past 12 months or the number of years participants have played videogames and reaction times/accuracy scores were also computed. Similar to the visual search task, RT and accuracy were recorded online for each array type. Error trials and practice trials were excluded from analysis along with responses outside of 100-1200ms (Kopp et al., 1996). Participants with < 80% overall accuracy were removed. Separate mixed-design ANOVAs were used to analyze accuracy and reaction time scores, with playing behaviour (videogame player, non-videogame player) as the between-subject variable and array type (congruent, incongruent, neutral) and distance (small, medium, large) as the within-subject factors. Participants were grouped as previously stated in the method section. Correlational analyses were also ran in order to identify potential relationships between gaming hours and gender (separately) and the dependant variables.

EEG Recording

All recordings were taken in a soundproofed electrically shielded room adjacent to the control room where participants were monitored using a video camera. The electroencephalogram (EEG) was recorded using a 32-channel Brainvision active electrode system (Brainvision, Inc.). Electrodes were placed at FP1, FP2, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, C3, Cz, C4, T7, T8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, PO9, PO10, O1, Oz and O2. All active electrodes were referred to the vertex and grounded with an electrode placed on the forehead. Horizontal and vertical eye movements were recorded bipolarly using electrooculargrams (EOG) placed 1cm away from the outer canthi of each eye, and above and below the left eye. EEG signals were digitized constantly at a rate of 1000Hz and filtered on-line using a band pass of 0.1-50Hz. The impedance of all electrodes was maintained below 10 kΩ.

EEG Analysis

Ocular related artifacts such as blinks and lateral eye movements were corrected using Gratton & Cole’s (1983) method. All recordings were filtered offline at a band-pass of 0.1Hz (12dB/Oct Slope) and 30Hz (24dB/Oct Slope). All channels were visually inspected, and those with a substantial number of trial removals (25% trial removal) due to artefacts found during semi-automatic data inspection were removed completely from analysis before were re-referencing. Removed channels of importance were re-interpolated using a triangulation and linear algorithm. Non-ocular related artefacts containing deflections exceeding ±100μV and activity below

0.5µV were removed. Data from correct trials was segmented into epochs of 200ms pre-flanker to 1050ms post-flanker. Epochs were created for each trial type at each trial distance and separated further by left or right handed response and then averaged. Prior to averaging, each epoch was baseline corrected with respect to the pre-flanker interval (200ms). All analysis was completed using Brain Analyzer 2 (Brain Products GMBH.).

Mean activity (µV: please see Appendices), peak amplitude (µV) and peak onset latency (ms) measures were taken from each trial type (congruent, incongruent, and neutral) x each spatial distance (small, medium, large) at central electrode sites (Fz, Cz, Pz, Oz). Due to the non-lateralized nature of the recorded potentials (N2c and P3), only electrodes across the midline of the scalp were used. All time windows were taken from Kopp et al. (1996) and amended slightly after visual inspection of the individual waveforms of each participant; N2c: 350-450ms post flanker; P3: 450-550ms post flanker). P3 component data (mean activity, peak amplitude, peak latency) were initially analyzed using a mixed-design ANOVA. Flanker compatibility (congruent, incongruent, neural), spatial distance (small, medium, large), electrode site (Fz, Cz, Pz, Oz) were the within-subjects variable, with videogame playing group (VGP, NVGP) as the between subject variable. N2c data were entered into mixed-ANOVAs of similar design, however as only incongruent data was relevant for this component; the flanker compatibility variable was not required.

Lateralized readiness potentials (LRPs) were computed from incongruent trial type data elicited over the primary motor cortex at C3 and C4. Data elicited at each electrode site was subtracted from one another to get a measure for each hand (right-handed responses C3-C4; left-handed responses C4-C3) before being combined and averaged for a single LRP measure. Mean amplitude (µV), peak amplitude (µV) and peak latency onset (ms) data was analysed during (150-250ms post target) with distance as the within-subject variable (small, medium, large) and videogame playing behaviour as the between subject variable (VGP, NVGP). Subsequent facilitatory and interference analyses were also computed, facilitatory by comparing congruent and neutral, whereas interference analyses comparing incongruent and neutral trials only.

Interactions that breached sphericity were corrected using the Greenhouse-Geisser correction.

Results

Behavioural Results

Correlations combining both genders were computed to measure the relationship between the numbers of hours played and the reaction time and accuracy results of each trial type and distance combination. Reaction time data yielded a significant relationship with incongruent trials at all three stimulus distances, indicating the more hours participants played, the faster their reaction time (Small: r = -.346, *p* (two-tailed) < .05; Medium: -.350, *p* (two-tailed) < .05; Large: r = -.374, *p* (two-tailed) < .05). Additionally, neutral trials at the large distance displayed the same significant pattern, r = -.344, *p* (two-tailed) <.05, and approached significance at the remaining distances (Small: r = -.297, *p* (two-tailed) = .078; Medium: r = -.315, *p* (two-tailed) = .062). Although a similar trend was produced for congruent trials, neither small, medium or large distances approached significance when related to number of hours played. In relation to accuracy, only the correlation between number of hours and accuracy on the incongruent trials with large distance between target and flankers approached significance, r = -.315, *p* (two-tailed) = .061, indicating reduced accuracy for videogame players during these trials.

Secondary correlations including only males yielded no significant relationship between the numbers of hours played and reaction time or accuracy scores for any distance and trial type combination.

In a similar fashion to the analyses carried out in previous studies of videogame players (Green & Bavelier, 2003) a mixed-design ANOVA was carried out combining both genders included trial type (congruent, incongruent, neutral) and distance (small, medium, large) as the within subject factors and videogame playing behaviour (videogame player, non-videogame player) as the between subject variable. Reaction time analysis found a main effect of trial type (F(1.267, 43.063) = 361.005, *p*<.001) and distance (F(1.685, 57.299) = 35.867, *p*< .001). A significant interaction between distance and trial type was also observed (F(3.104, 105.531) = 62.449, *p*<.001). Paired t-tests indicate this interaction (Fig. 3) was primarily driven by significantly reducing reaction times for small distances compared to medium (t(35) = -2.138, *p*< .05) and large distances (t(35) = -6.839, *p* < .001) during congruent trials; alongside significantly increased reaction times during incongruent trials with small distances when compared to medium (t(35) = 10.436, *p*< .001) and large distances (t(35) = 12.433, *p*< .001). Finally, a trend main effect of videogame playing behaviour (F(1, 34) = 3.274, *p* = .079) indicated a trend for videogame players to respond faster on average than non-videogame players. No interactions with the between group variable were observed.

An identical mixed ANOVA computed using accuracy data yielded a significant main effect of trial type (F(1.115, 37.924) = 55.912. *p*< .001) and distance (F(1.261, 42.879) = 48.355, *p*< .001). A significant trial type × distance interaction was also observed (F(1.802, 61.259) = 35.121, *p*< .001) but no significant main effect or interaction with the between-subject variable was observed. Breaking down the trial type × distance interaction using paired t-tests indicated no significant differences between congruent trials at all distances. Of most significance was incongruent small trials being significantly less accurate than incongruent medium (t(35) -2.966), *p*< .01) and large trials (t(35) = -7.088, *p*< .001).

Table 1. Reaction time descriptive statistics and standard deviations.

Distractor Distance	Congruent	Incongruent	Neutral
VGPs			
Small	352.40 ±13.13	435.31 ±14.73	383.65 ±11.62
Medium	357.75 ±12.18	406.06 ±12.96	375.49 ±12.68
Large	366.72 ±14.03	398.65 ±11.93	380.39 ±11.86
NVGPs			
Small	369.13 ±9.74	462.95 ±10.92	406.41 ±8.62
Medium	376.21 ±9.03	434.59 ±9.61	399.29 ±9.40
Large	383.42 ±10.40	427.32 ±8.85	402.21 ±8.79

Table 2. Accuracy data descriptive statistics and standard deviations

Distractor Distance	Congruent	Incongruent	Neutral
VGP			
Small	90.64 ±2.28	79.00 ±3.04	88.55 ±2.08
Medium	90.55 ±2.31	86.91 ±2.7	91.09 ±2.30
Large	91.18 ±2.33	88.00 ±2.31	90.18 ±2.36
NVGP			
Small	90.40 ±1.69	80.90 ±2.26	89.65 ±1.54
Medium	90.40 ±1.71	86.95 ±2.02	90.10 ±1.70
Large	90.30 ±1.72	89.10 ±1.71	90.20 ±1.75

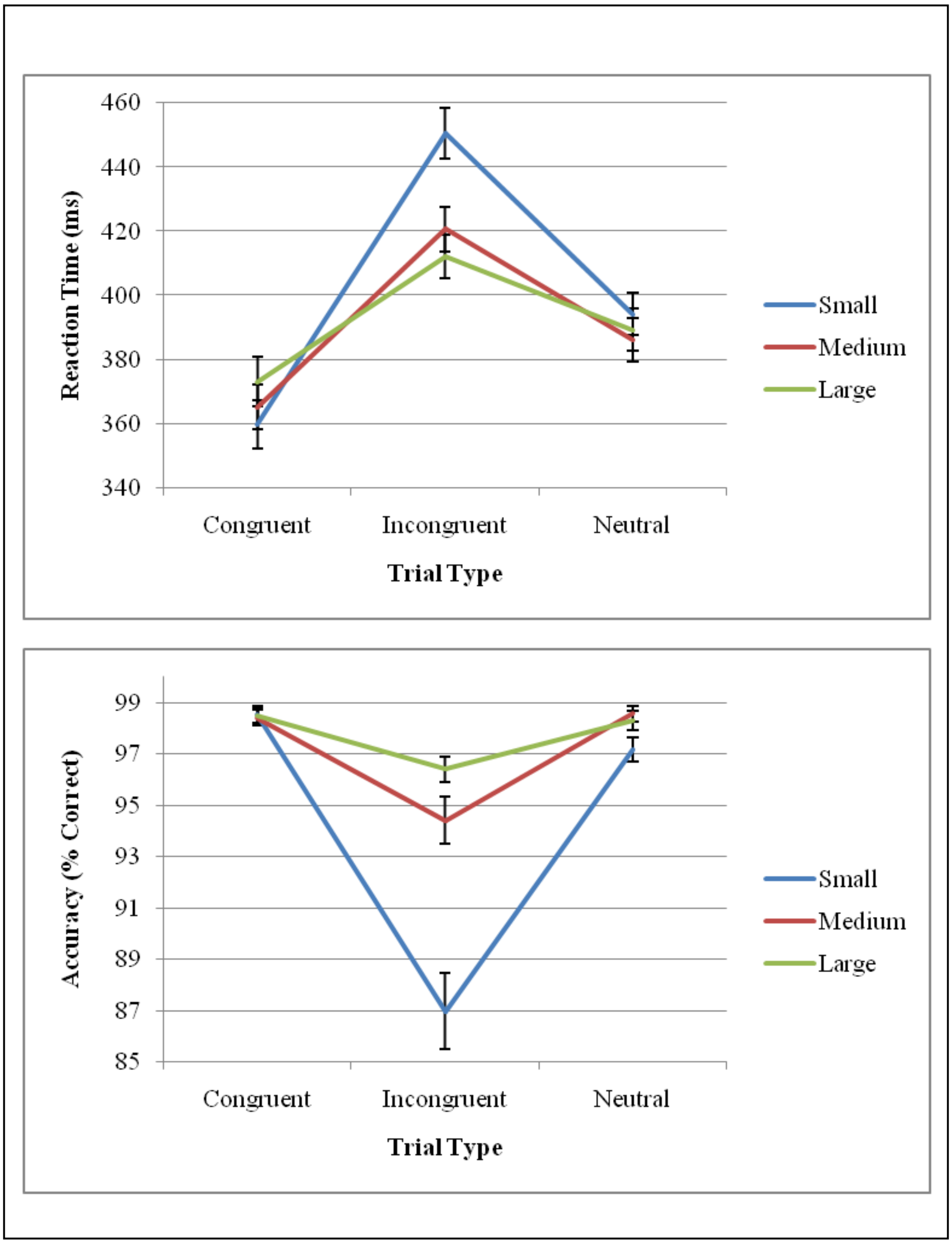


Figure 3. Reaction time (ms) data (top) and accuracy data (% Correct) (below) as a function of trial type and flanker distance.

Electrophysiological Results

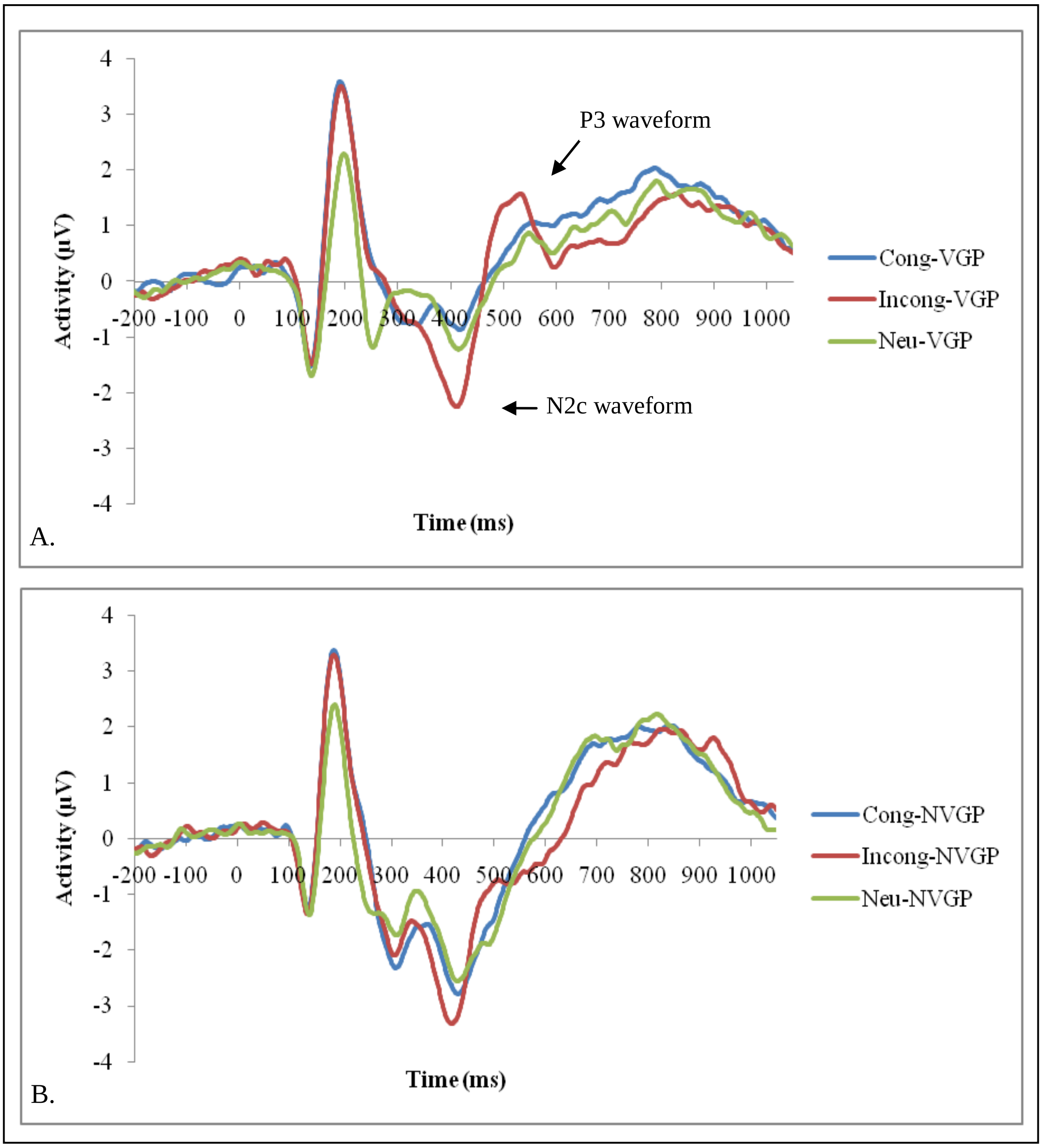


Figure 4. Electrophysiological recordings from Fz as a function of each trial type (A: VGPs; B: NVGPs).

N2c Latency (Incongruent Only). Initial correlational analysis computed between number of hours played and average N2c latency onset at each electrode site and flanker distance yielded a significant negative correlation at Fz during small flanker distance trials, r = -.352, *p* (two-tailed) < .05. No other significant relationships were observed.

A mixed-design ANOVA with electrode site (Fz, Cz, Pz, Oz) and flanker distance (small, medium, large) as within-subject variables with videogame playing group (videogame player, non-videogame player) as the between subject variable was computed. A significant main effect of electrode site (F(1.955, 66.481) = 7.733, *p*< .001) and distance (F(1.390, 47.265) = 12.386, *p* < .05) was observed. Paired t-tests indicated Pz (382.694 ms) elicited significantly earlier N2c potentials when compared to Fz (411.564 ms) (t(35) = 4.463, *p*< .05) and Oz (401.231 ms) (t(35) = 3.378, *p*< .05). Paired t-tests also indicated small flanker distances elicited significantly later N2c onset in comparison to medium (t(35) = 4.235, *p*< .05) and large flanker distances (t(35) = 3.810, *p* = < .001). No interactions or main effects with the between subject variable were observed.

Table 3. Means and standard deviations of the N2c peak latency.

Distractor Distance	Small	Medium	Large
VGP			
Fz	415.47 ±29.39	405.40 ±24.23	410.40 ±24.38
Cz	402.80 ±27.61	385.13 ±25.57	385.20 ±24.16
Pz	388.87 ±30.05	376.00 ±23.68	372.93 ±26.27
Oz	406.87 ±39.48	399.00 ±39.56	404.40 ±37.01
NVGP			
Fz	420.71 ±24.40	410.14 ±26.23	406.29 ±22.65
Cz	401.62 ±27.08	391.14 ±20.47	383.52 ±23.03
Pz	398.52 ±36.81	383.90 ±35.05	373.00 ±27.69
Oz	401.38 ±44.02	398.81 ±39.31	398.81 ±42.43

*N2c Peak Amplitude (Incongruent Only).*Initial correlational analysis to investigate the relationship between number of hours played and N2c amplitude yielded a single significant positive correlation during medium flanker distance trials at Fz, r = .344, *p* (two tailed) < .05, indicating the more hours played over the past 12 months the less negative N2c amplitudes were elicited.

Table 4. Means and standard deviations for N2c peak amplitude.

Distractor Distance	Small	Medium	Large
VGP			
Fz	-3.6 ±3.83	-2.9 ±3.36	-3.1 ±3.72
Cz	-2.0 ±2.41	-2.1 ±2.508	-1.6 ±2.21
Pz	2.5 ±2.51	2.1 ±2.53	1.7 ±1.89
Oz	1.7 ±3.01	0.4 ±3.22	0.2 ±2.85
NVGP			
Fz	-4.2 ±2.82	-4.7 ±2.89	-3.4 ±2.5
Cz	-1.6 ±3.38	-1.1 ±2.84	-0.5 ±2.33
Pz	2.7 ±3.39	3.3 ±2.97	3.0 ±2.99
Oz	0.9 ±2.78	1.3 ±2.65	0.3 ±2.39

N2c amplitude data was then entered into a mixed-design ANOVA with electrode site (Fz, Cz, Pz, Oz) and flanker distance (small, medium, large) as the within-subject variables and videogame playing behaviour (videogame player, non-videogame player) as the between-subject variable. A main effect of electrode site was observed (F(1.935, 65.803) = 30.464, *p*< .001) alongside an electrode site × distance interaction (F(3.764, 127.977) = 6.674, *p* < .001).

Paired t-tests indicated the frontal electrode site yielded a significantly more negative N2c amplitude when compared to all other electrode sites (Cz: t(35) = -3.756, *p* < .001; Pz: t(35) = - 7.411, *p*< .001; Oz: t(35) = -5.403, *p*< .001).

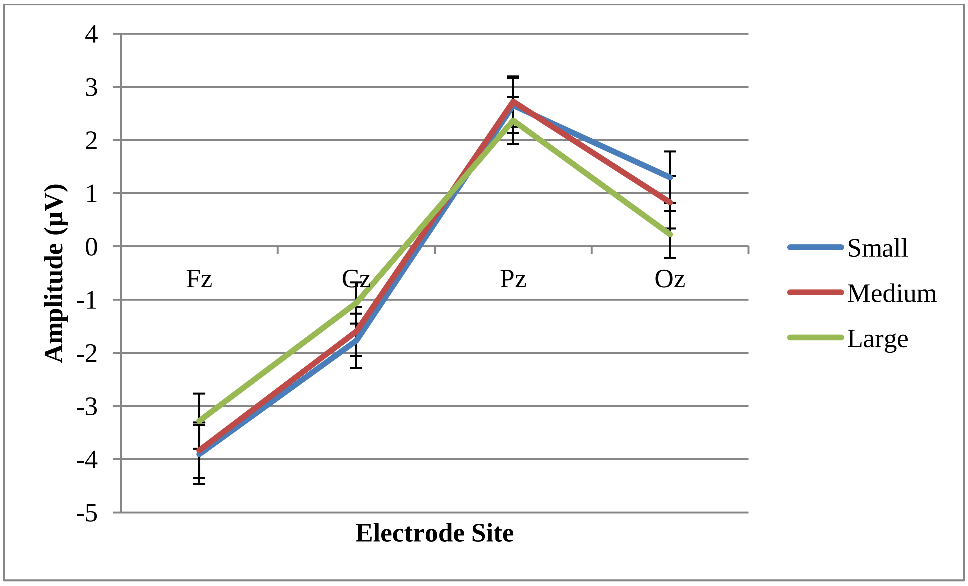


Figure 5. N2c Amplitude data at each electrode site as a function of flanker distance.

A significant distance × videogame playing group was observed (F(1.613, 54.826) = 4.471, *p* = .022).

An electrode site × distance × videogame playing three-way interaction was also observed (F(3.764, 127.977) = 3.657, *p*< .01). To further interpret this three-way interaction, a one-way ANOVA including each electrode site and flanker distance combination indicated no significant between-group differences. Due to substantial analyses of the above interaction, significant results have been reported in a table below.

Table. 5. Summary table of the electrode site × distance × videogame playing group three way interaction break down. Each directional relationship shown relates to a more negative N2c.

	Fz	**Cz**	**Pz**	**Oz**
VGP		N.S.		Medium > Small **; Large > Small**
NVGP	Medium > Large **; Medium > Small*; Small > Large*	N.S.	Large > Small**; Large > Medium**	Large > Medium **

Note: Only significant differences are reported.

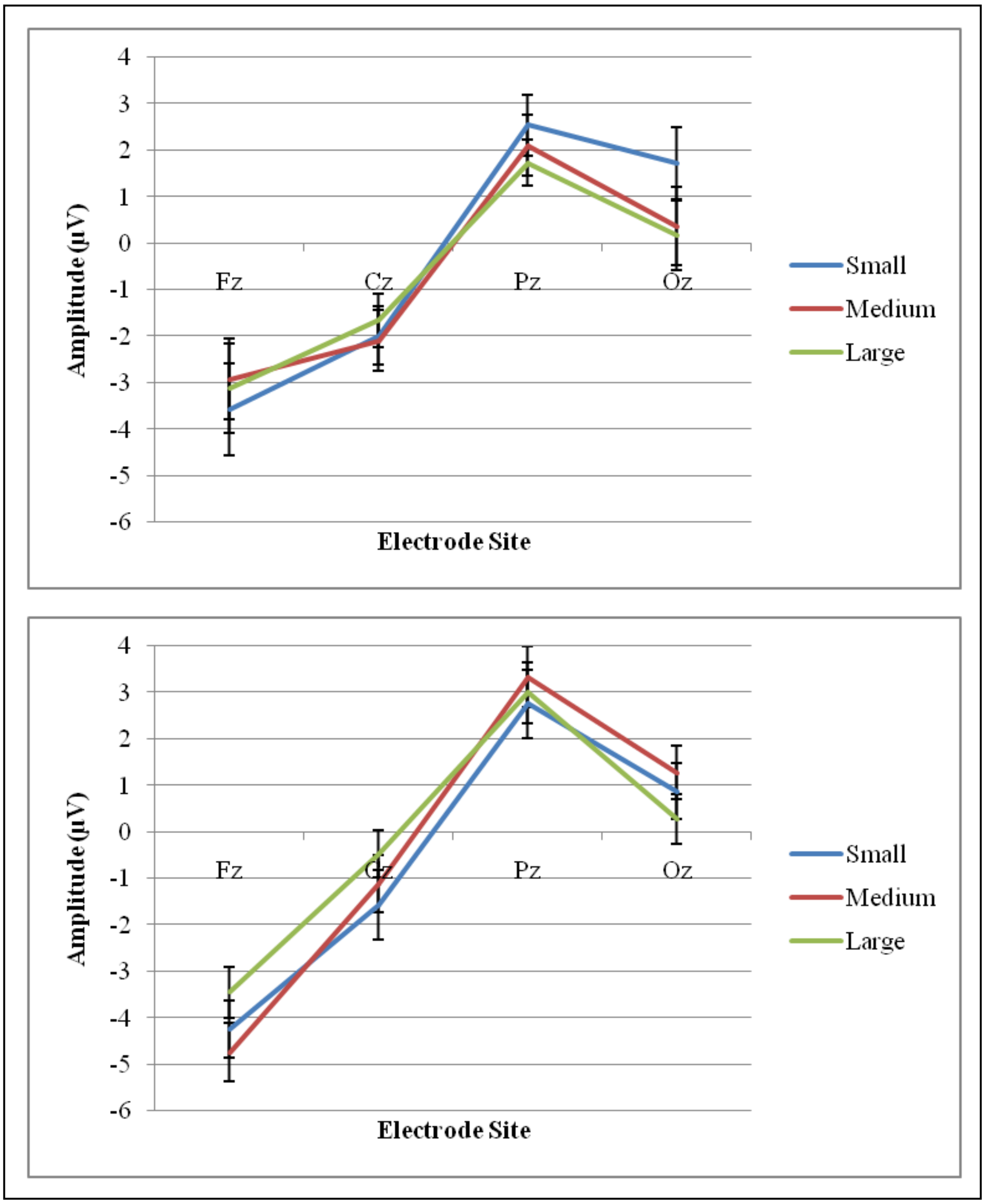


Figure 6. N2c amplitude data for each electrode site as a function of flanker distance as for VGPs and NVGPs respectively.

P3 Latency. A correlational analysis was computed to identify potential relationships with the numbers of hours played and P3 onset for each trial type/flanker distance combination at each electrode site. A significant positive relationship was identified at Pz during congruent small (r = .668, *p* (two-tailed) <

.001), neutral small (r=.476, *p* (two-tailed) < .01) and congruent medium trials (r = .431, *p* (two-tailed) < .01). A final significant positive correlation was observed at the occipital electrode site during neutral small trials (r = .730, *p* (two-tailed) < .01) indicating the more hours participants used videogames, the more their P3 were delayed during these trials.

Table 6. P3 Latency means and standard deviations for congruent trial types.

Distractor Distance	Small	Medium	Large
VGP			
Fz	525.20 ±23.96	508.20 ±29.01	504.00 ±31.02
Cz	504.13 ±28.06	482.47 ±28.35	487.87 ±31.73
Pz	497.80 ±40.00	482.80 ±34.89	478.67 ±29.58
Oz	462.93 ±21.19	473.60 ±34.03	470.13 ±32.68
NVGP			
Fz	514.29 ±28.19	508.76 ±32.94	507.76 ±33.85
Cz	514.00 ±26.37	500.86 ±32.36	498.71 ±34.23
Pz	491.00 ±33.35	484.33 ±39.99	471.43 ±27.46
Oz	460.57 ±24.12	463.38 ±22.73	472.48 ±30.57

Table 7. P3 Latency means and standard deviations for incongruent trial types.

Distractor Distance	Small	Medium	Large
VGP			
Fz	525.20 ±23.96	508.20 ±29.01	504.00 ±31.02
Cz	504.13 ±28.06	482.47 ±28.35	487.87 ±31.73
Pz	497.80 ±40.00	482.80 ±34.89	478.67 ±29.58
Oz	462.93 ±21.19	473.60 ±34.03	470.13 ±32.68
NVGP			
Fz	514.29 ±28.19	508.76 ±32.94	507.76 ±33.85
Cz	514.00 ±26.37	500.86 ±32.36	498.71 ±34.23
Pz	491.00 ±33.35	484.33 ±39.99	471.43 ±27.46
Oz	460.57 ±24.12	463.38 ±22.73	472.48 ±30.57

Table 8. P3 Latency means and standard deviations for neutral trial types.

Distractor Distance	Small	Medium	Large
VGP			
Fz	510.00 ±43.44	504.13 ±40.59	508.07 ±37.24
Cz	501.60 ±34.47	494.93048 ±37.24	498.67 ±35.51
Pz	488.13 ±27.2	481.93 ±32.32	477.67 ±26.55
Oz	482.20 ±34.96	467.80 ±30.58	465.93 ±26.63
NVGP			
Fz	529.43 ±27.66	528.90 ±31.9	521.86 ±33.32
Cz	498.05 ±36.55	488.86 ±37.8	489.95 ±40.9
Pz	467.52 ±28.54	469.86 ±31.61	464.19 ±28.32
Oz	455.52 ±10.34	462.48 ±15.37	464.19 ±23.75

A mixed-design ANOVA (setup as previously described) yielded significant main effects of electrode site ($F(2.476, 84.195) = 63.695$, $p< .001$), distance ($F(2, 68) = 5.704$, $p< .01$) and congruency ($F(2, 68) = 3.650$, $p< .05$). Paired t-tests indicated P3 component was detected towards the back of the skull at the occipital site significantly earlier than Pz ($t(35) = 2.066$, $p< .05$), Cz ($t(35) = 8.695$, $p< .001$) and Fz ($t(35) = 11.188$, $p< .001$). Further comparisons showed small trials elicit significantly later P3 components than both medium ($t(35) = 2.199$, $p< .05$) and large trials ($t(35) = 2.733$, $p< .05$). Finally, paired t-tests indicated congruent trials elicited significantly later P3 components than neutral trials ($t(35) = 1.529$, $p< .05$). Congruent trials also elicited slower components than incongruent trials; however this effect only approached significance.

A significant interaction of electrode site × congruency was found ($F(6, 204) = 10.012$, $p< .001$) which in-turn was also modulated by videogame playing behaviour ($F(6, 204) = 2.301$, $p< .05$). A three-way interaction of all within-subject variables was also found to be significant ($F(7.811, 265.579) = 2.072$, $p< .05$). In addition to these interactions, an electrode site × videogame playing group interaction approached significance (F(2.476, 84.195) = 2.3914, *p* = .086).

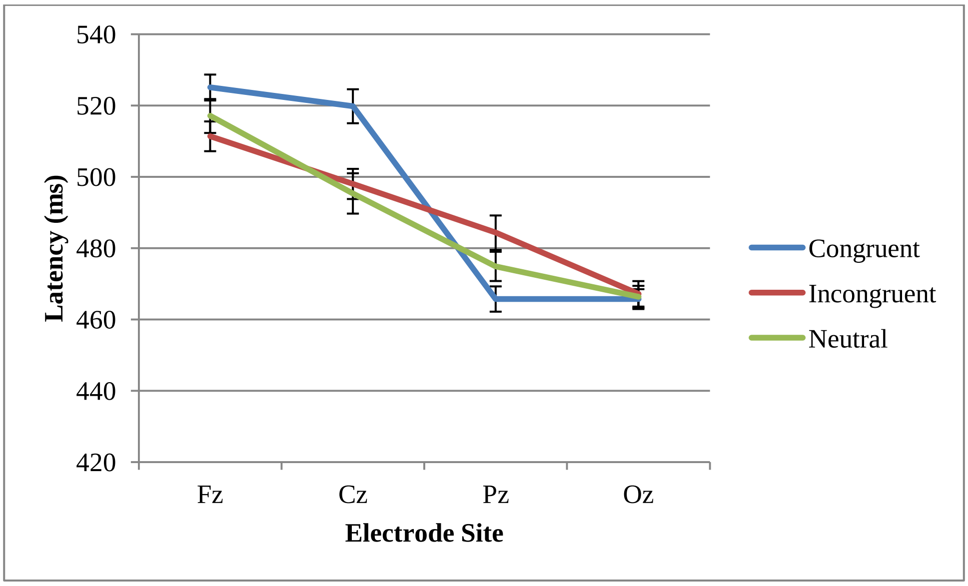


Figure 7. P3 Latency data for each electrode site as a function of trial type.

Planned comparisons indicated congruent trials yield significantly later onset P3 components at frontal (t(35) = 3.772, *p*< .001) and central (t(35) = 3.856, *p*< .001) electrode sites when compared to incongruent trial types. However, this pattern is reversed at posterior sites (t(35) = -4.501, *p*< .001), with no significant difference at the occipital electrode site.

The electrode site × congruency × videogame playing behaviour was further explored using a one-way ANOVA. During congruent trials, videogame players elicited significantly later waveforms at the posterior (Pz) electrode site when compared with non-videogame players (F(1, 34) = 4.714, *p*< .05). However, non-videogame players during neutral trials were found to elicit significantly later P3 components when compared to videogame players at the frontal electrode site (F(1, 34), *p* = .050). Although marginally significant, this pattern was reversed at parietal (F(1, 34) = 3.510, *p* = .070) and occipital electrode sites (F(1, 34) = 3.354, *p* = .076), showing videogame players elicit later P3 potentials than non-videogame players.

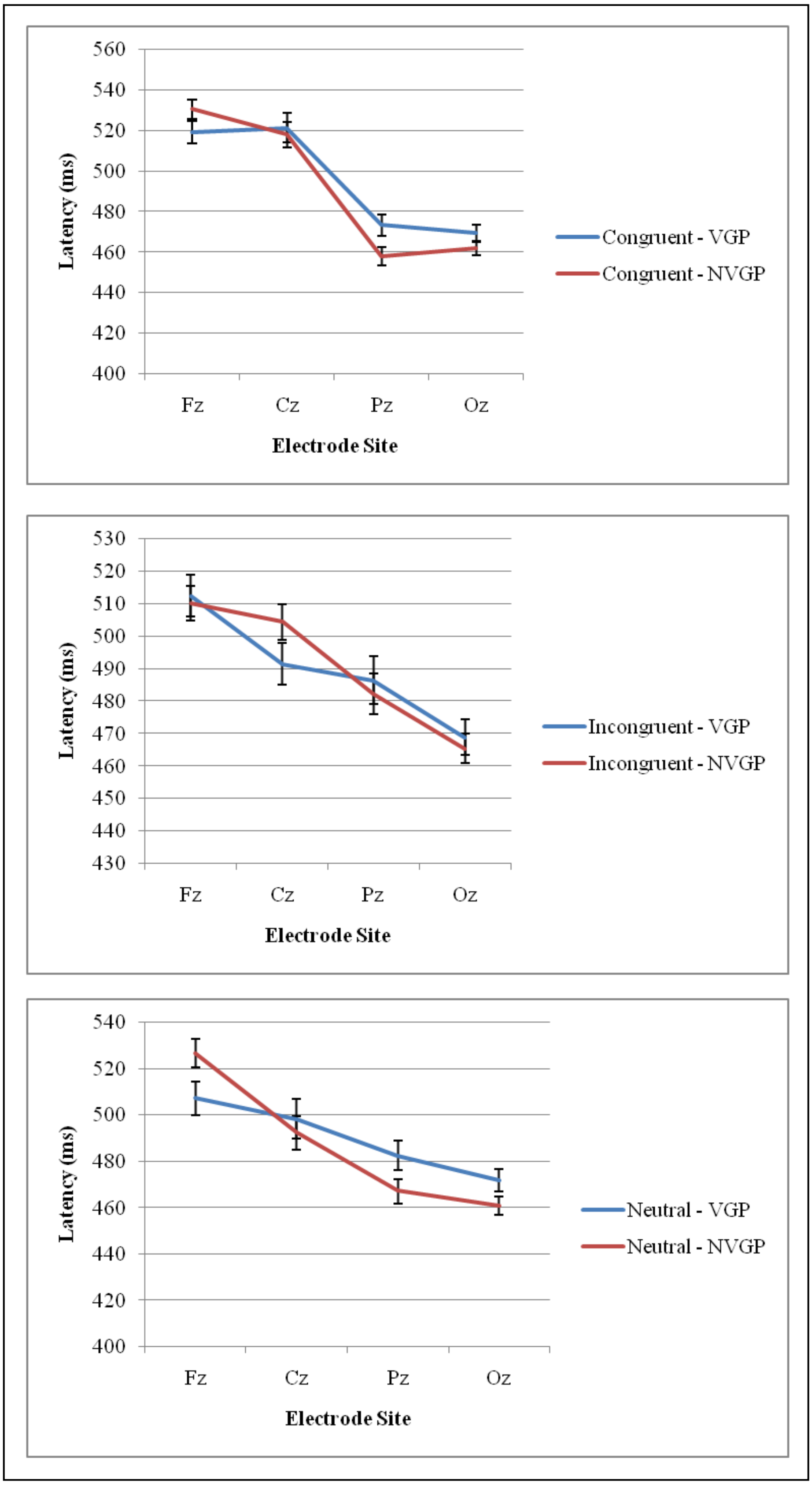


Figure 8. Individual graphs showing P3 latency data at each electrode site as a function of trial type and videogame playing status.

P3 Peak Amplitude. Initial correlation analyses indicated only incongruent small trials at the frontal electrode site show a relationship between P3 amplitude and the number of hours played (r = .344, *p* (two-tailed) < .05), indicating P3 amplitude increases with number of hours played. No other trial type/flanker distance combinations at the remaining electrode sites produced significant correlational relationships with the number of hours played.

Table 9. P3 Peak amplitude means and standard deviations for congruent trial types.

Distractor Distance	Small	Medium	Large
VGP			
Fz	1.39 ±4.7	1.70 ±4.27	1.76 ±3.95
Cz	4.41 ±2.87	4.35 ±2.34	3.96 ±2.78
Pz	5.85 ±4.18	4.96 ±2.73	5.46 ±3.01
Oz	1.87 ±3.57	1.58 ±3.2	1.79 ±3.39
NVGP			
Fz	-0.08 ±2.45	0.24 ±1.85	0.25 ±2.1
Cz	2.91 ±2.74	3.00 ±2.31	2.58 ±2.75
Pz	5.99 ±2.73	5.18 ±3.07	5.58 ±3.05
Oz	2.36 ±2.54	1.54 ±2.77	1.64 ±2.5

Table 10. Peak amplitude means and standard deviations for incongruent trial types.

Distractor Distance	Small	Medium	Large
VGP			
Fz	2.08 ±3.66	2.86 ±4.47	2.69 ±5.34
Cz	6.13 ±2.87	6.62 ±2.97	5.79 ±2.899
Pz	6.30 ±3.71	6.33 ±3.61	6.08 ±3.25
Oz	2.95 ±3.7	1.60 ±3.96	2.31 ±3.47
NVGP			
Fz	0.17 ±2.38	0.25 ±2.4	0.35 ±2.17
Cz	4.62 ±3.55	5.08 ±2.84	5.05 ±3.12
Pz	6.00 ±3.22	6.83 ±3.08	6.58 ±3.02
Oz	2.35 ±2.95	2.51 ±2.84	1.57 ±2.53

Table 11. Peak amplitude means and standard deviations for neutral trial types.

Distractor Distance	Small	Medium	Large
VGP			
Fz	0.86 ±4.23	1.70 ±4	1.81 ±3.93
Cz	4.30 ±2.68	4.57 ±2.68	4.92 ±2.55
Pz	6.46 ±4.11	6.05 ±3.2	6.39 ±3.34
Oz	3.06 ±3.86	2.57 ±3.46	2.59 ±3.81
NVGP			
Fz	-0.70 ±2.4	0.17 ±2.03	0.14 ±2.74
Cz	3.38 ±2.86	3.34 ±2.84	3.36 ±2.53
Pz	7.01 ±3.28	6.34 ±2.85	6.07 ±2.88
Oz	3.07 ±3.1	1.94 ±2.93	1.99 ±2.94

A mixed ANOVA in the same design as used previously identified a main effect of electrode site (F(1.950, 66.299) = 20.818, *p*< .001) and congruency (F(1.252, 42.566) = 28.978, *p*< .001). Planned comparisons indicated P3 amplitude was significantly greater at the posterior electrode site when compared to frontal (t(35) = 6.208, *p*< .001), central (t(35) = 5.506, *p*< .001) and occipital sites (t(35) = 6.980, *p*< .001). Additional planned comparisons indicated incongruent trials yielded significantly larger P3 amplitudes than in the case of both congruent (t(35) = 5.972, *p*< .001) and neutral trial types (t(35) = 3.836, *p*< .001).

Furthermore, significant within-subject interactions electrode site × distance (F(3.199, 108.767) = 7.444, *p*< .001) and electrode site × congruency (F(3.713, 126.239) = 13.322, *p*< .001) were observed.

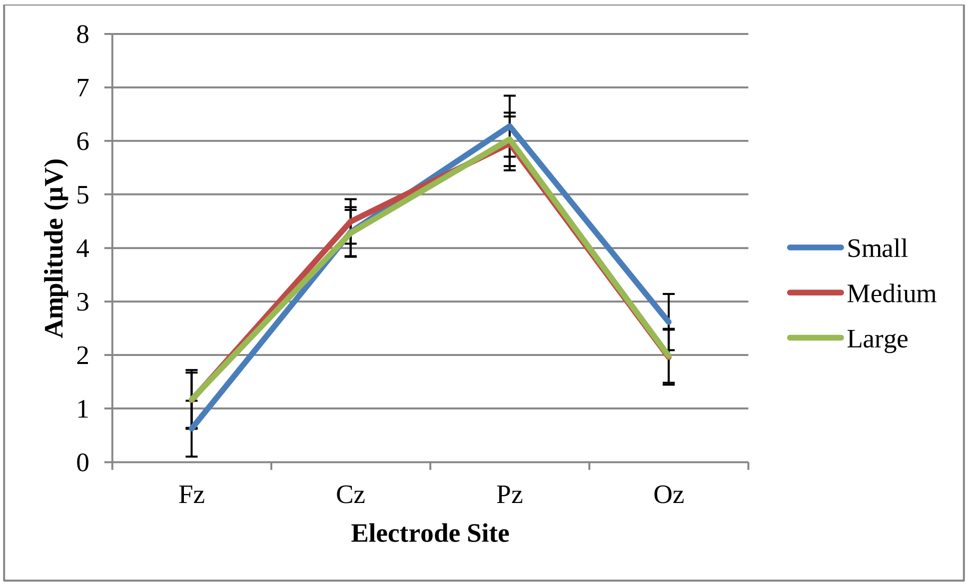


Figure 9. P3 Amplitude values at each electrode site as a function of flanker distance.

Paired t-tests of the electrode site × distance interaction indicated small trials produced significantly smaller P3 amplitudes at frontal electrodes when compared to medium trials (t(35) = -2.733, *p*< .01), however this pattern was reversed at posterior (t(35) = 2.040, *p* = .049) and occipital (t(35) = 3.388, *p*< .01) electrode sites.

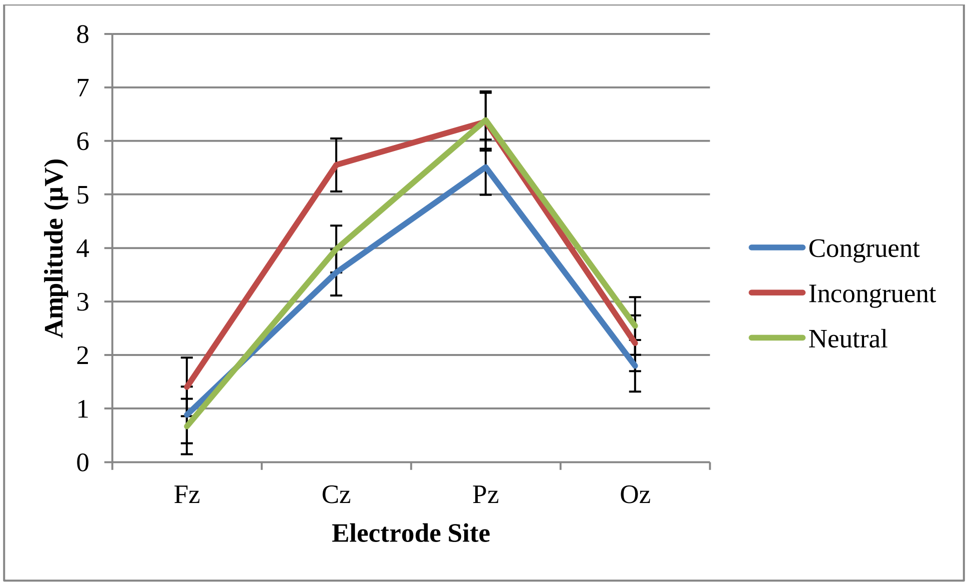


Figure 10. P3 Amplitude values at each electrode site as a function of trial type.

Paired t-tests computed to further investigate the electrode site × congruency interaction indicated congruent trials yielded significantly smaller P3 potentials at central (t(35) = -6.418, *p*< .001), posterior (t(35) = -3.616, *p*< .01) and occipital sites (t(35) = -2.239, *p*< .05) electrode sites (approaching significance at the frontal electrode site (t(35) = -2.003, *p* = .053)). Incongruent trials were also found to yield significantly larger P3 amplitudes when compared to neutral trials at frontal (t(35) = 3.496, *p*< .01) and central electrode sites (t(35) = 5.532, *p*< .001); this difference was eliminated at posterior and occipital electrode sites.

An approaching significance three-way within subject interaction was identified (F(6.301, 214.243) = 1.903, *p* = .078) in addition to the same interaction modulated by videogame playing behaviour (F(6.301, 214.243) = 1.834, *p* = .090).

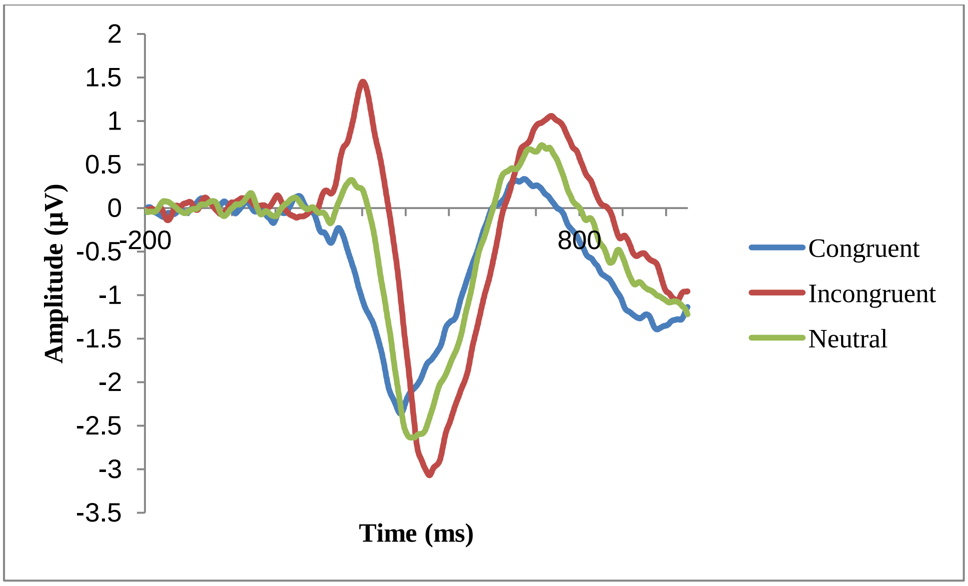


Figure 11. LRP waveforms elicited by each trial type.

LRP Amplitude (Congruent and Neutral). An identical analysis to that above was computed using peak amplitude data. A main effect of congruency (F(1, 34) = 34.164, *p*< .001) and a congruency × flanker distance interaction (F(2, 68) = 3.415, *p*< .05) was observed. No main effect or interaction with videogame playing group reached significance. A paired-t-test indicated congruent trials elicited significantly more negative peak amplitude when compared to neutral trials (t(35) = -6.096, *p*< .001). Paired t-tests indicated neutral trials elicited significantly less negative peak amplitudes when compared to congruent trials at small and medium distances (t(35) = -5.069, *p*< .001; t(35) = -6.045, *p*< .001, respectively). A similar pattern was also observed during large flanker distance trials, although this difference only approached significance (t(35) = -1.979, *p* = .056).

*LRP Latency (Incongruent and Neutral).*A mixed-design ANOVA of LRP latency data was computed using just incongruent and neutral congruency trials with distance (small, medium, large) as the second within-subject variable alongside videogame playing behaviour (videogame player, non-videogame player) as the between subject variable.

Table 12. Means and standard deviations for LRP latency for each trial type.

Distractor Distance	Small	Medium	Large
VGP			
Congruent	331.07 ±24.79	337.53 ±18.47	323.33 ±33.94
Incongruent	313.13 ±25.89	306.13 ±18.17	293.00 ±23.76
Neutral	333.13 ±20.33	333.80 ±25.08	333.13 ±18.34
NVGP			
Congruent	325.14 ±34.09	333.57 ±18.18	330.19 ±26.21
Incongruent	297.71 ±22.40	305.10 ±26.14	293.19 ±28.56
Neutral	315.67 ±47.57	323.10 ±34.55	332.24 ±29.21

Table 13. Means and standard deviations for LRP peak amplitude for each trial type.

Distractor Distance	Small	Medium	Large
VGP			
Congruent	-2.26 ±0.96	-2.25 ±1.48	-1.66 ±0.89
Incongruent	2.05 ±0.90	1.68 ±0.85	1.53 ±0.83
Neutral	-1.27 ±1.02	-1.51 ±0.80	-1.35 ±0.86
NVGP			
Congruent	-2.18 ±0.08	-2.50 ±0.96	-1.96 ±1.05
Incongruent	2.31 ±1.05	2.54 ±1.03	1.90 ±0.97
Neutral	-1.21 ±1.04	-1.08 ±1.05	-1.39 ±0.97

A main effect of congruency (F(1, 34) = 38.640, *p*< .001) and approaching significant interactions of videogame group × distance (F(2, 68) = 2.734, *p* = .072) and congruency × distance (F(2, 68) = 3.022, *p* = .055) were observed. Independent sample t-tests indicated videogame players elicited significantly delayed LRP waveforms when the flanker distance was small (t(35) = 5.847, *p*< .05). No differences were observed with medium or large flanker distances.

A paired t-test indicated incongruent trials elicited significantly earlier negative LRP deflection than neutral trials (t(35) = -6.290, *p*< .001). Paired t-tests also indicated incongruent trials elicited significantly earlier LRP waveforms when compared to neutral trials at each flanker distance (small: t(35) = -2.627, *p*< .05; medium: t(35) = -3.129, *p*< .01; large: t(35) = -7.345, *p*< .001). Directional differences indicated significantly earlier incongruent trial LRP elicitations during large flanker distances when compared to small and medium distances (t(35) = 2.442, *p*< .05; t (35) = 2.573, *p*< .05, respectively).

*LRP Amplitude (Incongruent and Neutral).*An identical mixed-design ANOVA as employed previously was computed using LRP amplitude data for incongruent and neutral trials only. A significant main effect of congruency was observed (t(35) = 19.850, *p*< .001) indicating incongruent trials elicited significantly more positive LRP peak amplitudes as a neural correlate of incorrect response priming. This was to be expected (Kopp et al., 1998). A main effect of videogame playing group was also identified (F(1, 34) = 5.290, *p*< .05), indicating videogame players elicited significantly smaller peak amplitude across both neutral and incongruent conditions when compared to non-videogame players. Independent samples t-tests indicated VGPs elicited significantly smaller LRP peak amplitude to incongruent trials compared to NVGPs (33.093) = -2.662, *p* < .05), while no difference was observed between groups during neutral trials (*p* > .05).

Discussion

Despite finding no significant behavioural between subject effects in the current study, a trend difference between VGPs and NVGPs in reaction times indicated a similar effect to recent studies may have been present (Green & Bavelier, 2003; 2006a;2006b;Castel et al., 2005). Any lack of a behavioural difference in both reaction time and accuracy may be due to two factors; firstly, increased participant numbers in an effort to tease out smaller effects hidden in the task. This may also be due to the nature of covert recruitment and seen as evidence of weaker effects than videogame literature has previously suggested. Indeed, no correlation between videogame hours and reaction time further suggests any effect or effects too small to be statistically significant. Secondly, the task itself may not be powerful enough to identify between-group differences especially with very high accuracy percentages being the norm. Although stimulus proximity and inter-stimulus-interval manipulation can manipulate the difficulty of incongruent trial types most, most individuals score approximately 90% correct for the most difficult trial types (Sanders & Lamers, 2002).

The N2c was primarily elicited at the frontal electrode site during incongruent trials. Previously the N2c has been identified as a correlate of attentional classification of task relevant stimuli (Pritchard et al., 1991) and associated with flanker compatibility processing (Kopp et al., 1996). Similar to Kopp et al., (1996) the N2c appeared to be confined to incongruent trials, potentially questioning the process the N2c reflects, and defining the components executive control process as being more related to inhibition of erroneous priming. Additionally the N2c was significantly delayed during small flanker distance trials known to cause greater interference, further supporting the N2c as a neural correlate of flanker compatibility processing. The significant N2c peak amplitude, videogame player × distance × electrode site interaction indicated NVGPs processed small and large distances was observed, where VGPs processing remained largely consistent over all distances (as measured over most electrode sites). Such a pattern of results may reflect VGPs processing irrelevant flanking stimuli even at large distances whereas NVGPs do not. One explanation of this may result from VGPs enhanced visuospatial resolution in the periphery (Green & Bavelier, 2007). A second explanation may be due to VGPs possessing additional attentional resources that allow the, to attend to these flankers in the periphery and allow them to be processed. Furthermore, VGPs elicited reduced N2c negativity in the occipital lobes for small distance trials, whereas NVGPs elicited more negative N2c amplitude during smaller distance trial types at frontal and central electrode sites. This pattern of results suggests VGPs may utilize different areas of the brain compared to NVGPs, perhaps representative of alternative strategy use.

A previously examined ERP component, the P3 has been linked to enhanced top-down processing and decision making in VGPs, specifically related to the inhibition of distractors as opposed to any sort of target prioritization (Wu et al., 2012; Mishra et al., 2011). The current finding of significantly greater mean activity for VGPs when compared to NVGPs conforms to these previous studies in that VPGs may possess enhanced perceptual decision making. This result, alongside P3 mean activity being significantly higher throughout incongruent trials, may reveal this modulated perceptual decision making to reflect enhanced inhibition of distractors. Previous research has identified the P3 as being elicited by rare or unpredictable relevant information (Polich, 2007; Hillyard & Picton, 1987), however as the task used equal probability trial types, any difference in VGPs processing of uncommon stimuli can be eliminated. The P3 component elicited in this case is more likely to reflect the strength of the perceptual decision making process to inhibit irrelevant flanking stimuli. This result indicates that videogames may alter more than low-level exogenous processes (Chrisholm et al., 2010), but supports previous findings that top-down attentional discrimination and processing is modulated. One might argue the importance of modulated top-down components specifically that videogames do not alter only basic low level elements of the visual system, but higher level cognitive functions that may be more able to transfer to additional tasks outside of videogame playing.

Possibly of most significance is finding of a difference in the incongruent late window LRP between groups, with VGPs eliciting significantly smaller peak LRP than their NVGP counterparts (the same result approached significance for mean amplitude). The LRP is thought to be a neural correlate of central activation of motor responses elicited from the motor cortices (Eimer, 1998). A standard LRP for a congruent trial would elicit a single positive deflection, representing priming of the correct hand; whereas correctly answered incongruent trials typically elicit a negative deflection prior to a later positive deflection, representative of initial priming of an incorrect/opposite hand response (Eimer & Schlaghecken, 2003). This deflection from negative to positive is thought to represent inhibition at the motor activation stage of processing. Therefore, VGPs eliciting a significantly smaller initial negative (incorrect) deflection may be indicative of VGPs possessing an advanced ability in reversing primed responses. With regards to videogame play, this makes sense as gamers are often primed to respond to an expected stimulus (e.g. enemy player) which may not be present.

One might argue that in unison with an altered N2c component and LRP, the current research supports work by Clark, Lanphear and Riddick (1987) whose videogame intervention appeared to improve elderly adults response-selection processing. As the congruent and incongruent nature of the Eriksen Flanker task is very similar to S-R paradigms, here I observed significant differences in the elicitation of multiple components concerned with compatibility and inhibition. An altered N2c and LRP supports more recent work by Castel, Pratt and Drummond (2005) who summarized that VGPs used similar visual processing strategies to NVGPs, but possessed faster stimulus-response mappings. Although no significant difference in component latency was found, our observed differences in amplitude and mean activity may be indicative of more efficient stimulus-response mapping, or at the very least efficient processing at the stimulus-response stage.

In summary, VGPs appear to display enhancements in several cognitive domains including attention, executive control and motor activation; however the task itself may not have been demanding enough to bring out noticeable behavioural differences. The current study lends support to VGP’s enhancements leaning towards advanced inhibitory abilities, at both the perceptual discrimination and response stages of the processing stream. Further investigation of the motor processing stage is required; the current study identified more efficient inhibition, but only during incongruent trials, and with no significant differences in latency I may have yet to find the processing stages responsible for enhanced response times so commonly found in VGPs (Dye et al., 2009).

Chapter 4. Attention to Distractors

Upon observing modulation of the N2c and LRP, components reflecting executive control, and motor-response forms of inhibition, chapter 4 aims to further investigate how videogame playing may modulate selective attention towards distractors - specifically, whether VGPs modulation in selective attention relates more so to target prioritization, or that of distractor inhibition. To do this, I employed a visual search paradigm (Lorenzo-Lopez et al., 2008) designed to elicit the selective attention components N2pc and P3 in order to identify whether VGPs and NVGPs do differ in their attentional mechanisms within the processing stream, or whether this is predominantly attributable to alterations in executive control and motor response.

Spatial attention i.e. the ability that mediates our capability to detect a target amongst non-targets in visual space is essential to normal everyday function. This form of attention is utilized when driving a car, crossing the street, or simply identifying where a desired item sits on a supermarket shelf. It is therefore logical to explore potential ways of improving such abilities.

Green and Bavelier (2003) used a visual search paradigm in which the perceptual load could be increased or decreased alongside flanking stimuli that could facilitate or hinder target identification. Although visual search efficiency in terms of basic response time and accuracy data were not the focus of that study, the flanker compatibility effect measure is thought to give an accurate representation of attentional resources (Lavie & Cox, 1997). Videogame players retained a compatibility effect as perceptual load of the visual search was manipulated from easy to difficult, whereas non-videogame players flanker compatibility effect decreased, respectively. As a result, VGPs showed significantly greater compatibility effects compared to NVGPs at the highest difficulty, indicating VGPs possess greater attentional resources than NVGPs. This paradigm was repeated with an additional manipulation, flanking distractors were presented at variable distances in the periphery in order to test attentional resources across both central and immediate peripheral vision (Green & Bavelier, 2006b). Again, VGPs possessed greater attentional resources in central vision, but this pattern remained in peripheral vision – indeed I found a pattern of results concluding a greater attentional resources and control of those resources in Chapter 2 of this thesis.

Castel, Pratt, and Drummond (2005) utilized a more traditional visual search paradigm in which difficulty could be manipulated through increasing or decreasing distractor similarity to the target stimulus. Whilst no differences in accuracy was observed, VGPs displayed enhanced response times when compared to NVGPs. Meta-analyses of videogame literature has identified this as a common trend, significantly reduced reaction times with no detriment to accuracy (Dye, Green, & Bavelier, 2009). However, the initial experiment of the Castel et al., (2005) paper tested between group differences in an inhibition of return (IOR) paradigm, and although VGPs showed reduced response times, the IOR effect in both groups remained the same. Therefore, the authors conclude that habitual video game play fails to alter any attentional mechanisms tapped by the test of IOR, and faster reaction times which are believed to stem from enhanced stimulus-response mapping. Importantly, the authors suggested enhanced executive control may modulate the allocation of attention, which may in turn explain enhanced endogenous attention as observed by Green and Bavelier (2003). Indeed, through the use of the attentional network test (a combined test of attentional alerting, orientation, and executive control), VGPs were again found to possess greater attentional resources than NVGPs (Dye, Green, & Bavelier, 2009).

Visual search tasks have been thoroughly studied in the past in relation to electrophysiological responses (e.g. Luck & Hillyard, 1990, 1994a, 1994b). The paradigm itself requires the participant to identify a target item present within an array of non-target distracting items. Two components of interest, well documented in the investigation of visual search, are the N2pc and P3 (Luck & Hillyard, 1994a; 1994b; Kiss, Van Velzen, & Eimer, 2008). The N2pc is a negative deflection at approximately 200ms after target onset, which is laterally expressed in the parietal area of the brain in response to stimuli in the contralateral field. The N2pc is thought to reflect attentional processes used when completing a visual search, specifically attentional mechanisms responsible for selecting a target-relevant stimuli amongst task-irrelevant distractors (Kiss et al., 2008). This is further supported by an absence of N2pc elicitation in homogenous arrays consisting of identical non-target information, since spatial attention is not required on such trials (Luck & Hillyard, 1994). The later P3 component is often expressed as a positive deflection between 300-600ms containing two subcomponents, the P3a elicited in the frontal lobe and the subsequent P3b elicited in the posterior lobe (Polich, 2007). Donchin (1981) postulated the P3 reflected the allocation of attentional resources and the updated neural representation of the visual environment. As the P3 is elicited after target presentation, the time taken for this component to be elicited reflects the length of time required to evaluate and categorize the stimulus (Curry & Polich, 1992).

The current study aimed to assess the effect of videogame playing on the neural correlates of visual search. The paradigm was based on a visual search task used by Loreno-Lopez, Amenedo and Cadaveira (2008). This task was chosen as it reliably elicits the N2pc and P3 waveforms. The visual search task consisted of three types of bilateral search arrays; target pop-out defined by orientation, distractor pop-out singleton defined by orientation and colour, and non-target trials. The inclusion of a distractor singleton aimed to measure attentional control in VGPs and NVGPs, attentional capture of this singleton would elicit the N2pc waveform and potentially delay response times.

An additional methodological improvement as suggested by Boot et al., (2011) was that of covert recruitment. Covert recruitment aimed to reduce demand characteristics within the groups, so VGPs would not perform better as they were being recruited as expert gamers, and vice versa for NVGPs. Previous studies utilizing covert recruitment have tested temporal order judgement (Donohue, Woldorff, & Mitroff, 2010) and change detection (Clark, Fleck, & Mitroff, 2011) and both successfully found differences between VGPs and NVGPs, however no study has yet used covert recruitment with either visual search or EEG, let alone the two combined. The combination of these methodologies provides a unique platform to measure where in the processing stream habitual game playing may affect visuospatial attention without the potential demand characteristics imposed by overt recruitment techniques.

In line with past videogame research, it was hypothesized that videogame players would display reduced reaction times with no speed-accuracy trade-off. Additionally, one would expect these behavioural differences to be mirrored in electrophysiological recordings. Reduced latencies of the N2pc and P3 in the visual search task were expected in VGPs when compared to NVGPs, reflecting earlier target selection and object categorization, respectively. The amplitudes of the N2pc and P3 were also predicted to differ in VGPs as a reflection of enhanced top-down processing (Kiss et al., 2008; Wu et al., 2012) whereas early visually evoked potentials (such as the N1 and P1) thought to reflect bottom-up processing were expected to remain unchanged.

A further consideration was to predict a modulation of the N2pc during pop-out distractor trials. Previous videogame research has indicated VGPs possess additional attentional resources, and that these resources frequently ‘spill-over’ and process additional items (Green & Bavelier, 2003). However, differences in the processing of pop-out distractors may not translate to statistical differences in behavioural measures due to the enhanced inhibitory capabilities VGPs have displayed in previous literature (Green & Bavelier, 2006a; Chrisholm et al., 2010) and in the previous chapter through modulations in the N2c and LRP waveforms.

Method

Participants

A sample of 42, comprising undergraduate and postgraduate students was recruited from the University of Hull to take part in a study under the pseudonym, 'Investigating the underlying neural correlates of attention'. A pseudonym was used to ensure participants were unaware that videogame playing behaviour was being measured, thus avoiding the issue of demand characteristics and placebo effects (cf. Boot et al., 2011). A measure of videogame play was covertly taken as one part of a 'free time' questionnaire. Undergraduates were awarded course credit for participation and postgraduates received fiscal compensation. In total, eight participants were removed due to poor accuracy (<75%) (n=1), poor EEG recordings (n=2) or not fitting either the videogame player or non-videogame player criteria (n=5) .VGPs were classified on the basis of spending an average of 6 or more hours of action videogaming (typified as high salience fast tempo games) per week, whereas NVGPs played less than 2 hours per week of non-action videogames (slower paced games) and no action games over the past 5 years. The 36 participants included 21 non-videogame players (5 males; 16 females) (M age: 23.52, SD: 5.45) and 15 videogame players (12 males; 3 females) (M age: 22.4, SD: 3.96). All had normal/corrected vision, right hand dominance and were free from medical ailments (as assessed by self-report).

Stimuli and Procedure

The following stimuli and procedure were based on those used by Luck and Hillyard (1994a). Participants were sat in a comfortable chair approximately 120cm from a 24inch Samsung LCD monitor with a standard QWERTY keyboard placed within reaching distance in front of the monitor. The room was darkened, soundproofed and shielded from electronic interference. The current visual search paradigm used a multi-element bilateral display consisting of 8 stimuli presented equidistantly around the perimeter of a virtual circle centred on a black fixation cross at 20, 60, 120, 160, 200, 240, 300 and 340°. All trials were conducted using a light grey background. The stimuli were presented equidistant from each other and from the central fixation cross with four stimuli presented in the left visual field and four stimuli presented in the right visual field. The stimuli were blue rectangles measuring 0.14°x0.81°, with an edge to edge distance between one another of 2° and 3° distance from the central fixation cross. Each array was presented within a 7.1° x

5.0°rectangle not visible to the participant. Both target and non-target stimuli were coloured blue (RGB: 0, 0, 255); the target stimulus differed in orientation only, with horizontal rectangles as non-target stimuli and the target stimulus being vertical. An irrelevant colour pop-out singleton was presented on some trials in the form of a vertical red (RGB: 255, 0, 0) rectangle. Participants were required to press the ‘m’ key during target-present trials and the ‘z’ key on homogenous and distractor trials. Prior to the experiment beginning participants were asked respond as quickly and accurately as possible.

The experiment was displayed on a PC comprising an Intel i5 quadcore processor (3.2Ghz) and 3Gb RAM connected to a 24-inch colour monitor running at 60 Hz. All stimuli were presented at a resolution of 640x480 resolution using E-Studio (V 1.1 Service Pack 3). Each trial began with a black fixation cross displayed at the centre of the screen for a random interval between 900 and 1100 ms (See Figure 1). Subsequently the bilateral multi-element array was displayed for 2000ms, during which time the participant was required to identify whether the target stimuli was present or absent by pressing the appropriate key. If no response was given after 2000ms, an incorrect response was coded. Once a response was made or the response time length was exceeded the next trial began.

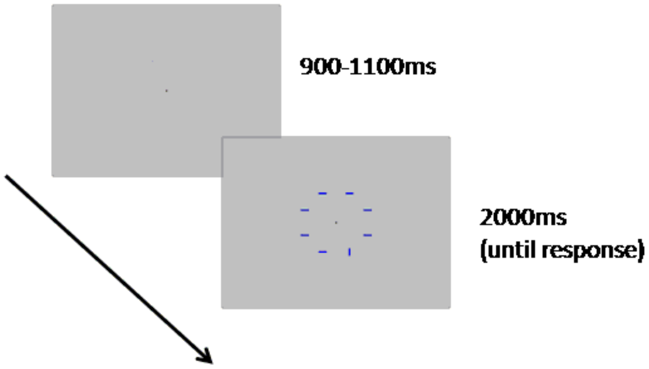


Figure 1. Example of visual search target trial procedure. The figure depicts a target present trial.

Participants were given 36 practice trials before the experiment proper. The main body of the experiment consisted of 10 blocks of 64 trials, with each block separated by a break (participants were able to determine the length of their breaks but asked prior to the experiment not to exceed 2 minutes in length). In total 384 target arrays (p=.6), 128 homogeneous arrays (p=.2) and 128 irrelevant target distractor arrays (p=.2) were used. Target stimulus positioning was equally likely to be displayed in one of the eight available positions, ensuring 50% of target trials displayed the target in the left visual field, and the remaining in the right visual field. This was also true for the irrelevant singleton distractor.

Data Analysis

Reaction times (RTs) and accuracy for every trial were recorded. Trials that contained errors or were part of the practice trials were excluded from all analyses. Additionally, responses with RTs shorter than 100ms or longer than 1000ms were not analyzed. The method of covert recruitment unfortunately yielded an imbalance in genders across groups; due to this, one-way ANOVAs were conducted for each array type with gender as the between group variable to identify any potential effects of gender. Subsequent correlation analyses further investigated the dependence on hours of gaming per week across all participants (prior to those removed who did not fit VGP/NVGP criteria) as well as for males only. Finally, a separate 2 × 3 mixed-design ANOVA was used to analyze data when grouped as videogame player or non-videogame player (as is common in the literature); the within-subject variable array type (target, distractor, homogenous) and player group (videogame player, non-videogame player) as the between-subject variable. All analyses were completed for both accuracy and reaction time measures.

EEG Recording

All recordings were taken in a soundproofed electrically shielded room adjacent to the control room where participants were monitored using a video camera. The electroencephalogram (EEG) was recorded using a 32-channel Brain Products active electrode system (ActiCap, Brain Products GmbH.). Electrodes were placed according to the 10/20 system at FP1, FP2, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, C3, Cz, C4, T7, T8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, PO9, PO10, O1, Oz and O2. All active electrodes were referenced to the vertex during set up before being referenced to the average of all electrodes during recording, and grounded with an electrode placed on the forehead (ActiCap Manual, Brain Products GmbH). Horizontal and vertical eye movements were recorded bipolarly using electrooculargrams (EOG) placed 1cm away from the outer canthi of each eye, and above and below the left eye. EEG signals were digitized constantly at a rate of 1000Hz and filtered on-line using a band pass of 0.1-50Hz using a QuickAmp amplifier (Brain Products GmbH.). The impedance of all electrodes was maintained below 10 kΩ. All recordings were further shielded from ambient noise, electrical artefacts and cable movement interference by having the ActiveShield submode (Brain Products GmbH.) activated through an online “guarding” process. (ActiCap Manual, Brain Products GmbH)

EEG Analysis

All recordings were filtered offline at a band-pass of 0.1Hz (12dB/Oct Slope) and 30Hz (24dB/Oct Slope). Ocular related artifacts such as blinks and lateral eye movements were corrected using Gratton & Coles (1983) method. Non-ocular related artifacts containing deflections exceeding ±100μV and activity below 0.5μV were removed. Data from correct trials was segmented into epochs of 200ms pre-stimulus to 900ms post-stimulus. Epochs were created for each trial type and for each visual field of target presentation before averaging. Prior to averaging, each epoch was baseline corrected with respect to 200ms prior to array onset. All analysis was completed using Brain Analyzer 2 (Brain Products GmbH.).

The P3 component analysis was confined to posterior electrodes (Fz, Cz, Pz, Oz). The peak latency window for the P3 (300-600ms) component was taken from Lorenzo-López, Amendo, and Pascual-Marqui (2008b) and visual inspection confirmed this time window to be appropriate. The mean peak onset, peak amplitude and mean activity within the time window of the P3 were analyzed in a similar manner to the behavioural results, i.e. using ANOVA and correlation analyses to check for gender effects before a mixed design ANOVA in order to measure between-group differences. The mixed-ANOVA included array type (target, distractor, homogenous) and electrode site (Fz, Cz, Pz, Oz) as the within-subject variables with videogame playing behaviour (VGP, NVGP) as the between subject variable.

Due to the laterality of the N2pc component, difference waveforms were calculated to isolate the N2pc from other unrelated bilaterally elicited components (Girelli& Luck, 1997; Luck & Hillyard, 1994a). Difference waveforms were calculated by subtracting ERP waveforms from arrays containing ipsilateral targets from arrays containing contralateral targets (relative to electrode locations). Initially the latency window in which the N2pc component was measured was taken from Lorenzo-López, Amenedo, &Cadaveira (2008a) at 200-275ms after stimulus onset. However this was subsequently changed to an earlier window of 175-275ms after visual inspection of individual participants average waveforms. All analysis was confined to parietal and parieto-occipital electrode pairs. Latency, amplitude, and mean activity data was as previously described (see P3 analysis section above). The final mixed ANOVA includes videogame playing group as the between subject factor (videogame player, non-videogame player), electrode site (P3/P4, P7/P8, PO9/PO10) and array type (target, non-target distractor) as the within-subjects factors. As the N2pc is thought to reflect the processing of contralateral stimuli more than ipsilateral stimuli, homogenous arrays were not included in these analyses.

All electrophysiological waveforms were extracted using three methods as supplied by Brain Products GmbH. Mean activity in the given time windows above, and peak waveform start (ms) and amplitude (highest amplitude µV) within the waveform time window. Note: Only Peak amplitude and peak latency analyses have been included below, for mean activity analyses please see the appendices of this thesis.

Any analyses breaching sphericity were Greenhouse-Geisser corrected.

Results

Behavioural results

One-way ANOVAs for each array type (target, distractor, homogenous) with gender (male vs. female) as the between-subject variable yielded no significant differences for both reaction time (all *p's*> .2) and accuracy scores (all *p's* > .5). As gender had no significant effect, both males and females were included in subsequent analyses.

One-tailed correlations combining all participants indicated a significant relationship between hours of videogames played per week and the reaction time it took to correctly identify target arrays, r = -.310, *p* (one tailed) <.05. Improved accuracy scores of the same relationship began to approach significance, r = .255, *p* (one-tailed) = .067. No other arrays yielded significant or approaching significant relationships with the numbers of hours played (remaining *p's* >.1).

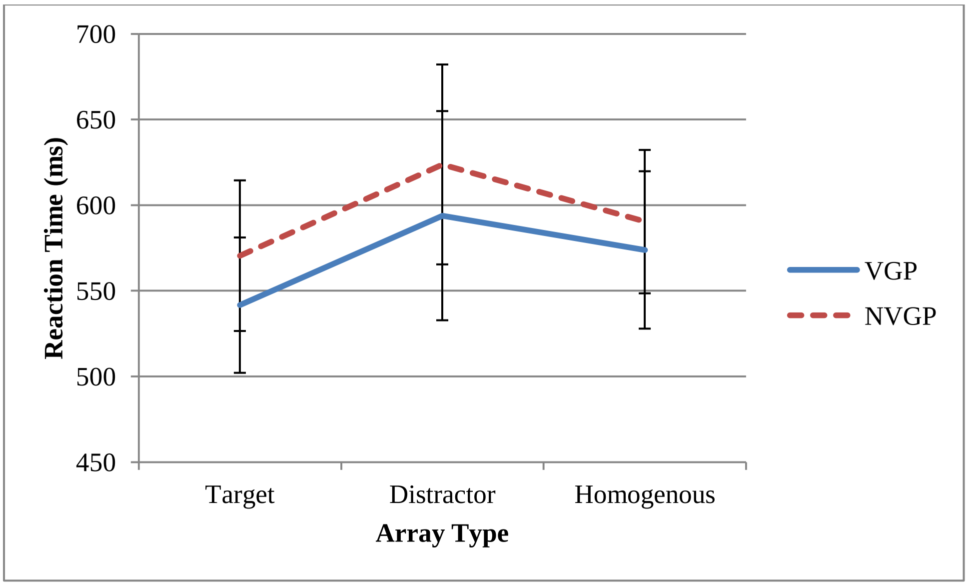
Secondary correlations including only males indicated a significant relationship between hours of videogames played and target array reaction times, r = -.435, *p* (one-tailed) <.05. No other relationships, for RT or accuracy scores, approached significance.

A mixed-design ANOVA combining both males and females included array type (target, distractor, homogenous) as the within-subject variable and videogame playing behaviour (VGP, NVGP) as the between-subject variable. Reaction time data indicated a main within-subject effect of array (F(1.543, 52.472) = 38.414, *p* <.001, indicating fastest response times for Target arrays, followed by no target and distractor arrays. No interaction between array type and the between subject variable (F(1.543, 68) = .767*, p* = .468) or main effect of videogame playing group (F (1, 34) = 2.780, *p* = .105) were found. A subsequent one-way ANOVA including each array type indicated videogame players identified target arrays almost significantly faster than non-videogame players (F(1, 34) = 4.099, p = .051; see Table 1 and Figure 2). No difference in distractor or homogeneous trials was observed.

Accuracy scores input into an identical male and female mixed-ANOVA also indicated a main effect of array type (F(2, 68) = 19.669, *p*< .001), with means showing Target arrays produced the highest accuracy scores and Distractor arrays the lowest. No interaction between array and videogame playing behaviour (F(2, 68) = 1.795, *p* = .174) or main effect of videogame playing behaviour (F(1, 34) = .287*, p* = .596) were found. As with reaction time analyses, a subsequent ANOVA including accuracy scores for each array type was computed with videogame playing as the between subject factor. No significant or approaching significant differences in accuracy were observed (all *p's* > .2).

Table 1. Mean reaction time (ms) and Accuracy scores (% correct) presented alongside standard deviations for each array type as a function of videogame player status.

	Reaction Time (ms)		Accuracy (%)	
Array Type	VGP	NVGP	VGP	NVGP
Target	541.63 ± 39.51	570.51 ± 43.96	95.58 ± 2.71	94.55 ± 2.85
Distractor	593.86 ± 61.06	623.77 ± 58.35	91.07 ± 3.91	89.01 ± 6.54
Homogenous	573.86 ± 45.94	590.38 ± 41.85	91.29 ± 4.64	92.26 ± 5.95



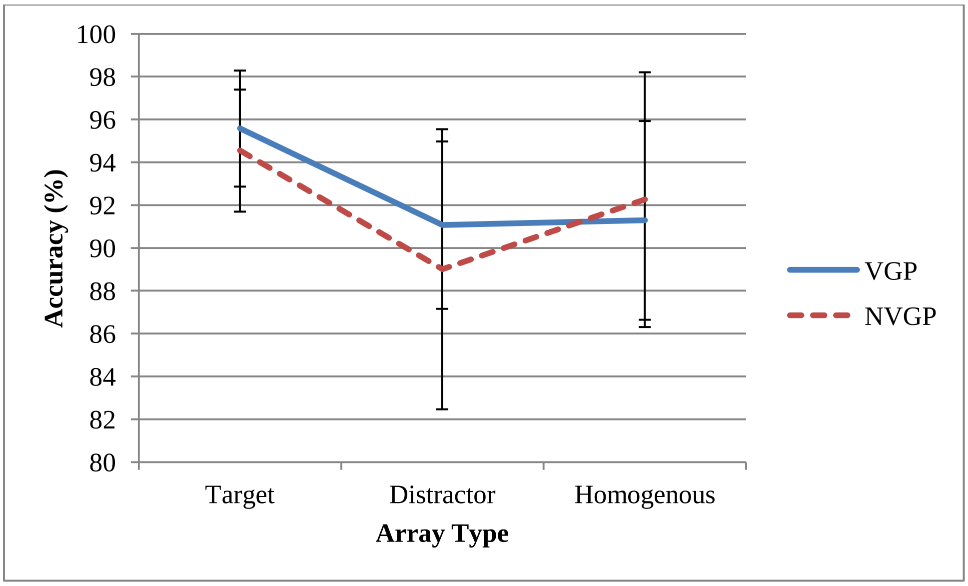


Figure 2. Reaction time (ms) and Accuracy (%) scores for each array type as a function of videogame playing status.

Electrophysiological results.

N2pc Latency. Correlational analysis including all participants showed a positive relationship between the number of hours played and latency N2pc elicitation at P3/P4 electrode pair during distractor trials, r = .330, *p* (two-tailed) <

.05. Subsequent analysis including only males indicated no significant relationships between N2pc latency and the number of hours played.

Table 2. N2pc latency means and standard deviations for all analysed electrode pairs.

Trial Type	Distractor	Target
VGP		
P7/P8	238.13 ±4.82	230.48 ±4.07
P3/P4	241.87 ±4.21	229.38 ±3.56
PO9/PO10	230.80 ±6.58	225.76 ±5.56
NVGP		
P7/P8	242.67 ±7.43	240.76 ±6.28
P3/P4	229.38 ±5.88	246.24 ±4.97
PO9/PO10	240.60 ±7.60	235.38 ±6.42

A mixed-ANOVA yielded a main effect of array type (F(1, 34) = 7.405, *p* = .01) indicating the N2pc was elicited significantly earlier during distractor trials in comparison to target trials. A main effect of electrode pair (F(1.531, 52.047) = 4.002, *p* = .034) was also observed. Paired samples t-tests indicated the N2pc was detected earliest at the PO9/PO10 electrode site in comparison to both P3/P4 (t(35) = 2.216, *p* = .033) and P7/P8 electrode sites (t(35) = 2.274, *p* = .029). No main effect of videogame playing group or other interactions between variables reached significance.

N2pc Amplitude. Bivariate correlation including all participants indicated the greater number of hours of videogames played the more negative the N2pc waveform elicited at P3/P4 electrode sites during distractor trials, r = .466, *p* (two-tailed) < .005. A similar trend was noted at P7/P8 electrode sites, although not significant, r = .297, *p* (two-tailed) = .079. Analyses including just males yielded no significant associations between the number of hours played and N2pc amplitude, although the relationship observed with P3/P4 distractor trials approached significance, r = .063, *p* (two-tailed) = .063.

Table 3. N2pc peak amplitude means and standard deviations for all analysed electrode pairs.

Trial Type	Distractor	Target
VGP		
P7/P8	-2.51 ±.34	-3.46 ±.28
P3/P4	-1.80 ±.21	-2.86 ±.17
PO9/PO10	-2.57 ±.31	-2.59 ±.26
NVGP		
P7/P8	-2.28 ±.48	-2.54 ±.41
P3/P4	-1.90 ±.32	-2.18 ±.27
PO9/PO10	-2.16 ±.38	-2.06 ±.32

A mixed-design ANOVA with videogame playing group as the between-subject variable produced a significant main effect of array type (F(1, 34) = 4.193, *p* < .05), whereby mean voltages indicating distractor arrays (M: -2.635 µV) yielded more negative N2pc waveforms in comparison to target arrays (M: -2.191 µV). A main effect of electrode pair was also observed (F(2, 68) = 6.587, *p* = .002). Paired t-tests indicated N2pc waveforms elicited at the P7/P8 electrode pair were significantly more negative than waveforms elicited at P3/P4 (t(35) = -3.855, *p* <.000) and PO9/PO10 electrode sites (t(35) = -4.234, *p*< .000). Although no main effect of videogame playing group was observed, a significant interaction between electrode pair and videogame group reached significance (F(2, 68) = 3.799, p = .027) (See Fig. 3). Amplitude data for each electrode pair was entered into a one-way ANOVA with videogame playing group as the between-subject variable. Non-videogame players elicited significantly more negative N2pc waveforms at the P3/P4 electrode site (F(1, 34) = 8.397, *p* = .007) with a similar but non-significant trend at

P7/P8 electrodes (F(1, 34) = 2.460, *p* = .126). Almost no difference was observed between groups at the PO9/PO10 electrode site, F(1,35) = .022, *p* = .822.

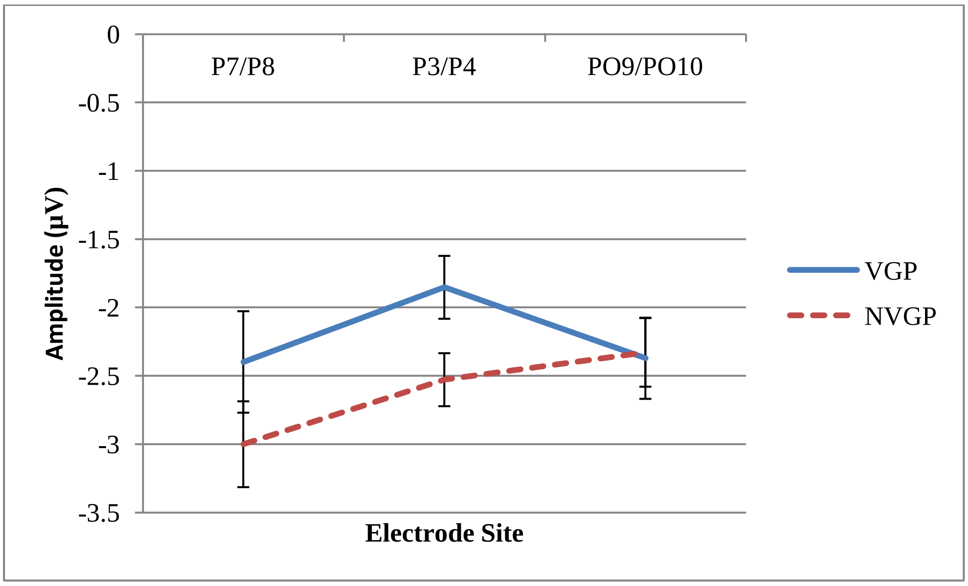


Figure 3. N2pc amplitude (µV) at each electrode pair as a function of videogame playing status.

P3 Latency. As before correlational analyses were run combining all participants and separately for just males, and the number of hours played was compared to the latency onset of the P3 component at for each combination of array type and electrode site. The number of hours played appeared to increase the P3 onset during homogenous trials at Cz, r = .467, *p* (two-tailed) = .004. No others reach significance.

Data input into a mixed-ANOVA showed a main effect of electrode site (F(1.886, 62.222) = 6.229, *p*< .000). A main effect of array type was noted (F(1.560, 51.478) = 48.408, *p*< .000) (See Fig. 4). An array type × electrode site interaction was also present (F(3.071, 101.338) = 18.569,*p*< .000), and further analyses indicated target arrays elicited significantly delayed latencies at frontal and central electrodes (Fz: t(34) = 6.458, *p*< .000; Cz: t(35) = 5.490, *p*< .000) alongside significantly earlier elicitation at the occipital electrode site when compared to homogenous arrays, t(35) = 3.684, *p* = .001.

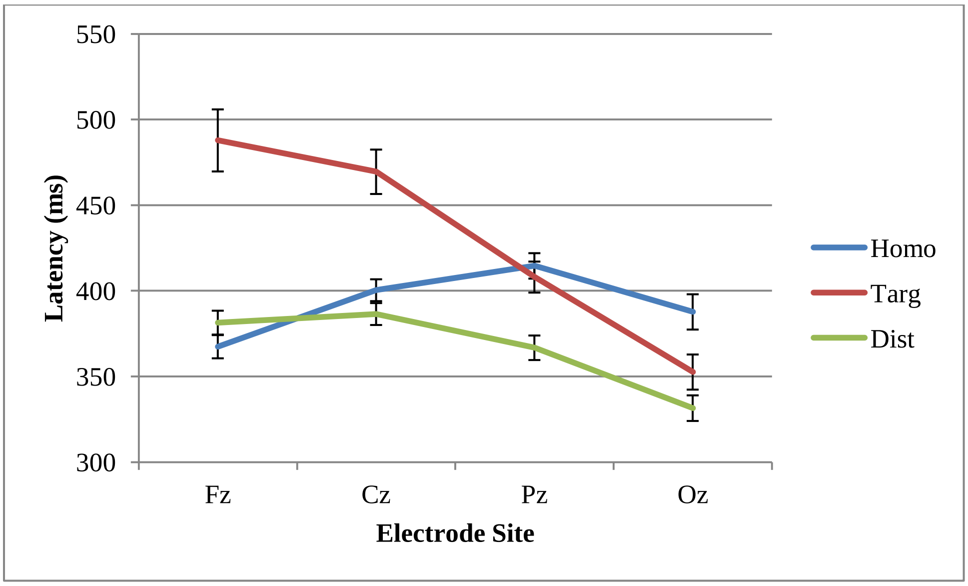


Figure 4. P3 latency values at each electrode site as a function of array type.

Table 4. P3 peak latency means and standard deviations.

Trial Type	Homogenous	Target	Distractor
VGP			
Fz	376.13 ±10.23	494.00 ±27.39	398.00 ±10.53
Cz	420.60 ±9.63	488.93 ±19.59	391.73 ±9.67
Pz	421.00 ±11.21	417.53 ±13.68	364.80 ±10.82
Oz	388.66 ±15.57	349.13 ±15.49	328.00 ±11.29
NVGP			
Fz	385.70 ±8.86	481.7 ±23.72	364.95 ±9.11
Cz	380.20 ±8.34	450.15 ±16.97	381.25 ±8.37
Pz	408.20 ±9.71	398.60 ±11.85	368.80 ±9.37
Oz	386.80 ±13.49	356.10 ±13.42	335.10 ±9.78

A significant between-subject effect of videogame playing group was also observed, (F(1, 33) = 4.448, *p* = .043), with means indicating non-videogame players elicited significantly earlier P3 components than videogame players (Mean – VGP: 403.211ms; NVGP: 389.213ms). No other significant interactions were observed.

P3 Amplitude. Correlational analyses again combining both genders and for just males yielded no significant relationships between numbers of hours played and P3 amplitude. A main effect of electrode site was found (F(1.978, 65.262) = 23.886, *p*< .000) and paired t-tests indicated Pz yielded significantly larger P3 amplitudes than all other electrode sites (Fz: t(34) = -6.901, *p*< .000; Cz: t(35) = 6.382, *p*< .000; Oz: t(35) = 5.896, *p*< .000). A significant effect of array type was observed (F(2, 66) = 29.175, *p*< .000) as was an array type * electrode site interaction was also observed (F(3.549, 117.118) = 39.145, *p*< .000). Further analyses indicated homogenous arrays elicited significantly larger amplitudes at the frontal electrode site (t(34) = 3.629, *p* = .001) and significantly smaller amplitudes at posterior (t(35) = -6.667, *p*< .000) and occipital electrodes (t(35) = -9.634, *p*< .000) when compared to target arrays. These comparisons were also significant in homogenous to distractor comparisons. No other significant interactions were observed.

Table 5. P3 peak amplitude means and standard deviations.

Trial Type	Homogenous	Target	Distractor
VGP			
Fz	1.17 ±.66	0.28 ±.46	-0.24 ±.59
Cz	2.99 ±.65	3.82 ±.54	2.81 ±.61
Pz	4.45 ±.82	6.17 ±.78	5.84 ±.86
Oz	0.64 ±.70	4.85 ±.77	5.28 ±.81
NVGP			
Fz	1.37 ±.57	0.36 ±.40	0.22 ±.22
Cz	3.33 ±.56	3.32 ±.47	3.43 ±.53
Pz	4.69 ±.71	6.29 ±.67	5.63 ±.75
Oz	-0.42 ±.61	2.41 ±.66	2.51 ±.70

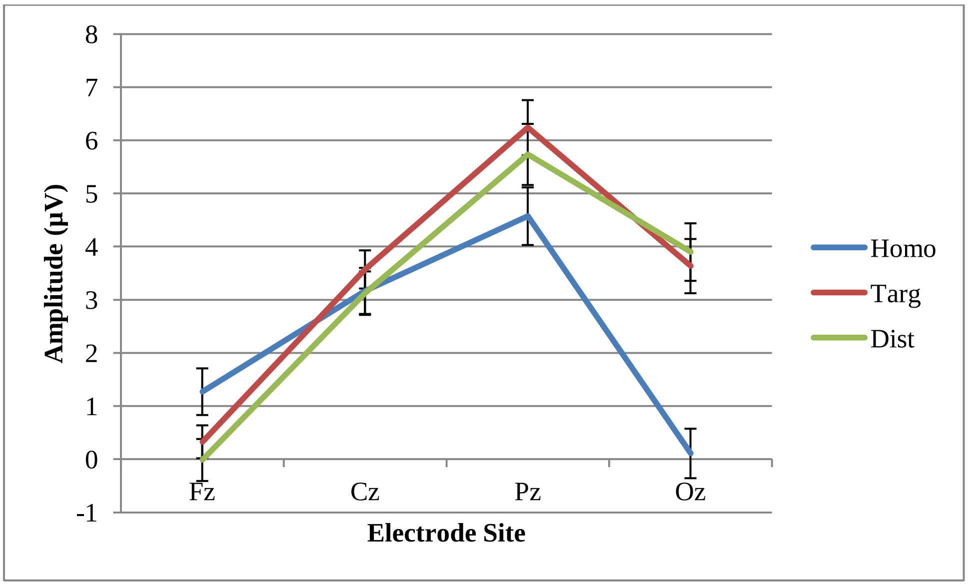


Figure 5. P3 amplitude values elicited at each electrode site as a function of array type.

Discussion

The behavioural results revealed a relationship between videogame playing and enhancements in visual selective attention. Correlational analysis indicated those who reported higher amounts of action videogame play responded significantly faster than individuals with less videogame experience during target trials; this relationship almost reached significance for accuracy data also. The association between gameplay and reaction time was further corroborated by an almost significant effect identified during analysis of variance. As the results indicate faster response time at no expense of accuracy, no speed-accuracy trade-off occurred, in agreement with past literature (Dye et al., 2009). However, due to a methodological confound (trial numbers not being counterbalanced) main effects of array type must be interpreted with caution.

Correlational analysis of electrophysiological recordings indicated slower N2pc peak onset during distractor trials (at P3/P4) for participants with more hours of reported monthly videogame play over the past 12 months. Additionally, analyses of the N2pc tended to indicate non-videogame players elicited more negative N2pc waveforms during distractor trials in comparison to videogame players. These findings indicate differences in the underlying neural mechanisms involved in visual selection between the two groups, specifically in distractor processing/inhibition. Indeed Wu et al., (2012) postulated that from greater P2 and P3 amplitudes VGPs possessed greater inhibition to irrelevant distractors, whilst reduced N2pc amplitudes in VGPs during distractor trials in the current study may reflect reduced processing of the irrelevant distractors. Luck et al., (1997) noted N2pc amplitude as a correlate of the amount of attention allocated during visual search, indicating videogame players may require less attentional resources to process distractor arrays than non-videogame players.

A fairly consistent, and unexpected main effect of array (i.e. distracters eliciting potent N2pc potentials) may have been due to the non-target distractor differing from remaining distractors by two features, both colour and orientation; and therefore affected waveforms in distractor trials for the N2pc. Distractor stimuli sharing similar features as target stimuli have been found to elicit N2pc components during both target and distractor arrays types (Luck & Hillyard, 1994b). This double feature differentiation between distractor and homogenous arrays may increase exogenous attentional orientation and thus be responsible for the greater amplitude of the N2pc for NVGPs during distractor trials in comparison to target trials in

NVGPs. Indeed, previous research by Luck et al., (1997) observed increased N2pc amplitudes to stimuli defined by conjunctions. Furthermore reduced N2pc amplitudes in VGPs may represent more efficient suppression of competing stimuli and, specifically irrelevant stimuli difficult to prevent attending to such as the pop-out singleton distractor. A negative correlation indicating more delayed N2pc onset with increases in gaming hours may reflect VGPs enhanced attentional control, and that the distractor singleton does not capture attention in VGPs as early as it does in NVGPs.

Some similar patterns to N2pc findings were notable during P3 analysis, specifically significantly earlier P3 onset for non-videogame players. On the other hand, some evidence was present to suggest greater mean activity of the P3 in videogame players when compared to non-videogamers. An unexpected finding of reduced latency for P3 in NVGPs may once again indicate a prioritization in P3 related processes such as stimulus evaluation (Polich, 1996; 2003) and the allocation of visual attention (Polich, 2007; Johnson, 1988). Typically we would expect enhancements in processing to elicit earlier P3 latencies, thus a later P3 in VGPs may be evidence of modulated processes earlier in the processing stream. Despite this, the amplitude of the P3 is thought to indicate the amount of attention allocated to a specific task (Kok, 1997; AnlloVento & Hillyard, 1996); and like Wu et al., who found larger P3 amplitudes in VGPs during an attentional field of view task, the current data suggests videogame players may indeed have significantly modulated P3 components. Therefore, the results between latency and amplitude appear to be mixed between groups, with NVGPs showing reduced peak latencies, and VGPs showing differences in amplitude. It is, however, important to discuss the limitations of this P3 mean activity result, and that the current study may not provide sufficient enough evidence (significant differences and approaching significance for distractor and target trials respectively at Oz) to support Wu et al. Indeed, any lack of P3 modulation may be due to task differences between the current study and Wu et al. (2012) or perhaps an effect only observed due to a training regime and/or task repetition.

The covert design of the current study aimed to address points made by Boot, Blakely and Simmons (2011), who posited overt recruiting of participants may yield unwanted demand characteristics. This would suggest any differences found in a cross-sectional design could be attributable to a placebo effect. This issue was addressed in the current study through measures hidden within a ‘free time’ questionnaire, and deception at the consent stage. Although certain measures only approached significance (e.g. reaction times during target trials), response time averages differ between groups by similar amounts (approximately 20-40ms) to previously reported results (Castel et al., 2005; Green & Bavelier, 2006b – High load conditions). Despite the positives of covert recruitment, the technique proved inefficient and unreliable in finding participants that matched the extensive VGP of previous studies. Furthermore, this imbalance in group numbers may be responsible for failing to reach significance. Indeed, to ensure adequate concealment within the questionnaire, only a single measure of videogame playing was used within the questionnaire, and further studies should utilize more thorough videogame playing measures that take into account longer than 12 months of behaviour. Student participants often noted their past videogame behaviours as extensive, however not in the past 12 months due to their university schedules, a point that should be addressed in future studies when using a student population.

To conclude, an overall trend for faster RTs indicates differences in underlying processing and/or strategy use between groups during the visual search are indicative of enhanced spatial selective attention in VGPs. Differences in the N2pc suggest modulation of attentional processing in VGPs; specifically that reduced waveforms in distractor trials may indicate reduced effort required for processing, and increased latency a lack of prioritization in the N2pc may reflect enhancements in suppression of competing stimuli. The current results alongside the training study conducted by Wu et al. (2012) provide some support that the observed alterations in neural networks do modulate performance on these tasks and that videogame playing in turn is responsible for these neural alterations. However, differences in which neural patterns were affected between such tasks as this and Wu et al. (2012) indicate further investigation is required.

Chapter 5. Target Acquisition or Distractor Inhibition

Chapter 4 identified a difference in the N2pc between VGPs and NVGPs, a neural correlate thought to reflect the attentional mechanisms responsible for target selection and distractor inhibition (Kiss et al., 2008). Further research into the N2pc (Hickey et al., 2009) identified the N2pc may be made of two further subcomponents, the target negativity and the distractor positivity. Chapter 5 uses the paradigm created by Hickey et al., (2009) in order to further investigate whether the modulation of selective attention mechanisms in VGPs relates to target prioritisation or distractor inhibition. In addition to this, the simple visual search paradigm used in this chapter elicits reliable early sensory-evoked potentials, allowing me to investigate the earliest (0-200ms) mechanisms of the stimulus processing stream.

Past research has found videogame playing behaviour can be directly attributed to enhanced visual selective attention. The flanker compatibility paradigms used in previous research (Green & Bavelier, 2003; 2006a) and Chapters 2 and 3, contains exogenous flanking stimuli. In contrast, the central perceptual load task requires endogenous attentional control to successfully select targets and prevent the processing of distractors, cognitive abilities required to complete classic feature and conjunction visual search tasks. Indeed, visual search tasks have been used within videogame literature. Their findings have led to the conclusion of videogame players possessing faster stimulus-response mappings but similar strategies and no enhancement in the deployment or speed of said strategies when compared to non-videogame players (Castel, Pratt, & Drummond, 2005). A recent meta analysis found increased processing speed in videogame players at no expense of accuracy, but the mechanism behind these enhancements remains unknown (Green, Dye, Bavelier, 2009).

The purpose of the visual search paradigm used in Chapter 4 was to identify whether this enhanced attention in videogame players stemmed from modulated N2pc and P3; event-related potentials thought to correlate with attentional processing. Although between-subject effects in the previous visual search task did not always pass the conventional threshold for statistical significance, differences were observed in both N2pc latency and amplitude between groups, indicating VGPs had delayed N2pc onset but more negative N2pc amplitudes when compared to NVGPs. From this one might postulate videogaming affects VGP’s ability to inhibit distractors in the processing stream is modulated, perhaps through the effort required or utilized for such processing. This modulation may stem from earlier alterations in the processing stream, such the attentional resources VGPs commit to other processes; or, VGPs may simply require fewer resources to successfully inhibit distractors.

Furthermore, modulation in the P3 (specifically the P3b) was also observed between groups, however these differences appear to be mixed. NVGPs were found to elicit a significantly earlier P3 component, whereas VGPs elicited greater mean activity than NVGPs during distractor and target present trial types. Theories that processing speed is enhanced by increased videogame experience, may suggest an earlier P3 elicitation in VGPs should be expected, however this was not the case. Perhaps this is an indication that videogame experience does not modulate indexing/classification speed of stimuli (Magliero, Bashore, Coles, & Donchin, 1984), or else the delay may be a residual effect of modulated processes earlier in the processing stream. Increases in P3 amplitude in VGPs may represent increased resource allocation to both target and the irrelevant pop-out distractor, and this would match previous findings that VGPs additional attentional resources often ‘spill-over’ and process exogenous distractor stimuli (Green & Bavelier, 2003) as a result of left over attentional resources.

Early investigation of the N2pc indicated it was a neural correlate of distractor inhibition (Luck & Hillyard, 1994b). Further research indicated the responsibility of the N2pc was to resolve ambiguities when processing multiple objects caused by ‘coarse coding’ according to theories of attention such as *ambiguity resolution theory* – a theory that suggests simultaneous coding of multiple items cannot be completed perfectly, and thus ambiguities occur in these representations (Luck, Girelli, McDermott, & Ford, 1997). Indeed, this may be the process used to inhibit distractors as previously postulated. Despite this, paradigms with a single target stimulus in the visual field alongside a single distractor in the opposite visual field have also identified strong N2pc components, indicating the N2pc may be a correlate of target processing as opposed to distractor inhibition (Brisson & Jolicoeur, 2007; Robitaille & Jolicoeur, 2006; Hickey, McDonald, & Theeuwes, 2006).

Hickey, Di Lollo and McDonald (2009) set about devising a visual search task that allowed them to test whether the N2pc accurately reflects inhibitory processing, or perhaps other attentional processes. Hickey et al., (2009) utilized the contralateral nature of the N2pc, and thus by presenting some items in the midline, activity elicited by lateralized targets and distractor could be assessed. This was done by manipulating the contralateral component of the N2pc; by moving the distracting and target stimuli between the midline and lateral visual fields, thus altering the deployment of attention. Any difference in the elicited N2pc can be accurately described as processing that respective stimulus. Furthermore, one of the presented stimuli was isoluminant to the background used in the task, ensuring differences in waveforms was not due to imbalances in sensory energy. Two subcomponents of the N2pc were noted, a distractor positivity; a positive deflection contralateral to the distractor item over the medial and dorsal areas of the parietal lobe. A second component, the target negativity, was made up of a negative deflection contralateral to the target stimulus originating from ventral areas of the parietal lobe.

Sawaki and Luck (2010) suggest these distracting stimuli elicit an attentional response regardless of any top-down influences, but this response can be inhibited to prevent attending to the irrelevant stimulus. This importantly gives evidence to attentional theories that postulate that singleton saliency is responsible for attention capture (bottom-up saliency hypothesis) or theories that require top-down goal influences (i.e. contingent involuntary orienting hypothesis – specifically that attentional capture is driven by the attentional control rule set of the task). The former is supported by distractor positivity elicited whether in attended space or not, whereas the latter shows saliency does not inevitably follow on to attentional capture and the authors note both theories must emphasize the importance of inhibitory/suppression mechanisms (Sawaki et al., 2010).

The current experiment aims to utilize this knowledge of the N2pc and its potential subcomponents in order to identify whether extensive videogame play affects target processing more, less, or the same as distractor processing. Past ERP literature in videogaming has postulated enhanced target processing in videogame players (Wu et al., 2012), however that was within a paradigm using a high number of distracting stimuli and therefore a more difficult task. The current paradigm aims to provide a controlled environment to elicit benchmarks for VGP and NVGP target and distractor processing abilities. As per results of the earlier visual search, I postulate VGPs will elicit reduced amplitude distractor positivity components and larger target negativity components, reflecting both enhanced distractor inhibition and target processing.

Method

Participants

In total, 54 undergraduate and postgraduate students were recruited from the University of Hull to take part in a study under the pseudonym, 'Investigating the underlying neural correlates of attention'. A pseudonym was used to ensure participants were unaware that videogame playing behaviour was being measured until the end of the experiment, thus avoiding the issue of demand characteristics and placebo effects (as mentioned in Boot et al., 2011). Undergraduates were awarded course credit for participation and postgraduates received fiscal compensation. Several participants were removed from the sample due to poor EEG recording (n=2), bad behavioural scores (n=1) or failure to complete the task (n=1). The remaining participants included 23 Non-videogame players (1 male; 22females) (M age: 21.48, SD: 5.342) and 17 videogame players (13 males; 4 females) (M age: 22.59, SD: 7.542), the remaining participants’ videogame playing behaviour fell between accepted criteria for VGP and NVGP classification, and were excluded from further analysis, apart from Correlational analysis. All participants had normal/corrected vision, right hand dominance and were free from medical ailments (as assessed by self-report).

A detailed measure of videogame play was taken after the paradigms were completed, including a summary of videogames played over the past 5 years, number of months played, number of sessions per month and average number of hours per session. The number of hours per session and sessions per month were used to approximate the number of hours per week played. Six hours per week of action videogame playing over the past 5 years was required to be classified as a videogame player. Action videogames include first and 3rd person shooter games alongside certain arcade style fighting games, action real time strategy games and massively multiplayer online role playing games (Examples of action games played by participants include: *Call of Duty*, *Gears of War*, *Street Fighter*, *DOTA2*, *Guild Wars 2*). Criteria for non-videogame players included two hours or less of non-action videogames over the past six months (Examples of non-action games played by participants include: *The Sims*, *Fifa 2013*, *Dirt*).

Stimuli and Procedure

Luminance flicker task. The following procedure was based on those used by Hickey, Di Lollo and McDonald (2009). Before participants took part in the scarce visual search they completed six runs of this task. This task's aim was to psychophysically match the brightness of two colours by adjusting the luminance of a rectangle of grey to match the luminance of a rectangle of red. The two rectangles were presented in the centre of the screen, completely overlapping one another. The two rectangles switched between the fore and background rapidly (Flicker Rate: 60Hz) creating a flickering effect. Participants were given instructions prior to each trial to increase/decrease the brightness of the grey rectangle in order to reduce the flickering effect. Half of the trials started with the grey rectangle luminance brighter than the red (~2cd/m^2), and half darker (~2cd/m^2). Brightness was increased by pressing the ‘z’ key and decreased by a press of the ‘m’ key. At the end of each trial a numeric value corresponding to an RGB value was collected, from these values a mean was computed that would serve as the background colour for the remainder of the experiment.

Visual search task. The following stimuli and procedure were based on those used by Hickey, Di Lollo and McDonald (2009). Participants were sat in a comfortable chair approximately 60cm from a 24inch Samsung LCD (60Hz Refresh rate) monitor and a standard mouse placed by the participant’s right hand. All trials were presented at 640x480 (Monitor at 1920x1080) resolution using E-Studio (V 1.1 Service Pack 3) ran using an Intel i5 quad-core processor (3.2Ghz) and 3Gb RAM. The room was darkened, soundproofed and shielded from electronic interference.

The scarce visual search paradigm presented only two stimuli from a choice of four, a green square, green diamond, red short line and red long line on any given trial. Each trial consisted of one red item and one green item, creating four possible stimulus combinations. All trials begin with a variable inter-trial-interval between 1350 and 1650ms, during this ITI a small black fixation cross was presented at the centre of the screen. This fixation cross was also present throughout the entire trial. Participants were given a target at the beginning of each block (red or green stimulus) and required to discriminate between the two stimulus forms using the pre-defined mouse buttons. Participants completed a short practice block of 36 random trials before continuing onto the experiment proper. The experiment consisted of 10 blocks in total, half of which participants were directed to discriminate the forms of the green stimuli, and half the red stimuli. Each block consisted of 112 trials. Participants were given a brief rest between blocks.

Participants were given their target stimulus at the beginning of each block alongside a brief set of reminders ensuring fixation at the centre of the screen and to reduce movements to a minimum. In the green stimulus condition participants were required to identify the target as a square or diamond; in the line condition participants were required to identify whether the line was short or long. These conditions were fully counterbalanced between participants as was the response mapping of the mouse buttons.

The stimuli were presented equidistant from each other and from the central fixation cross at 5 visual degrees from the fixation point and each other. The green square stimulus measured 0.6x0.6 visual degrees and was rotated 45 degrees to create the green diamond stimulus. The red short line measured 0.8x0.15 visual degrees and the red long line measured 1.2x0.15 visual degrees. The shade of green used in the experiment (37.5 cd/m^2) was substantially brighter than the shade of red (3.8 cd/m^2). This shade of red was the colour and brightness used in the luminance flicker task completed prior to the visual search, thus each participants visual search background was tailored to be equiluminant with the participants perceived brightness of the red stimulus to ensure any observed differences in waveforms are not due to the residual effects of imbalanced sensory energy.

Stimuli could appear on the screen in one of six locations. Two positions were located on the vertical midline, 5 visual degrees above and below the fixation cross. The remaining four positions were located at 60, 120, 240 and 300 visual degrees from 0. The stimuli remained on screen for 750 ms unless a response was made, after which a new trial was presented. Stimuli positioning was made up of a combination of Hickey et al.’s (2009) Experiment 3 and Experiment 4 through the inclusion of a midline condition. Target present and target absent trials were equally proportionate, as was the probability of the target stimulus being present in the upper and lower visual field. Stimulus locations varied so that 28% of trials the green stimulus was situated on the vertical meridian and the line lateralized, 28% of trials the red stimulus was situated on the vertical meridian and the square lateralized, 28% of trials the green and red stimuli were both lateralized with one in each hemifield, and the remaining 16% consisted of trials were both stimuli were placed on the vertical meridian, one in the upper and one in the lower visual field.

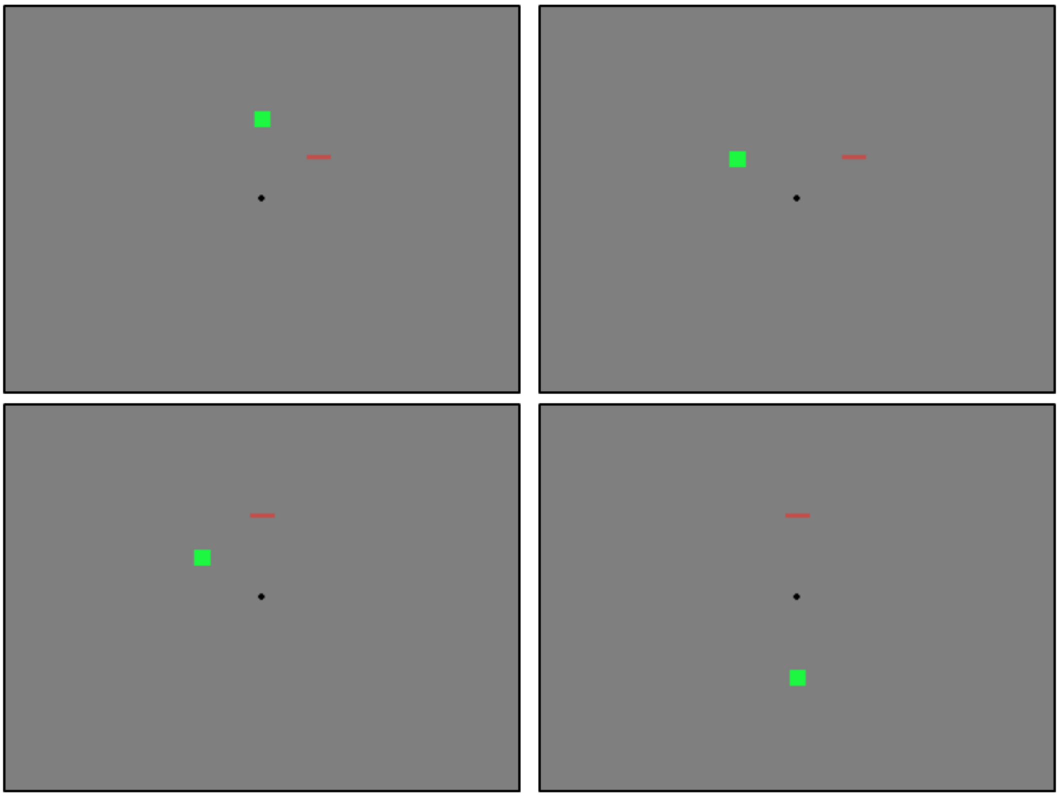


Figure 1. Four trial conditions of the visual search paradigm, displaying the luminous square and isoluminant line stimulus. From top left to bottom right: Vertical meridian square, lateralized line; lateralized square and contralateral line; lateralized square and vertical meridian line; both stimuli on the vertical meridian.

Visual Search analysis. Reaction times (RTs) and accuracy for every trial were recorded for each array type. Trials that contained errors or were part of the practice trials were excluded from analysis (in reaction time analyses). A between-subject ANOVA was used to analyze accuracy and RT data with trial formation (Vertical meridian target, lateralized distractor vs. lateralized target, contralateral distractor vs. lateralized target, vertical meridian distractor vs. vertical meridian target, vertical meridian distractor) and target type (green stimulus vs. red stimulus) as within-subject variables and playing behaviour (videogame player, non-videogame player) as the between-subject variable. Effects that breached sphericity were greenhouse-geisser corrected.

EEG Recording

All recordings were taken in a soundproofed electrically shielded room adjacent to the control room where participants were monitored using a video camera. The electroencephalogram (EEG) was recorded using a 64-channel Brainvision active electrode system (Brainvision, Inc.). Electrodes were placed at Fp1, Fp2, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, TP9, CP5, CP1, CP2, Cp6, TP10, P7, P3, Pz, P4, P8, PO9, O1, Oz, O2, PO10, AF7, AF3, AF4, AF8, F5, F1, F2, F6, FT9, FT7, FC3, FC4, FT8, FT10, C5, C1, C2, C6, TP7, CP3, CPz, CP4, TP8, P5, P1, P2, P6, PO7, PO3, POz, PO4 and PO8. All active electrodes were referenced to the vertex and grounded with an electrode placed on the forehead. Horizontal and vertical eye movements were recorded bipolarly using electrooculargrams (EOG) placed 1cm away from the outer canthi of each eye, and above and below the left eye. EEG signals were digitized constantly at a rate of 1000Hz and filtered on-line using a band pass of 0.1-50Hz. The impedance of all electrodes was maintained below 10 kΩ. All recordings were further shielded from interference by having the ActiveShield function (Brainvision, Inc.) activated.

EEG Analysis

Visual search. All recordings were filtered offline at a band-pass of 0.1Hz (12dB/Oct Slope) and 30Hz (24dB/Oct Slope). Ocular related artifacts such as blinks and lateral eye movements were corrected using Gratton & Coles (1983) method. Non-ocular related artifacts containing deflections exceeding ±100μV and activity below 0.5μV were removed. Data from correct trials was segmented into epochs of 200ms pre-stimulus presentation to 800ms post-stimulus presentation. Epochs were created for each trial type (formation of stimuli) and for each target stimulus (square or line) before averaging. Prior to averaging, each epoch was baseline corrected with respect to 200ms prior to array onset. All analysis was completed using Brain Analyzer 2 (Brain Products GMBH.).

The target negativity/distractor positivity component analysis was confined to posterior electrodes (PO7 and PO8) from trials with the luminous square presented on the vertical meridian and a lateralized isoluminant line. As stimuli presented on the vertical meridian would not elicit any contralateral activity, manipulating the position of stimuli whilst controlling for sensory energy allows us to isolate the target negativity and distractor positivity waveforms. Data was extracted for the attend-to-square trials at 230-280ms post stimulus presentation and 175-325ms for attend-to-line trials as per Hickey et al., (2009). An initial mixed-design ANOVA included trial type (attend-to-line vs. attend-to-square) and laterality of target stimulus (contralateral, ipsilateral), as the within subject variable variables, and videogame playing behaviour (action videogame player, non-videogame player) as the between subject variable. The side the target was presented on, and the upper/lower hemifield variables were both collapsed. Secondary mixed-design ANOVAs were computed separately for both attend-to-square and attend-to-line trial types using mean amplitude from the previously stated time windows.

As noted by Hickey et al., (2009), certain trial types including those with lateralized targets and contralateral distractors elicited prominent early sensory ERPs. Visual inspection of grand average waveforms showed distinct P1 (70-175ms), N1 (160-250ms), P2 (230-300ms), N2 (250-300ms) and P3 (300-550ms) waveforms. Using BrainVision Analyzer 2 peak export function, peak latency and max peak amplitude data was extracted for each participant using the above time windows. This data was entered individually into a mixed-design ANOVA with laterality (ipsilateral vs. contralateral), target side (left vs. right) hemifield (upper vs. lower) target type (square vs. line) as within subject variables and videogame playing group (VGP vs. NVGP) as the between-subject variable.

Results

Behavioural Results

Individual trial conditions were collapsed into four separate trial types; (a) trials with lateralized target and a contralateral distractor, (b) trials with a lateralized target and distractor on the vertical meridian, (c) trials with the target stimulus on the vertical meridian and a lateralized distractor, (d) trials with both target and distractor on the vertical meridian. Therefore hemifield and target side (i.e. visual field the target/distractor was presented) were collapsed. Both response time and accuracy data were entered into identical mixed-design ANOVAs with Target (Luminous Square vs. Isoluminant Line) x Trial Type (A vs. B vs. C vs. D) as within subject variables, and the videogame playing group (VGP vs. NVGP) as the between subject variable.

Response time data showed a target type × videogame group interaction (F(7365.339, 1386.115) = 5.314, $p < .05$). Secondary analyses showed an approaching significant difference between groups in the isoluminant attend-to-line target type (t(38) = -1.991, $p = .054$), indicating VGPs showed a trend to respond to the line trials faster than NVGPs.

No significant between group differences or interactions with group were observed within accuracy data.

Table 1. Response time (ms) and Accuracy (% Correct) data for each of the four collapsed trial formations.

		Response Time (ms) (SD)		Accuracy (%)	
Luminous Square		VGP	NVGP	VGP	NVGP
	Lateralized Target Lateralized Distractor	520.009 (10.056)	523.508 (8.646)	88.272 (2.128)	87.500 (1.830)
	Lateralized Target Vertical Meridian Distractor	523.816 (9.920)	524.252 (8.529)	88.971 (2.230)	86.902 (1.917)
	Vertical Meridian Target Lateralized Distractor	520.215 (9.843)	520.462 (8.462)	88.897 (2.217)	87.962 (1.906)
	Vertical Meridian Target Vertical Meridian Distractor	517.507 (10.046)	520.674 (8.637)	88.676 (2.332)	87.609 (2.005)
Isoluminant Line					
	Lateralized Target Lateralized Distractor	548.548 (8.367)	569.831 (7.194)	87.684 (2.570)	83.261 (2.209)
	Lateralized Target Vertical Meridian Distractor	548.541 (7.962)	571.269 (6.845)	87.206 (2.542)	82.826 (2.185)
	Vertical Meridian Target Lateralized Distractor	549.288 (8.119)	572.269 (6.980)	86.949 (2.463)	83.179 (2.117)
	Vertical Meridian Target Vertical Meridian Distractor	550.863 (8.317)	568.726 (7.150)	87.353 (2.574	83.098 (2.213)

Electrophysiological Results

Analysis of the current experiment followed the same procedure as Hickey et al., (2009). The current experiment was counterbalanced across participants with regards to condition order; but as this was not found to significantly interact in previous results (Hickey, 2009) condition order was not included in any subsequent analysis.

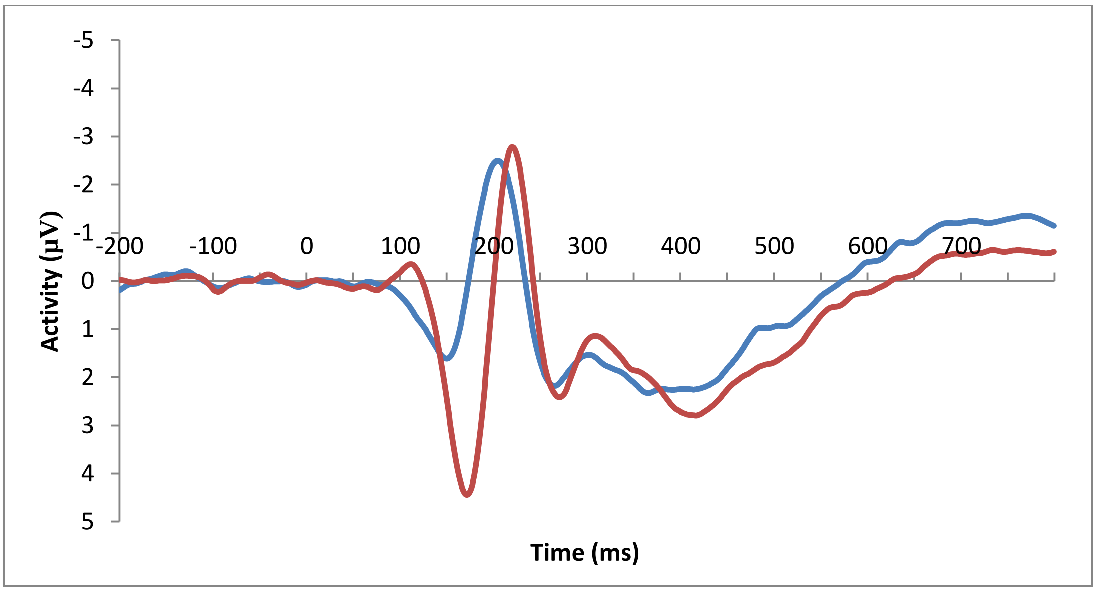
To identify differences between waveforms elicited from trials with and without balanced luminance in the visual field an initial ANOVA included three attend square trial types: target stimulus in the vertical position with a lateralize isoluminant distractor, target stimulus in a lateralized position with the isoluminant distractor placed on the vertical meridian, and trials in which the target stimulus was in a lateralized position with an isoluminant contralateral line stimulus.

During trial types with imbalanced luminance across visual fields, electrophysiological waveforms contralateral and ipsilateral to the target stimulus begin to deviate from one another approximately 80-90ms post stimulus onsets. Subsequent early sensory visual ERPs were observed: P1 (150ms), N1 (225ms), P2 (260ms), N2 (290ms) and P3 (350-400ms). Based on analyses by Hickey et al., (2009), mean activity was extracted 220-260ms after stimulus during attend square trials in which the target stimulus was presented laterally and isoluminant line stimulus was presented in the contralateral visual field; when contralateral and ipsilateral waveforms began to diverge. Upon visual inspection of the waveforms, the current experiment appeared to have slightly delayed (~20ms) ERP waveforms when compared to previous data (Hickey et al., 2009), the below analysis was computed with a modified 235-275ms extraction window.

Distractor side and hemifield were collapsed as these are not of interest in the current study and trials in which both stimuli were presented on the vertical meridian were included. An Electrode Laterality (Ipsilateral vs. Contralateral vs. Vertical) x Videogame playing group (VGP vs. NVGP) ANOVA was computed, yielding a significant main effect of laterality (F(26.481, 1.015) = 55.263, *p*<.000). Paired t-tests show trials in which stimuli were presented on the vertical meridian elicited the most positive mean activity when compared to both ipsilateral (t(39) = 4.566, *p*<.000) and contralateral electrode sites (t(39) = 11.748), *p*<.000). No significant main effect (including between contralateral and ipsilateral waves) or interactions with the between subject variable reached significance.

Table 2. Peak activity means and standard deviations for target negativity and distractor positivity waveforms.

Trial Type	VGPs	NVGPs
Distractor Positivity		
Lateral luminous target, Contralateral dist	2.43 ±3.22	1.72 ±2.7
Contralateral luminous target, Lateral dist	1.87 ±3.35	1.36 ±2.77
Lateral luminous target, Contralateral dist	2.57 ±2.73	1.78 ±3.00
Contralateral luminous target, Lateral dist	1.14 ±2.14	1.25 ±2.81
Target Negativity		
Contralateral isoluminant target, Vert dist	1.39 ±2.96	-0.71 ±3.22
Lateral isoluminiant target, vert dist	2.34 ±1.51	1.59 ±2.06
Contralateral isoluminant target, vert dist	0.76 ±2.34	0.57 ±3.00
Lateral isoluminant target, vert dist	1.35 ±2.85	0.69 ±2.03



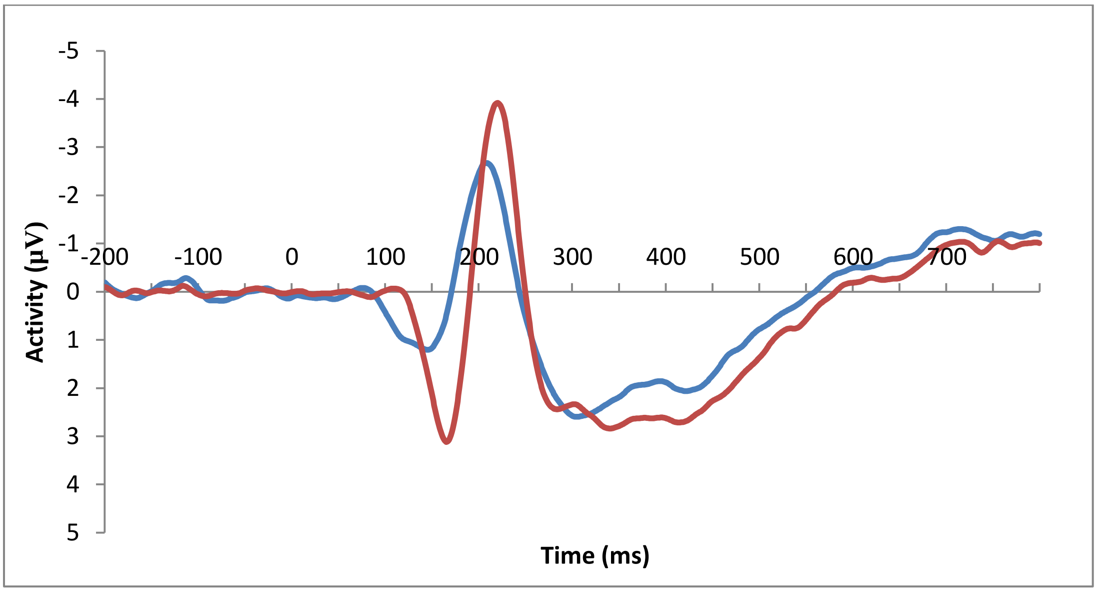


Figure 2. Top: Trials displaying a lateralized target stimulus with isoluminant line on the vertical meridian. Bottom: Trials with lateralized target stimulus and contralateral isoluminant line. The red waveform represents contralateral electrode recording from the target stimulus, whereas the blue is data recorded from the ipsilateral electrode.

As shown in the previous, attend to square only analyses, differences (see Fig. 2) in amplitude of standard early visual sensory ERPs most likely result in imbalances in sensory energy between visual hemifields (lateralized target and contralateral isoluminant line). Furthermore, on trials in which sensory energy was balanced (target placed on the vertical meridian with a lateralized isoluminant line), contralateral and ipsilateral waveforms remained constant until a contralateral positive deviation shortly after the elicited N1. This positive deviation is thought to reflect the lateralized processing of the distracting isoluminant distracting stimulus, and shall be referred to as the *distractor positivity*.

Upon visual inspection of the electrophysiological waveforms, the time windows used by Hickey et al., (2009) appeared slightly too early, and did not encompass the same electrophysiological landmarks of waveforms elicited by the current experiment. Therefore, analyses was conducted using a 250-300ms extraction for attend to square trials, and a 215-340ms extraction window for attend to line trials. The following analyses include different trial types: attend-to-square analyses include trials displaying lateralized distractors and targets on the vertical meridian (*distractor positivity*); attend-to-line analyses include trials displaying lateralized targets and distractors presented on the vertical meridian (*target negativity).*

Secondary ANOVAs were computed using attend-to-square and attend-to-line data, respectively. Attend-to-square data (*distractor positivity)* revealed a significant main effect of laterality (F(20.379, .869) = 23.460, *p*< .000) indicating significantly more positive contralateral waveforms were observed. An approaching significant interaction between laterality and videogame playing group was also observed (F(2.954, .869) = 3.400, *p* = .073), post hoc testing indicated no significant between group differences, both groups displayed significantly more positive contralateral waveforms than ipsilateral waveforms (VGP: t(16) = 3.679, *p*< .05); NVGP: t(23) = 2.785, *p*< .05)).

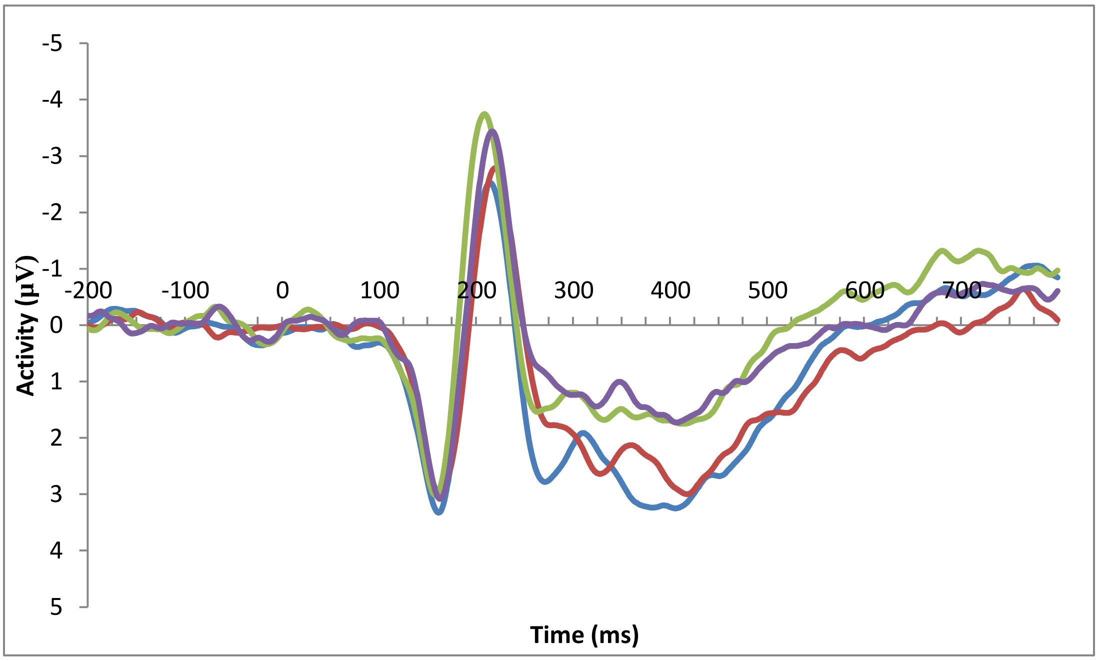


Figure 3. Attend-to-square waveforms during trials in which the target stimulus was presented on the vertical meridian with a lateralized isoluminant line distractor. Contralateral waveforms are presented as red for VGPs and green for NVGPs. Blue and purple lines represent ipsilateral waveforms for VGPs and NVGPs, respectively. Note: Trial presentation occurred at 0ms and the vertical axis has been reversed.

A mixed-design ANOVA of attend-to-line (*target negativity)* data indicated a significant main effect of laterality (F(38.539, 2.535) = 15.201, *p*<.000), suggesting significantly more negative contralateral waveforms. A significant main effect of stimulus side and laterality was also observed (F(15.667, 3.674) = 4.265, *p*< .05), indicating more negative waveforms contralateral to either distractor side which is to be expected. A stimulus side by videogame playing group interaction was also observed as significant (F(9.837, 1.595) = 6.167, *p*< .05). Independent sample t-tests indicated NVGPs produced close to significantly more negative waveforms to stimuli presented in the left hemifield (t(39) = 3.701, *p* = .062) compared to VGPs. Paired t-tests indicate VGPs had significantly more positive waveforms to stimuli presented in the left visual hemifield when compared to the right (t(16) = 2.767, *p*< .05). NVGPs showed no such difference. Although the between subject main effect of videogame playing group remained non-significant (*p*<.2), a trend can be observed in the current data for NVGPs displaying more negative target negativity than VGPs.

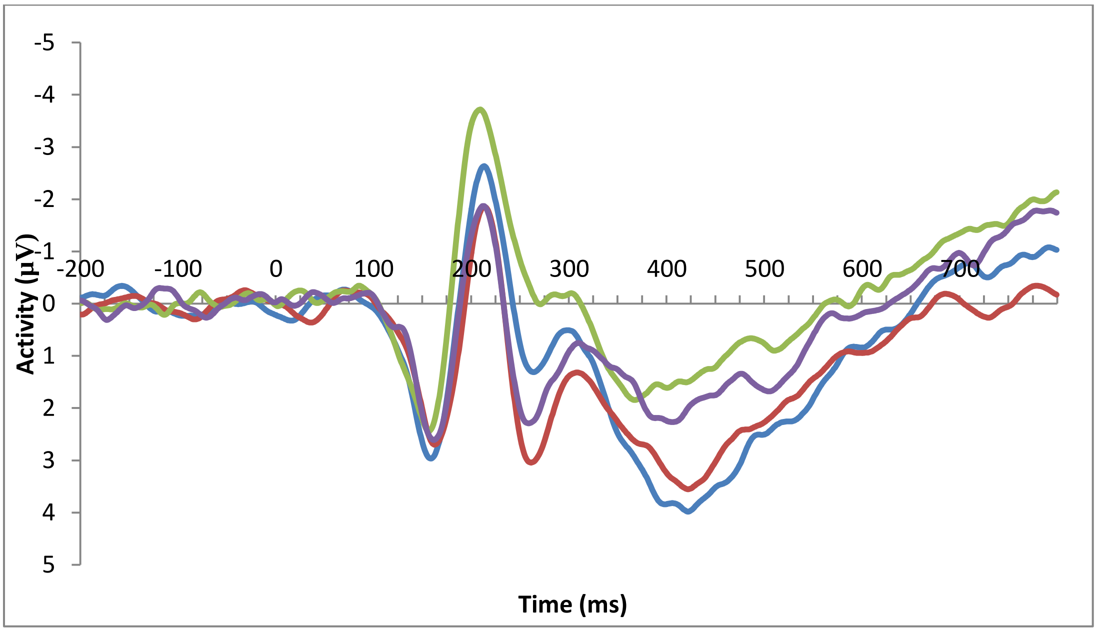


Figure 4. Attend-to-line waveforms during trials with vertical meridian bright square stimuli and lateralized isoluminant line. Contralateral waveforms are presented as red for VGPs and green for NVGPs. Blue and purple lines represent ipsilateral waveforms for VGPs and NVGPs, respectively.

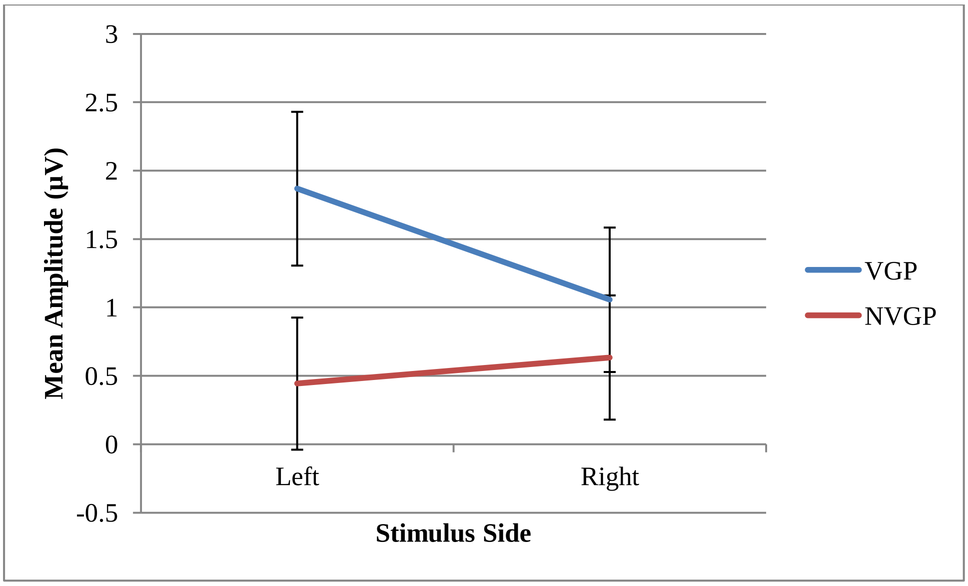


Figure 5. Target negativity mean amplitude stimulus side by videogame playing group interaction.

Additional ERP analysis

Additional analysis was conducted on early sensory ERP components elicited throughout the experiment. Brain Analyzer 2.0 automatic peak latency and maximum peak amplitude export tools were used to extract data for each participant using time windows established through visual inspection of grand averages calculated throughout earlier experimental analyses. Important: Identification of between group differences in early sensory ERPs was not hypothesized and thus this analysis is exploratory. Furthermore analysis of the N2 component will include the N2pc time window, and therefore summation of the distractor positivity and target negativity – the standard analysis that would occur if I were unable to isolate the target negativity and distractor positivity waveforms. Early sensory ERPs were analysed and are included in the appendix of this thesis.

Discussion

As with previous research, although non-significant, VGPs appeared to display faster reaction times than NVGPs with no speed-accuracy trade-off (Dye et al., 2009). A trend for more positive distractor positivity was observed in VGPs, whilst NVGPs showed more negative target negativity waveforms compared to VGPs. VGPs also showed delayed elicitation of certain early sensory ERPs (P1 and N2), whilst NVGPs showed greater negative deflections in both the N1 and N2 time windows. Unlike in the visual search experiment conducted earlier in this thesis (Chapter 4) and dissimilar to other research (Wu et al., 2012), no modulation of the P2 or posterior P3 was observed.

Although reaction time and accuracy of the current task are not of particular interest, primarily due to the low difficulty of the task, a general trend for faster reaction times in VGPs without any loss in accuracy was unsurprising (Dye et al., 2009). Several explanations including faster stimulus response mapping (Castel et al., 2005) or perhaps faster motor priming and response as shown in the flanker paradigm earlier in the thesis are responsible for reduced latency.

Differences between groups were observed in both distractor positivity and target negativity subcomponents of the N2pc. VGPs showed a trend for more positive distractor positivity, whereas NVGPs showed significantly more negative target negativities when the target was presented in certain visual fields. One might therefore surmise that videogame playing takes cognitive emphasis away from target processing and increases focus on distractor processing and suppression. This is supported by previous fMRI research which found reduced activation to dynamic distracting stimuli in the motion sensitive cortex in VGPs compared to NVGPs (Bavelier et al., 2012). This is further supported by Wu et al., (2012), who concluded from modulated P2 and P3 waveforms that distractor processing suppression is enhanced after videogame play. Furthermore, one might argue that increased target negativity in gamers could be viewed as reduced attentional requirements in VGPs to successfully process targets, in combination with enhanced distractor suppression, however this is speculation and further testing is required.

One might argue differences in the early sensory ERPs between groups, for example significantly earlier (and unexpected) P1 waveforms in NVGPs, suggest earlier processing of the array. Although no interaction between videogame group and laterality was observed, a main effect of laterality was noted, indicating both groups processed the target stimulus earlier than distractor. This may indicate earlier activation of sensory gain control (i.e. sensory amplification) (Hillyard, Vogel & Luck, 1998) for both the target and distracting stimuli in NVGPs, and thus causing amplification of contradictory representations (i.e. both target and distractor) indicating no real behavioural gain. Although no significant differences were observed in level of amplification of this gain control between groups (i.e. P1 amplitude) (Hillyard et al., 1998), earlier processing may indicate less pre-attentive control in NVGPs than VGPs. A possible secondary explanation comes from research by Wijers, Lange, Mulder & Mulder (1997) who found delayed P1 latencies when stimuli were presented on isoluminant backgrounds. Indeed our NVGP group displayed significantly earlier P1 latencies during isoluminant target trials when presented in the lower hemifield. This suggests one explanation of unexpected earlier P1s is that videogame playing reduces sensitivity to isoluminant stimuli, and therefore VGPs display delayed P1 latencies.

Although no differences in P1 amplitude were observed, NVGPs elicited significantly greater contralateral N1 amplitudes than VGPs. However this may be less important as, unlike the P1, the attended and unattended N1 may activate in separate neural populations (Johannes, Muente, Heinze, & Mangun, 1995). Again, this amplitude increase suggests increased gain effects on the target stimulus in NVGPs (Hillyard et al., 1998), and increased N1 amplitudes have been found to correlate with improved response time and target detection in certain paradigms (Heinze, Luck, Mangun, & Hillyard, 1990; Eimer, 1997). Despite this, NVGPs showed a trend for delayed reaction times, indicating ERP correlates that suggest earlier processing should most likely be accompanied by enhanced behavioural results should take place, they either fail to do so, or are outweighed by enhancements in VGPs elsewhere in the processing stream.

Differences in the N2 component were observed. Unsurprisingly they interacted with laterality and thus referred to the N2pc, subcomponents of which are believed to be target negativity and distractor positivity (Hickey et al., 2009). Between groups P2 differences where found between target presentations sides, and thus thought to be novel observations. Recent research indicated the P2 component correlates as an index of attention and working memory (Lefebvre, Marchand, Eskes, & Connolly, 2005). Although differences were observed, further testing was unable to pinpoint where these interactions were driven from. Consequently, I can postulate the effects on the P2 waveform were very small, and require further testing to isolate the specific circumstances under which P2 differences occur between groups.

Chapter 6. Working Memory Capacity and Attention

Atkinson and Shiffrin (1968) originally proposed the multi-store model proposing information from our environment passed to sensory memory. If this information was attended to, it would then pass to short term memory before transference to long term memory if rehearsed. However, Baddeley and Hitch (1974) noted this very simplistic model did not take into account the manipulation of memory. Their conception of short-term memory processes, termed *working memory*, comprises a number of components controlled by a central executive. The *phonological loop* in which auditory memory traces are held and can be rehearsed and the *visuo-spatial sketchpad* used to temporarily store and manipulate visual information to the multi-store model. The latter of which can be further subdivided into the *visual cache* responsible for shape and colour, and the *inner scribe* responsible for spatial awareness and movement, which in turn communicates with the central executive (Logie, 1995).

The function of working memory to maintain online visual representations of briefly presented items shares aspects with exogenous attention. Recent research even suggests that working memory may recruit areas of the brain also involved in visual attention (Theeuwes, Belopolsky, & Olivers, 2009). Research by Kane, Bleckley, Conway and Engle (2001) found strong correlations between attentional control and working memory capacity when observing individual differences. Evidence for the attentional blink effect, a measure of temporal allocation of attention can be best understood by capacity limitations in working memory, and the inability for participants to form memory representations of stimuli subsequent to the initial target (Jolicoeur, 1999). Furthermore, in an experiment where participants were required to report on properties of two presented stimuli, participants performed better when asked to report on two properties from a single stimulus as opposed to one property from each (Duncan, 1984). This was originally argued to reflect limits in visual processing and the difficulty of attending to multiple objects. However, repetition of this experiment showed the same pattern of results occurred after stimuli were masked, indicating this within-object effect may reflect working memory capacity (Awh & Jonides, 2001).

After all, one could argue that vision is a constant series of brief snapshots between saccadic shifts; and the ability to attend to information in these snapshots alongside maintaining visual representations of information from current and previous snapshots is required for the most basic of tasks. Through a series of experiments using event-related potentials, Fukuda and Vogel (2009) observed that individuals with high-capacity working memory completed subsequent attentional tasks (such as a Cued target identification task with post target probe arrays to involuntarily capture exogenous attention) with better performance in comparison to low-capacity individuals. Consistent similarities in goal-based attentional ERPs across all participants indicated differences in attention were due to an inability to override attentional capture of irrelevant stimuli during distractor onset. Similar observations have been noted indicating high-capacity individuals have more flexible methods of orientating attention whereas low-capacity individuals maintain a spotlight method (Bleckley, Durso, Crutchfield, Engle, & Khana, 2003). On the other hand, some studies have had difficulty finding this correlation in more complex tasks (Kane, Poole, Tuholski, & Engle, 2006); although, when controlling for top-down and bottom-up processing, conditions involving more top-down processing yielded the expected correlation in high and low-capacity individuals.

Visual working memory capacities have been investigated extensively. For example, Sperling (1960) noted an average memory range of 4.3 items regardless of whether the array was letter only or letters and numbers mixed. Other previous research has taken note of “chunking” and offered evidence for approximately seven chunks being held in short term memory. A similar memory range of approximately four items was observed using conjunction arrays, where each stimulus contained multiple features and colours this indicates that visual working memory may have a limited capacity for features so long as these features are confined to a small number of objects (Vogel & Luck, 1997). More recent research took this previous research of memory capacity into account and noted the importance of controlling for the steps of when and how information is chunked; and, to prevent long term memory chunking information and the utilization of further non-capacity limited sources such as sensory memory. This research offered similar results to that of Sperling (1960) and Vogel et al., (1997) with an average of four items in capacity limited short term memory.

The tasks used to measure short term memory capacity stemmed from letter and number information presented in lines and matrices used by Sperling (1960). These arrays would be presented briefly and the participant would then be required to fill out a pre-prepared grid with information presented in the stimulus array. Approximately a decade later, a slightly different variation of the Sperling task was created by Phillips and Baddeley (1971) (in Baddeley, 1997). This used a 5x5 matrix in which an item would be presented in approximately half of the cells for any given trial. Participants viewed one of these patterns briefly, followed by a variable retention interval, and then a second pattern. They were then required to make a same/different judgement as to whether the two patterns matched or differed. As expected, accuracy and reaction time delays correlated with the length of the retention interval but importantly it was also observed that visual storage exceeded the 1.5 second storage limit found in previous studies (Posner & Keele, 1967). Notably, research has identified the process underlying this task found to be dissociable of spatial working memory using healthy and brain-damaged patients (Della Sala, Gray, Baddeley, Allamano & Wilson, 1999) as measured using classic tasks such as the Corsi Block Tapping task (Milner, 1971).

In recent years, finding a specific neuroanatomical structure to directly attribute to working memory of any sort has proven difficult. Observations in visuo-spatial working memory using positron emission topography (PET) have shown activation in the right hemisphere prefrontal, parietal, occipital and premotor cortices during a visuo-spatial memory task (Jonides, Smith, Koeppe, Awh, & Minoshima, 1993). Prefrontal activation has also been observed in participants completing a face perception visual working memory task, although activation was not uniform in strength across prefrontal and occipital lobes, areas thought to be associated with face working memory (Courtney, Ungerleider, Keil, & Haxby, 1997). Additionally, single cell activity in the prefrontal lobe of macaques was found to correlate with visual working memory during a simple matching task (Miller, Erickson, & Desimone, 1996) and when activity was interrupted, performance declined (Goldman-Rakic, 1988).

Using a modified visual working memory task devised by Phillips and Baddeley (1971), recent research has used ERP methodology to identify individual differences in working memory capacity (Vogel & Machizawa, 2004). This task involved between 1 and 10 coloured squares being presented in each hemifield for a brief period of time and reappearing after a short retention interval; this was all preceded by a directional cue allowing participants to shift attention to the appropriate hemifield within which to remember stimuli before the arrays were displayed. Information was presented in both visual hemifields to balance sensory energy across each array. After a brief time delay and a presentation of another stimuli set participants were required to make a same/different judgement whilst assessing the two arrays that were presented, in 50% of which one item in the array changed colour. Electrophysiological waveforms were recorded across posterior parietal, temporal occipital and lateral occipital electrodes. Contralateral delay activity (CDA) was measured as the mean waveform recorded at sites contralateral to the hemifield in which correct responses were made, subtracted from ipsilateral waveforms. The average working memory capacity observed was 2.8 items and each individual’s working memory capacity was found to correlate with their CDA amplitude difference between arrays containing 2 and 4 items per hemifield.

The CDA has also been found to reliably correlate with the control mechanisms behind visual memory, where poor attentional control may cause irrelevant stimuli to be unnecessarily consumed and add load to working memory capacity (Vogel, McCollough, & Machizawa, 2005). Individuals with a high memory capacity elicited significantly smaller amplitudes to displays containing distracting stimuli in comparison to displays with no distractors, indicating more efficient processing. On the other hand, individuals with lower memory capacity showed more inefficient processing as amplitudes elicited by distractor displays were similar to target-only displays with equal stimuli numbers (Vogel, McCollough, & Machizawa, 2005). A second task changed stimuli colour in place of orientation.

Similar results were noted to that of experiment 1, indicating that the CDA is a reliable correlate for the control of memory during a task of lower demands. A third experiment tested both the exclusion and appending of items and found that low capacity and high capacity individuals were found to elicit similar CDA waveforms when appending distractor items. However, high capacity individuals showed an increased CDA for excluding items before a sharp fall indicating high capacity individuals processed distracting items but prevented them being appended into memory, in contrast low capacity individuals maintained an increased CDA, indicating the items had been unnecessarily appended into memory.

Despite the above evidence for an ‘active trace’, i.e. a neurophysiological waveform that correlates with an active representation of items held within working memory, some have questioned its validity. For example, Vogel and Machizawa (2004) noted CDA amplitude prediction may be modulated by task difficulty (Hillyard, Vogel, & Luck, 1998) and differences in executive function processing (Baddeley, 1996), as opposed to solely working memory representations. Lewis-Peacock, Drysdale, Oberauer and Postle (2012) noted the majority of physiological studies in working memory and short-term memory require participants to remember certain information, this information always being behaviourally relevant. Therefore, as the information to be remembered is relevant it is likely to be in the focus of attention, making the ‘active trace’ component potentially correlate just as much with attention, if not more so than with working memory. Lewis-Peacock et al. (2012) used a recognition paradigm that allowed the authors to separately measure activity of both attended and unattended memory items using fMRI. Evidence for the active trace of attended items was found, however representations of unattended memory items soon fell back to baseline levels. Importantly, the later could be quickly re-activated if cued in a subsequent part of the trial, indicating the information was indeed remembered. More recently, a study investigating the oscillatory neural activity of memory trace via electroencephalography found attended memory items yielded an active trace, whereas unattended memory items remained at baseline (LaRocque, Lewis-Peacock, Drysdale, Oberauer, &Postle, 2013). This therefore supported the results of the previous study and indicated that the active trace may indeed reflect the focus of attention as opposed to short term memory retention.

Spence and Feng (2010) noted the importance of working memory and the allocation of resources, specifically the ability to integrate long term memory and outside knowledge to make decisions in driving and puzzle games. They also acknowledged the interrelated nature of spatial attention and memory, and that many studies have noted videogame players' improved spatial attention (e.g. Green & Bavelier, 2003) but at the time of writing this thesis no study exclusively tested working memory outside of a cognitive battery, and no study has explored the electrophysiological correlates of working memory in videogame players. Despite this, although not the primary focus of the study, several studies have included both working memory and short-term memory paradigms within cognitive batteries etc.

Research investigating the effectiveness of videogame training on the elderly yielded interesting results regarding executive function (Basak, Boot, Voss, & Kramer, 2008), a cognitive component thought to be utilized in working memory processes (Baddeley, 1971). Twenty older adults were selected to play a real-time strategy game for just less than 24 hours over the course of 7-8 weeks alongside twenty control older adults with no training schedule. Participants were tested on a cognitive battery made up of measures in executive control and visuospatial attention in the first, fourth and seventh week of the experiment. Although significant improvement in visuospatial abilities transferred to mental rotation and thus did not follow the pattern of improvement established by Green & Bavelier (2003), significant improvements were observed in four of the six non-attention tasks, including working memory and short term memory. Both the visual short term memory task (change blindness) and n-back task yielded significant improvements with medium effect sizes across the three testing sessions (Basak et al., 2008).

A similar experiment to that by Basak, Boot, Voss, and Kramer (2008) using a younger population combined longitudinal training groups alongside cross-sectional expert vs. novice comparisons (Boot et al., 2008). The longitudinal participants were non-game players that either played an action game, real-time strategy or puzzle game for a total of 21.5 hours over the course of several sessions (controls were passive and played no videogame). The cross-sectional participants were made up of individuals that had played more than seven hours a week over two years (video game players), as well as controls with one hour or less experience per week. Once again, videogame players and trained non-gamers did not show significant differences in visuospatial attention, unlike Green and Bavelier (2003). Furthermore, 21 hours of videogame training was found not to be enough to elicit any improvements across any domains aside from enhanced mental rotation in Tetris players. Despite this, expert videogame players did significantly differ from their novice counterparts on four tasks, one of which being a visual short term memory change blind task (Boot et al., 2008).

A recent study conducted a double-blind trial to decipher whether the popular brain training game *Brain Age* and *Tetris* boosted cognitive functions in younger adults (Nouchi, Taki, Takeuchi, Hashizume, Nozawa, Kambara, Atsushi, Sekiguchi, Miyauchi, Kotozaki, Nouchi, & Kawashima, 2012). Amongst several significant differences in executive processes and processing speed between young adults trained in ‘Brain Age’ and those playing ‘Tetris’, significant enhancements were also found in working memory. As part of the cognitive battery administered in the study, participants trained using the ‘brain training’ intervention displayed significant improvements in the recall aspect of the Operation Span task (requiring participants to remember stimuli whilst completing arithmetic problems of varying difficulty and cognitive effort), and also in the Letter-Number Sequence subtest of the WAIS-III, requiring recall of letter and number strands in different orders. Despite this, the Arithmetic subtest of the WAIS-III, requiring participants to solve math problems without a pen and paper did not show significant between-group differences.

Most recently a study once again blurred the boundaries between visuospatial attention and visual short term memory, by aiming to identify effects of videogame playing on visual attention capacity using Bundesen’s (1990) Theory of Visual Attention as a computational framework (Wilms, Petersen, Vangkilde, 2013). Three separate groups of videogame players were created based on past videogame playing behaviours, non gamers (<2 hours), casual gamers (4-8 hours) and experienced gamers (>15 hours per month). Each participant completed three tasks. The first task, the CombiTVA was made up of the whole and partial report paradigm (Sperling, 1960, and Shibuya & Bundesen, 1988, respectively), requiring participants to report the identity of red target letters displayed amongst blue non-target letters. The second task was a simple enumeration task, giving a measure of short term memory and maintenance of representations in memory. The third task was the Attentional Network Test (Posner & Petersen, 1990), thought to assess three different types of attentional processing (alerting, orienting and executive control). Unlike previous studies of subitizing items in the visual environment (Green & Bavelier, 2003), the study found no significant difference between groups in the amount of items videogame players, casual players and non-players in the number of items they can subitize. Despite this, using TVA-based modelling to estimate processing speed of items into visual working memory from the enumeration task was found to be significantly different between groups. The authors subsequently concluded that action videogaming improves visual attention through modulated encoding speed to short-term memory, that VGPs attentional capacity is no different from NVGPs, but they are able to utilize this limited capacity faster and with more efficiency than NVGPs (Wilms, Petersen, & Vangkilde, 2013).

In summary, previous videogame literature with regards to visual working memory provides mixed results. Whereas the above research has noted significant improvements in working memory amongst videogame players, Wilms et al., (2013) failed to observe significant improvements in working memory resulting from capacity increases and instead attributed enhanced processing speed in VGPs to between group differences, similar to research by Dye et al., (2009). Despite this, other research found significant improvement in accuracy during greater set sizes for VGPs, indicating they possess greater working memory capacity limits compared to NVGPs. Clearly further research into this domain is required. Not only would covert recruitment allow us to control for potential demand characteristics, but electrophysiology also provides us with a neural correlate of working memory capacity, a measure other than accuracy scores, to provide further insight into the processing of VGPs.

The current study aimed to further examine the cognitive domain of working memory and the effect habitual videogame playing has on capacity and processing speed. Using EEG, the onset and amplitude of the contralateral delay activity was recorded as VGPs and NVGPs completed a visual working memory task, based on that used by Vogel and Machizawa (2004). The change-detection task used a bilateral display of coloured squares whereby participants were required to identify whether one of these squares changed between a brief onset and repeated presentation of the array. The number of squares in each array was also manipulated in order to identify potential capacity differences across groups. As differences in both processing speed (Wilms, et al., 2013) and working memory capacity (Boot et al., 2008; Basak et al., 2008) have been found between VGPs and NVGPs behaviourally, I would expect differences in accuracy at the greater set size. Furthermore, a difference in the amplitude of the contralateral delay activity specifically reduced mean activity in VGPs compared to NVGPs would be expected at larger set sizes indicating reduced processing requirements.

Method

Participants

Fifty-three undergraduate and postgraduate students were recruited from the University of Hull to take part in a study under the pseudonym, 'Investigating the underlying neural correlates of attention'. A pseudonym was used to ensure participants were unaware that videogame playing behaviour was being measured until the end of the experiment, thus avoiding the issue of demand characteristics and placebo effects (as mentioned in Boot et al., 2011). In total, 16 participants were removed from analysis, due to poor accuracy (<75% in small arrays) (n = 1), poor EEG recording (n=3) and not meeting VGP or NVGP criteria (n=12) (N.B. These individuals that fell between VGP and NVGP groups were still included in correlational analyses). Undergraduates were awarded course credit for participation and postgraduates received fiscal compensation. The 37 participants included 22 Non-videogame players (1 males; 21females) (M age: 22.45, SD: 6.4) and 15 videogame players (13 males; 2 females) (M age: 23.27, SD: 7.8). All had normal/corrected vision, right hand dominance and were free from medical ailments (as assessed by self-report). A detailed measure of videogame play was taken after the paradigms were completed including games played over the past 5 years, the number of months played, sessions per month and hours per session. Six hours per week of action videogame playing over the past 5 years was required to be classified as a videogame player. Action videogames include first and 3rd person shooter games alongside certain arcade style fighting games, action real time strategy games and massively multiplayer online role playing games (Examples of action games played by participants include: Call of Duty, Gears of War, Street Fighter, DOTA2, Guild Wars 2). Criteria for non-videogame players included two hours or less of non-action videogames per week over the past 5 years (Examples of non-action games played by participants include: The Sims, Fifa 2013, Dirt).

Stimuli and Procedure

Working Memory Task. The following stimuli and procedure were based on the task used by Vogel and Machizawa (2004). Participants were seated approximately 60cm from a 24 inch Samsung LCD monitor displaying at 60Hz. Subjects were required to identify whether a test array of squares was the same or different (i.e. a change in colour) as a previous briefly displayed memory array. Memory arrays could consist of 2, 3, 4 and 5 stimuli per hemifield (See Fig 1); the subsequent test array displayed the same number of stimuli as the previous memory array. Stimuli were uniform in every feature apart from colour, and all measured 0.65x0.65 visual degrees. Stimuli could be one of 13 colours, each array could contain no more than 2 of the same colour (red, blue, aqua, navy, purple, white, orange, black, light green, dark green, brown, pink and yellow). All stimuli were presented on a light grey background throughout the entire experiment. Stimuli were presented in a fixed formation (symmetrical across each hemifield) for each array size (as shown in Fig. 1) in an effort to slightly reduce task difficulty and thus processing unrelated to visual working memory. Although conditions (change vs. no-change and trial types (array sizes 2, 3, 4, and 5) were presented randomly, the stimulus in which a change occurred was equally probable. Participants pressed the left mouse button to indicate the test array was different from the memory and the right button if the test array was the same. This response mapping was reversed for half of the participants.

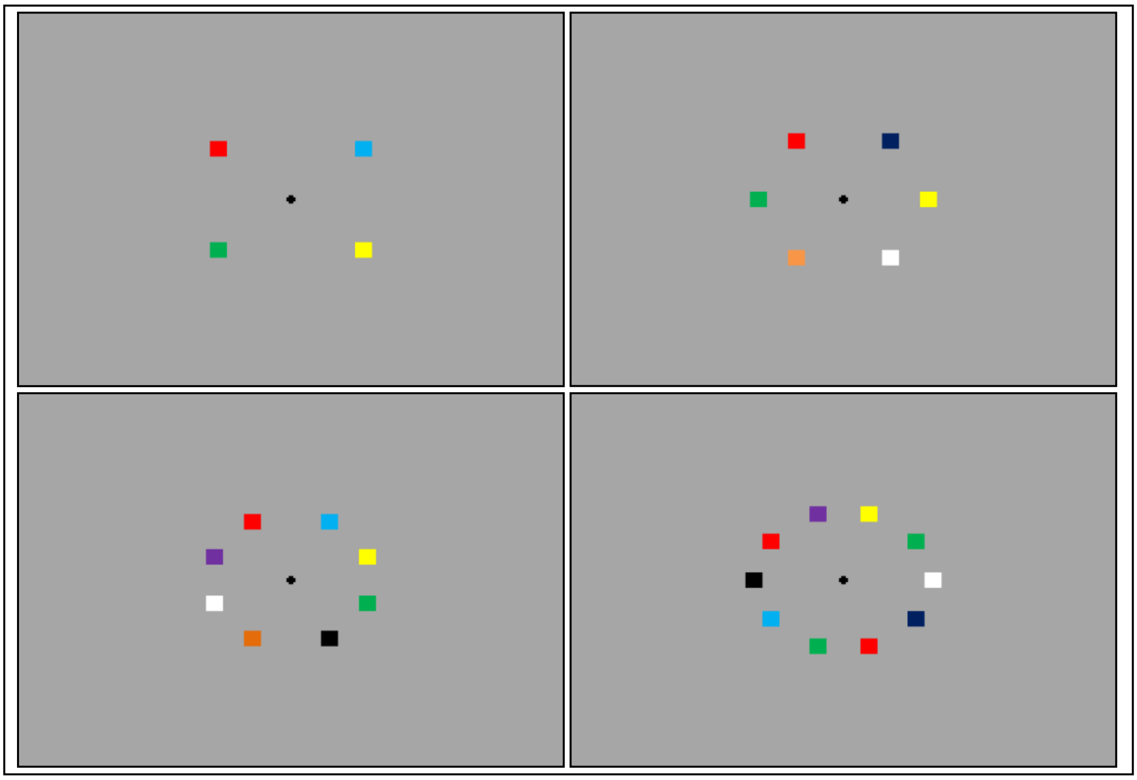


Figure 1. Example Memory Arrays for 2, 3, 4 and 5 stimuli conditions

Once consent was obtained, both verbal and written instructions were given to the participant before a short practice block of 36 trials to ascertain whether the task was fully understood. Participants were encouraged to be as accurate as possible whilst maintaining fixation on the central cross. From an EEG standpoint, participants were also told to remain relaxed and as still as possible. The experiment proper consisted of 15 blocks of 80 trials, each separated by a break the length of which was controlled by the participant (participants were encouraged to keep break times below 2 minutes).

Each trial began with a black fixation cross presented in the centre of the screen for a variable interval from 200-400ms, followed by a directional cue rendered approximately 5 visual degrees above the central fixation cross. The directional cue was a black arrow measuring approximately 6 visual degrees in length, the tail of the cue was perfectly horizontal, the point of the arrow always faced towards either the left or right side of the screen. The memory array was then presented for 100ms, as described earlier, depending on the array size; this consisted of coloured stimuli with equal numbers symmetrically placed on each side of the central fixation cross. A retention interval consisting of just a fixation cross was then presented for the next 900ms. The test array consisting of the same number of stimuli, in the same positions as the memory array was then presented for 2000ms or until a response was made. Participants were required to identify whether one of the stimuli had changed colour between each array display and to indicate their answer by pressing the relevant button of a mouse. A 1500ms blank screen was presented to indicate the end of each trial.

Each stimulus in the cued hemifield during change trials was equally probable to change whereas stimuli in the uncued hemifield never changed, ensuring no bias towards a stimulus presented in a specific location. The colour of each stimulus displayed in both the memory array and test array were randomly generated using a random number generator. Every participant completed the same randomly generated list of trials. A single stimulus changed colour between the memory and test array in 50% of trials.

Data Analysis

Reaction time and accuracy were recorded online for each array type. Despite this, this task focused on accuracy and only this was analyzed. Using accuracy and false alarm rates, I calculated each participant’s visual working memory capacity using a formula designed to take into account guessing (by including the rate of false alarms) originally developed by Pashler (1988) and further altered by Cowan (2001). The formula itself was $K=S(H-F)$, where K is the individuals memory capacity score, S the array size, H the hit rate probability and F the false alarm rate. A between-subject design ANOVA was used to analyze memory capacity scores, with playing behaviour (action videogame player, non-videogame player) as the between-subject variable. Participants were grouped using criteria stated previously.

As gender bias may be present as a consequence of covert recruitment, gender was also included as the between subject variable in an ANOVA similar to that mentioned above in order to identify any potential effects of gender.

EEG Recording

All recordings were taken in a soundproofed electrically shielded room adjacent to the control room where participants were monitored using a video camera. The electroencephalogram (EEG) was recorded using a 64-channel Brainvision active electrode system (Brainvision, Inc.). Electrodes were placed at Fp1, Fp2, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, TP9, CP5, CP1, CP2, Cp6, TP10, P7, P3, Pz, P4, P8, PO9, O1, Oz, O2, PO10, AF7, AF3, AF4, AF8, F5, F1, F2, F6, FT9, FT7, FC3, FC4, FT8, FT10, C5, C1, C2, C6, TP7, CP3, CPz, CP4, TP8, P5, P1, P2, P6, PO7, PO3, POz, PO4 and PO8. All active electrodes were referenced to the vertex and grounded with an electrode placed on the forehead. Horizontal and vertical eye movements were recorded bipolarly using electrooculargrams (EOG) placed 1cm away from the outer canthi of each eye, and above and below the left eye. EEG signals were digitized constantly at a rate of 1000Hz and filtered on-line using a band pass of 0.1-50Hz. The impedance of all electrodes was maintained below 10 kΩ. All recordings were further shielded from interference by having the ActiveShield function (Brainvision, Inc.) activated.

EEG Analysis

Ocular related artifacts such as blinks and lateral eye movements were corrected using Gratton & Coles (1983) method. All recordings were filtered offline at a band-pass of 0.1Hz (12dB/Oct Slope) and 30Hz (24dB/Oct Slope). Non-ocular related artefacts containing deflections exceeding ±100µV were removed. Data from correct trials were segmented into epochs of 200ms pre-fixation to 1000ms post-fixation (100ms after the test array). Epochs were created for each array size before being averaged. Prior to averaging, each epoch was baseline corrected with respect to the pre-fixation interval of 200ms. All analysis was completed using Brain Analyzer 2 (Brain Products GMBH.).

New channels made of parietal, parieto-occipital and occipital were computed for ipsilateral and contralateral changes (P7, P3, PO9, O1, P5, P1, PO7, PO3, P4, P8, O2, PO10, P2, P6, PO4, PO8) (change trials only) due to the lateral nature of the memory trace activity (Ikkai, McCollough, & Vogel, 2010). Difference waveforms were subsequently created by subtracting ipsilateral waveforms from contralateral waveforms. Mean amplitudes were taken from these difference waves for each array size using a window of 300-900ms (onset of memory array to 100ms post test array) as used by Vogel and Machizawa (2004). Due to the lateralized nature of this activity, no midline electrode sites were included in this analysis.

This data was input in a mixed-design ANOVA with array size (4, 6, 8, & 10, for which they would have to remember 2, 3, 4, & 5 items, respectively) as the within-subject variable and videogame playing behaviour (action-videogame player, non-videogame player) as the between subject variable. Additional mixed-design ANOVA analysis with gender as the between subject variable shall measure whether gender differences are not provide an explanation any observed differences in waveforms.

Interactions that breached sphericity were corrected using the Greenhouse-Geisser correction.

Results

Behavioural Results

A working memory capacity score was computed using the same formula as Vogel and Machizawa (2004) (Pashler, 1988; Cowan, 2001) as described in the methods section. No significant between subjects differences or interactions were observed (all *p*'s > .2) in the working memory capacity score.

Table. 1. Memory score averages and standard deviations for each memory array size for VGPs and NVGPs.

	Array Size Memory Score Average (S.D.)			
	2	3	4	5
VGP	1.61 (.18)	1.98 (.35)	1.85 (.45)	1.19(.58)
NVGP	1.56 (.22)	1.85 (.43)	1.88 (.54)	1.67 (.62)

Analysis of accuracy data showed a significant main effect of change was observed (F(1, 35) = 39.701, *p*< .001), with means indicating change trials (Mean:

107.39) were more difficult than non-change trials (Mean:127.209). A main effect of array was observed (F(3,105) = 487.473, *p*< .001), and planned comparisons indicated arrays presenting two stimuli in each hemifield elicited significantly more correct responses than array size 3 (t(37) = 13.410, *p*< .001), array size 4 (t(37) = 24.412, *p*< .001) and array size 5 (t(37) = 37.220, *p*< .001).

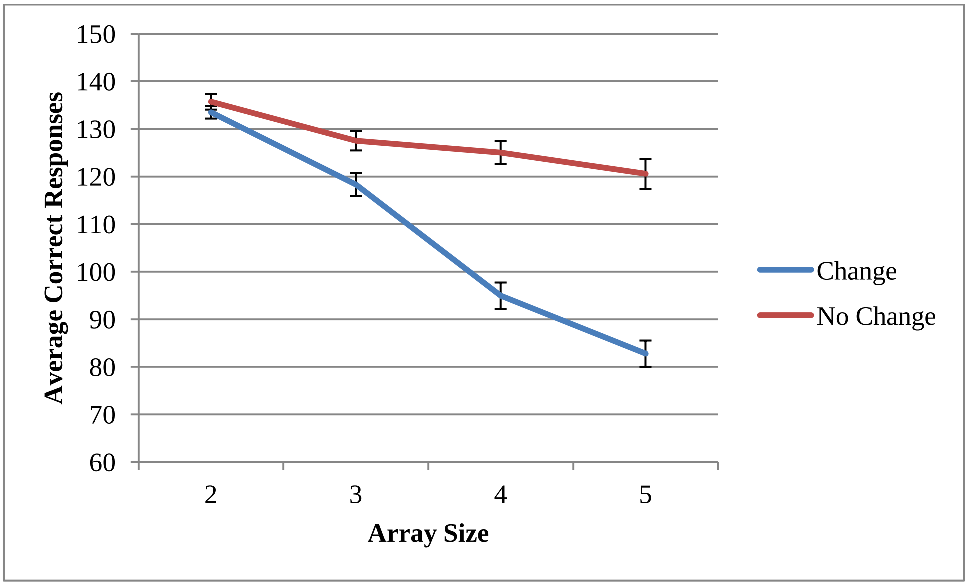


Figure 2. Average number of correct responses for each array size as a function on whether the response array differed (Change) or remained the same (No Change) from the memory array.

A change × array size interaction was also observed (F(3, 105) = 58.114, *p*< .001). Planned comparisons indicated no significant difference in average correct responses between change and no change trials during array size 2 (t(36) = -5.35, *p*>.5), but no change trials elicited significantly more correct trials during array sizes 3 (t(36) = -3.084, *p*< .005), array size 4 (t(36) = -7.416, *p*< .001) and array size 5 (t(36) = 7.611, *p*< .001).

No significant main effect or interaction with the between subject variable was observed (all *p*’s > .1).

Initial bivariate correlation controlling for gender (male only), computed with each array memory score yielded no significant relationships with action hours per week, weekly hours of videogame play over the past 12 months and number of years each participant has played videogames (all *p*’s > .4). Subsequent bivariate correlational analysis for each memory score array (accuracy and capacity score) were computed with action hours per week, weekly hours of videogame play over the past 12 months and the total number of years each participant has played videogames. No significant relationship between the variables reached significance (all *p* > .1).

Electrophysiological Results

The contralateral delay activity (CDA) for each array size was taken by averaging the mean activity across parietal, parieto-occipital and occipital recording sites for each hemisphere. Subsequently, contralateral waveforms were created by averaging activity of right hemisphere sites when participants were cued to remember the left side of the array, and vice versa. This process was repeated to create ipsilateral waveforms by averaging activity on the left hemisphere during left cued trials and right hemisphere activity on right cued trials. The CDA computed was the mean activity of the difference waveforms created by subtracting contralateral and ipsilateral waveforms for each array size.

Table 2. Peak amplitude means and standard deviations for each trial type of the contralateral delay activity (CDA).

	VGP	NVGP
2 Item Hemifield	-1.58 ±3.67	-1.46 ±4.28
3 Item Hemifield	-2.27 ±4.39	-3.72 ±4.27
4 Item Hemifield	-1.887 ±3.73	-3.04 ±5.28
5 Item Hemifield	-1.41 ±3.66	-0.69 ±3.37

The CDA for each memory array (2, 3, 4, 5 stimuli) was put into a mixed-design ANOVA with videogame playing group (VGP, NVGP) as the between subject variable. A main effect of array size was observed (F(3, 105) = 4.426, *p* = <.05) but no interaction (F(3, 105) = 1.421, *p* = .241) or main effect of videogame playing group (F(1, 35) = .561), *p*>.05).

Paired t-tests indicated the CDA in memory array 2 elicited significantly reduced amplitudes when compared to memory array 3 (t(36) = 2.465, *p*< .05) and 4 (t(36) = 2.940, *p*< .05) but not 5 (t(36) = -.765, *p* > .05), which may be expected from lack of effort during trials too difficult for the participants. A pattern observed in the data indicated memory array 5 elicited significantly smaller mean amplitudes when compared to memory arrays 3 (t(36) = -3.051, *p*< .005) and memory array 4 (t(38) = -2.748, *p*< .05).

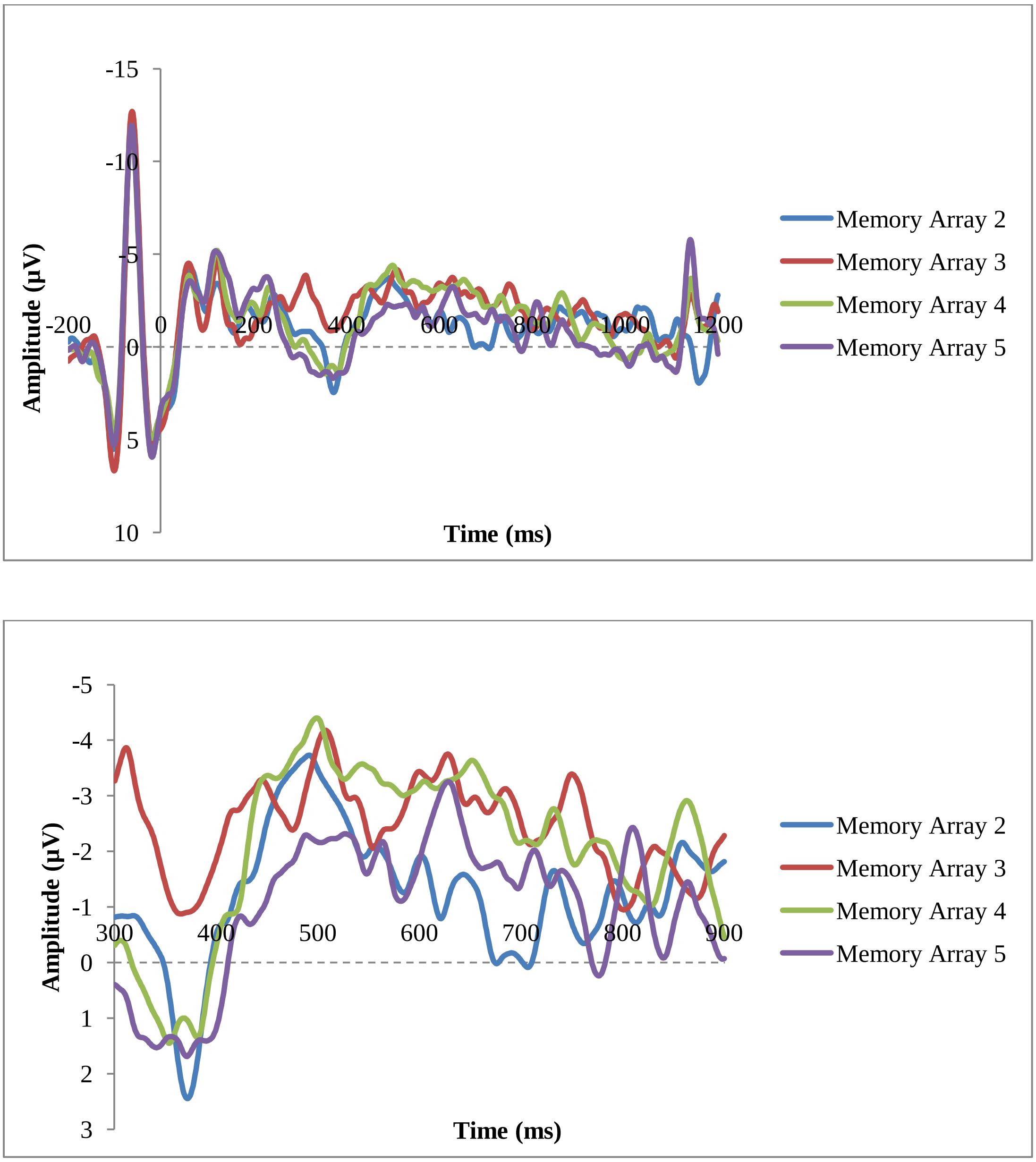


Figure 3. a) Average difference waveform (contralateral – ipsilateral) for each memory array size during a -200 to 1200 epoch. b) Close-up waveform of the 300-900ms post memory array onset time window in which mean activity was extracted for each memory array size.

Bivariate correlations including the average CDA for each memory array and action videogame hours per week, average gaming hours per week, total years of playing videogames yielded no significant relationship (all *p*'s > .3).

Previous research observed significant correlations between computed working memory capacity and the CDA amplitude difference between memory arrays of 2 and 4 items (Vogel & Machizawa, 2004). No significant correlations between average computed working memory capacities and amplitude difference between arrays of 2 and 4 items per side were observed (r = -.112, *p*> .5), and this held true when separate correlations for each group were computed (all *p*'s > .6).

Discussion

The current study did not show any significant differences in behavioural or neurophysiological findings between VGPs and NVGPs. Importantly, the current study successfully elicited the same waveforms as Vogel and Machizawa (2004), though accuracy scores indicated no between group differences. Despite this, interactions were observed indicating trials became most difficult when identifying change trials at greater array sizes. Computed memory capacity scores for each array size showed no significant differences between VGPs and NVGPs, either. The CDA failed to correlate with memory scores as noted by Vogel and Machizawa (2004) and did not interact with the between group variable. The implications for these null findings are discussed below.

The current study replicated the methodology of Vogel and Machizawa (2004) in every way bar the use of eye-tracking equipment and random stimulus positioning. Therefore, although participants were instructed prior to the experiment, and at each break between experimental blocks to fixate centrally, this could not be controlled for. Due to the lateralized nature of the CDA, participants failing to fixate centrally would elicit reduced contralateral waveforms due to the relevant stimuli being presented in central vision and not either the right or left visual field. Therefore, while the paradigm still successfully elicited a contralateral delay activity, it is uncertain whether or not this was confounded by participant eye movements. A plausible explanation for this anomaly is that participants that struggled to successfully detect changes/non-changes and compensated by fixating on the stimuli, and not at the fixation cross, thus affecting the CDA and increasing their accuracy.

A second explanation for the null result may be in the presence of additional, albeit irrelevant stimuli presented in the non-cued hemifield. Previous research has indicated VGPs possess increased or more efficient use of attentional resources and as such struggle to inhibit the ‘spilling over’ of these additional resources and process additional stimuli; an example of this being increased flanker compatibility effects in VGPs compared to NVGPs (Green & Bavelier, 2003, 2006b). However, this reasoning again fails to fully explain the current findings, as NVGPs computed memory scores and amplitude differences failed to correlate.

Furthermore, no correlations between amplitude differences of two and four stimulus arrays and memory scores were found. Vogel and Machizawa (2004) found a strong relationship between this CDA amplitude difference and participants’ average memory capacity scores, further indicating CDA is a neural correlate of working memory representations. One explanation might be the reduction in task difficulty, as the current experiment maintained stimulus formations for different array sizes, and did not produce random patterns in each visual hemifield. Indeed, amplitude of the CDA in working memory tasks is sensitive to the level of effort required to complete the task (Ruchkin, Canoune, Johnson, & Ritter, 1991).

With increasing support that working memory and selective attention are overlapping cognitive functions (Gazzeley & Nobre, 2012) (although not always the case; see: Luck & Vogel, 2001), the current study was theoretically appropriate in order to identify whether modulation in VGPs cognitive functions stems from or is also associated with enhanced working memory. Previous research by Wilms, Petersen and Vangkilde (2013) concluded that video game playing improved the encoding speed into visual short term memory, something which the current study can neither support nor contradict. The general consensus is that the CDA is sensitive to the number of visual representations currently held in visual working memory (Ikkai, McCollough, & Vogel, 2010) and not sensitive to processing speed. Furthermore, participants of the current study were not required to make speeded decisions, removing any possibility of identifying processing speed differences through behavioural data.

VGPs have displayed enhanced updating of working memory when compared to NVGPs when completing an N-back task (Colzato, 2012), enhanced accuracy during completion of well established change-blind paradigm (Luck & Vogel, 1997; Boot, Kramer, Simons, Fabiani, Gratton, 2008). Older adults have also shown significant improvements in switching between memory representations when completing an N-back task and improved capacity in visual working memory after approximately 23.5 hours of videogame training (Basak, Boot, Voss & Kramer, 2008). Additional paradigms that require sustained visual attention alongside working memory properties have also observed significant differences between

VGPs and NVGPs such as multiple object tracking (Green & Bavelier, 2006; Boot et al., 2008) and enumeration paradigms (Green & Bavelier, 2003; 2006).

In conclusion, although the current study failed to support previous findings, explanations regarding differences in methodology when compared to past behavioural-centric paradigms (Luck & Vogel, 1997) are most likely responsible. From a neural standpoint, the current study indicates seasoned videogame players cannot hold more representations in visual working memory, although one cannot be sure if differences storing and manipulating these representations in visual working memory really exist. Furthermore, processing speed is difficult to measure using the CDA, especially as the waveform contains little to no stand-out neurological landmarks to calculate temporal differences between groups. As previous research indicates, differences in working memory between groups may exist but may not be as strong of an effect as previously thought (especially when taking the effects covert recruitment may have on the results), however neural findings still appear strongest when observing differences in visual spatial and selective attention (Wu et al., 2012). In light of these result, further research should use a more comprehensive battery of memory tests are required in conjunction with neuroimaging techniques alongside covert recruitment to successfully assess potential modulation of working memory in VGPs.

Chapter 7. Visual Resolution in the Periphery

Attention in the visual periphery of VGPs and NVGPs have been thoroughly tested over the past decade or so. Several studies have used the Useful Field Of View (UFOV) (Green & Bavelier, 2003, 2006b; Dye & Bavelier, 2010), attentional field of view (Wu et al., 2012) and perceptual load/flanker compatibility (Green & Bavelier, 2003, 2006b) paradigms to understand whether any cognitive enhancement in VGPs extends beyond the typical field of view that a monitor used for gaming would display. The Useful Field Of View and attentional field of view paradigms measure an individual’s ability to extract target identity and location from a radial display of information spanning up to 30 visual degrees into the periphery, whereas flanker tasks measure individuals’ ability to inhibit salient distractors presented at varying degrees of visual angle.

Each of these experiments have identified attentional modulation in VGPs when compared to NVGPs extending up to 30 visual degrees into the periphery. Importantly, these differences have been replicated in training studies as well as with cross-sectional designs. These differences were in the form of enhanced attentional resources in flanker compatibility tasks (Green & Bavelier, 2003; 2006b) and improved accuracy in the UFOV task even when a concurrent central task was included (Green & Bavelier, 2006b) and reduced thresholds in a child-friendly UFOV (demonstrated by lower reaction times) in school-age children that play videogames (Dye & Bavelier, 2010). Wu et al., (2012) observed neurophysiological differences between participants trained on a fast paced highly salient action videogame and those on a slower non-action videogame. An enhanced P3 mean amplitude, thought to reflect an improved perceptual decision making process was observed in participants with extensive action videogame experience whilst completing an attention visual field (AVF) paradigm up to 30 visual degrees.

Another aspect of vision in the periphery is the visual phenomenon of “crowding”, referring to the increased difficulty of identifying a target stimulus when it is surrounded in close proximity by distracting stimuli as opposed to being presented in isolation. This phenomenon is based on the notion that visual acuity of an item (and thus its ability to be discriminated) is heavily influenced by the presence of nearby contours (Ehlers, 1936). This perceptual bottleneck limits finer visual search capabilities, specifically reducing object recognition when presented in close proximity to other objects/stimuli.

Whitney and Levi (2011) suggested five distinct criteria to identify “crowding”. Firstly, crowding impairs identification of an object, but not detection. Crowded objects do not perceptually disappear, but closely presented additional objects prevent feature detection and thus hamper target identification. Secondly, crowded objects are perceived as having high contrast, in that participants can see something is present in the visual environment, however these items often appear mixed together or unidentifiable. Thirdly, crowding is affected by the spacing between the target and distractor objects, and the eccentricity in the visual periphery where it is presented. The greater the distance between the target and flanking stimuli, the easier the target becomes to be identified. Greater target-flanker spacing is required at greater visual eccentricities to ensure target identification when compared to central vision. The fourth criteria set by Whitney and Levi (2011), notes anisotropies within the crowding phenomenon, that horizontally placed distractors surrounding stimuli on the horizontal meridian induce greater crowding compared to vertically placed distractors and vice versa for stimuli presented on the vertical meridian. Finally, two flankers induce greater crowding than one (Bouma, 1970), and a single flanker at an eccentricity greater than the target produces more crowding than a single flanker proximally closer to the fovea.

Crowding has also been found to occur when target stimuli move (Bex, Dakin, & Simmers, 2003). Similar to stationary stimuli, more peripheral flanking elements caused increased interference compared to those presented closer to the fovea. Trials in which the flanking stimuli moved ahead of the target stimulus caused increased crowding effects compared to those presented trailing the target. One potential explanation suggests the motion blur of the preceding stimulus inhibits identification of the later stimulus. Other explanations suggest that the processing of dynamic stimuli are biased towards processing the stimuli following the trajectory of motion first, therefore processing the flanking stimulus before the target.

As stated earlier, the effect of crowding has been found to vary across peripheral vision, creating larger contour interaction zones as peripheral eccentricity is increased. These contour interaction zones are the regions surrounding target stimuli where distractors decrease the ability to successfully discriminate the target (Toet & Levi, 1992). Further supporting research comes from Miller’s (1991) research into the semantic processing of flanking stimuli, noting visual angle as one of the highest influencing features of flanker compatibility, that the closer target-distractor proximity, the reduced ability to discriminate between flanker and central target.

The neurological components and correlates of visual crowding so far appear mixed, with evidence suggesting multiple areas of the visual cortex are recruited. For example, Pelli (2008) suggested that the representation of the visual field on V1 is logarithmically correlated with eccentricity in the visual field and further calculated that these representations must be projected 6mm apart on V1 otherwise items were perceived as an “unidentifiable jumble”. Freeman and Simoncelli (2010) posited that images with overlapping receptive spatial fields on the visual cortex were averaged according to a scaling parameter relating to the size of the stimulus and eccentricity at which it is presented. After fitting this scaling parameter function to participant results, Freeman et al., (2010) concluded their results reflected receptive field sizes of V2 in visual cortex of Macaques. Evidence for masking properties in visual crowding observed indicates the recruitment of V3 (Tyler & Likova, 2007). Indeed, orientation-selective adaptation as found in V1 was not affected by visual crowding, whereas fMRI observed adaptation weakening in V2 and V3 areas due to visual crowding (Bi, Cai, Zhou, & Fang, 2009). Furthermore, enhanced crowding elicited when stimuli were presented close to one another within the same visual hemifield was significantly stronger when compared to crowding flankers presented at the same proximity but on the other side of the vertical/horizontal meridian (Liu, Jiang, Sun, & He, 2009). These results indicate crowding stems from later visual areas where hemifields are represented separately.

Previous crowding research involving videogame players (VGP) concluded VGPs displayed superior visual resolution up to 25 visual degrees in the periphery using the crowding phenomenon when compared to non-videogame players (NVGP) (Green & Bavelier, 2007). The task used was a variant of that used by Toet and Levi (1992) to investigate interaction zones as a function of retinal location. Toet and Levi (1992) observed interaction regions increased linearly with the eccentricity they were presented at. Furthermore, these interaction zones were elliptical in shape with the radial axis being 2 to 3 times the length of the tangentially orientated axis. Participants were required to identify the orientation of a ‘T’ shaped stimulus flanked above and below by identical ‘T’ stimuli. In the experiment by Green & Bavelier (2007), visual acuity was measured and subsequently controlled for, and trials could be presented centrally or at 10 or 25 visual degrees into the periphery. The procedure used a three-up one-down staircase design, whereby every three consecutively correct responses, the distance between flanking stimuli and the target stimulus would be reduced and every incorrect response, the distance between flankers and target would increase (by 30, 400, or 600 min of arc depending on the eccentricity of the trial). Thresholds were taken and a measure of spatial resolution calculated as the distance between flanker and target stimulus by averaging the centre-to-centre spacing of the final 10 trials.

The current experiment uses the same task as Green and Bavelier (2007), extending the visual angle manipulated to 40 visual degrees in attempt to find the maximum visual eccentricity videogame playing appears to modulate. Unlike previous studies, the current experiment employed a covert recruitment design, in order to control for potential demand characteristics that may have been present in previous research. Participants were naive to the true purpose of the experiment before being given a measure of videogame assessment only after all data had been collected. As both cross-sectional and training design studies have yielded significant attentional and perceptual differences at 25-30 visual degrees (Green & Bavelier, 2003, 2006a, 2007, Wu et al., 2012, etc.) I hypothesized significant differences in crowding would be observed at those eccentricities found previously. Furthermore, we may find significant VGP enhancements at greater eccentricities, however these differences may begin to be reduced as limitations of the human visual system are reached. Previous research also noted a significant difference between VGPs and NVGPs in a single T condition, a measure of visual acuity, whereby VGPs were better able to correctly identify the orientation of a T stimuli in isolation at small presentation sizes than NVGPs. One may find similar results to Green and Bavelier (2007) in this respect, also.

Method

Participants

Thirty healthy male undergraduate psychology students from the University of Hull with normal or corrected-to-normal vision were recruited. Participants were identified as VGPs and NVGPs on the basis of a videogame playing behaviour questionnaire completed upon experiment completion. This questionnaire involved a comprehensive list of most played videogames over the past 5 years, how many months they played the game, how many sessions per month and how many hours in each session. An extended period of 5 years was used in comparison to previous papers (Green & Bavelier, 2007) as students were often found to reduce their gaming habits during university periods. Participants also gave information on their average gaming time over the past 12 months, the total number of years playing videogames and the size of screen and viewing distance when gaming.

A measure of weekly gaming hours was calculated from the hours per session and sessions per month of the past 5 years. To be considered a VGP, participants were required to play a single or combination of action videogames for over 6 hours per week, and NVGPs less than 1 hour of non-action videogames per week. Eighteen males (Mean: 19.5 SD: 1.2) were identified as VGPs and 7 males (Mean: 36.7 SD: 13) were identified as NVGPs. A total of 4 participants were excluded for failing to meet criteria for either group (N.B. these participants were included in correlational analysis that utilized videogame hours as a continuous variable), and a single participant was excluded for failing to complete the task. Participants received payment for experiment completion in the form of module credits.

Procedure

The current task used a mixed-design, with videogame and non-videogame players as the between subject variables and each viewing condition (visual eccentricity) as the within-subject factors.

Participants viewed a 40inch Panasonic screen displaying at 1280x1024 pixels displaying at 60 Hz using a chin-rest from two separate viewing distances in order to assess a full range of visual angles (57cm and 113cm). The experiment was presented using E-Prime 1.2 presentation software on an Intel 2.4Ghz dual core processor and 760 GT Nvidia graphics card.

Stimuli were based on those used by Green and Bavelier (2007), with three black T-shapes in a vertical formation on a light grey background. The initial T size was tailored for each participant in order to control for varying levels of visual acuity. Participants initially underwent 170 trials at each visual eccentricity in which the target T was presented in isolation. Participant initial T size during experimental blocks were 1.5 times the size of their final T alone threshold, this is known as the single T condition.

Participants were tested on six separate eccentricities, 0, 10, 25, 30, 35 and 40 visual degrees. Two different viewing distances were used to ensure enough pixels were available for to present stimuli at the small T-distance steps at lower visual eccentricities (0 and 10 visual degrees at 113 cm, the remaining viewing conditions at 57 cm). Participants placed their chin in a fixed chinrest throughout the duration of each block and were explicitly told to focus on the central fixation point when presented. Each eccentricity was presented in a separate block and blocks were fully counter-balanced across participants.

The central condition displayed stimuli in the centre of the screen and thus displayed no fixation dot. For the peripheral trials a fixation dot was presented in the centre of the screen and the target stimulus was presented on the horizontal meridian randomly to either right (P=.5) or left hand side (P=.5) of the fixation dot. Each stimulus was presented for a duration of 100ms immediately after a short auditory tone. The task was to identify whether the central target stimulus was orientated the right way up, or upside down, by pressing the corresponding answer keys on a keyboard. Participants were instructed to use their dominant hand for both responses. Participants were encouraged to accuracy over speed when responding. A brief high-pitch auditory feedback tone was played when the participant answered correctly on trials, and a low-frequency tone on incorrect trials.

The centre-to-centre spacing between flanking T-shapes and the target T shape during the experimental block was 30, 400, 600, 650, 700 and 750 min of arc (0, 10, 25, 30, 35, 40 visual degrees of eccentricity, respectively). This centre-to-centre spacing was controlled using a three-up one-down staircase design in which the spacing changed by 5% of the current min of arc. Each block (i.e. viewing angle) consisted of 200 trials. The final crowding threshold was taken as an average of the final 10 trials of each 200 trial block.

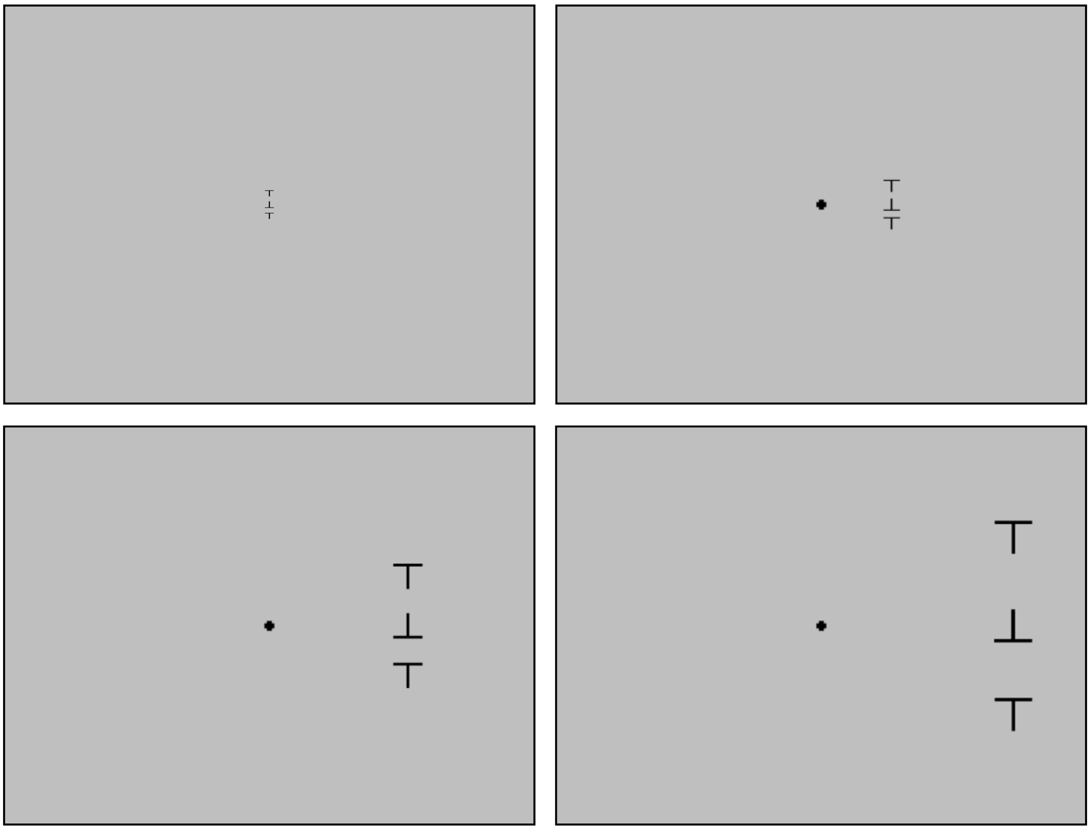


Figure 1. Example 3-T conditions for various visual eccentricities.

Results

Three T condition. As in previous research by Green and Bavelier (2007) the average center-to-center distance thresholds for each eccentricity were $\log_{10}$ transformed in order to equalize means and variance across each of the conditions (Leat, Li, &Epp, 1999).

Videogame playing behaviours (VGP, NVGP) and the log transformed centre-to-centre average for the final 10 trials of each eccentricity (0, 10, 25, 30, 35, and 40 visual degrees) were computed in a mixed design ANOVA. As expected, a main effect of eccentricity (F(3.446, 79.258) = 442.782, *p*< .001) was observed with centre-to-centre spacing increasing with greater eccentricity. Unlike Green and Bavelier (2007), no significant main effect of videogame playing group was observed (F(1, 23) = .915, *p* >.3). Videogame playing behaviour and visual eccentricity did not interact with one another (F(3.446, 79.258) > .7).

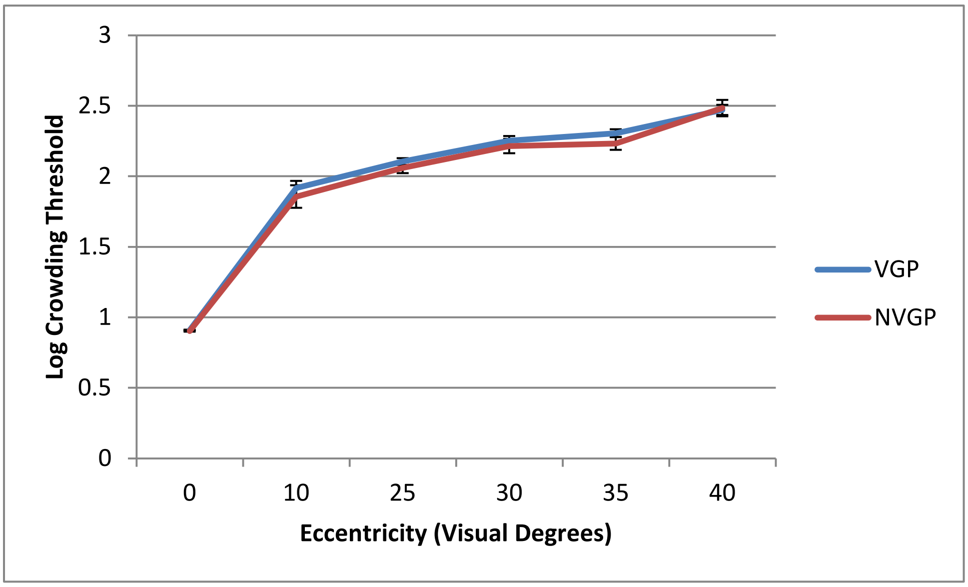


Figure 2. Log transformed crowding thresholds at each viewing angle as a function of videogame playing group.

Table 1. Three T condition Log 10 means and standard deviations.

Three - T	VGP	NVGP
0 Visual Degrees	0.91 ±0.01	0.90 ±0.01
10 Visual Degrees	1.91 ±0.21	1.85 ±0.2.0
25 Visual Degrees	2.10 ±0.10	2.05 ±0.08
30 Visual Degrees	2.25 ±0.14	2.21 ±0.11
35 Visual Degrees	2.30 ±0.12	2.23 ±0.1
40Visual Degrees	2.46 ±0.12	2.48 ±0.21

Bivariate correlational analysis indicated a significant correlation between weekly action hours and centre-to-centre spacing at 25 visual degrees (r = .400, *p* (two-tailed) <.05) and 35 visual degrees (r = .461, *p* (two-tailed) < .05). The above results would indicate a higher amount of videogame playing would yield lower, not higher spatial resolution at these eccentricities, and so would not support our original hypothesis.

Single T Condition. Following Green and Bavelier (2007), a similar 6x2 mixed-ANOVA was computed using $\log_{10}$ transformed data from the single T viewing condition, i.e. the condition used to measure visual acuity and set the starting T size for each participant. A main effect of eccentricity was observed ($F(2.963, 68.144) = 167.336$, $p < .001$) with individual T size increasing with eccentricity. No interaction between eccentricity and videogame playing was observed ($F(2.963, 68.144) = 1.060$, $p > .3$). A main effect of videogame playing was observed ($F(1,23) = 6.692$, $p < .05$) indicating videogame players required larger individual T sizes than non-videogame players.

Table 2. T Alone Log 10 corrected means and standard deviations.

T Alone	VGP	NVGP
0 Visual Degrees	0.84 ±0.03	0.83 ±0.06
10 Visual Degrees	1.13 ±0.05	1.04 ±0.87
25 Visual Degrees	1.21 ±0.09	1.12 ±0.05
30 Visual Degrees	1.29 ±0.12	1.20 ±0.045
35 Visual Degrees	1.36 ±0.13	1.26 ±0.06
40Visual Degrees	1.46 ±0.10	1.37 ±0.06

Discussion

Results of the current study do not appear to support the conclusions of Green and Bavelier (2007), in that previous experience in action videogame playing did not contribute to any significant enhancements in the spatial resolution of vision.

The current study attempted to extend the findings of the previous research with the aim of identifying the visual angle boundary in which habitual videogame play ceases to modulate visual spatial resolution. Despite this, the results indicated no differences between groups at any viewing angle in the three T condition and thus failed to replicate previous results (Green & Bavelier, 2007). However, correlational analysis indicated a negative correlation between centre-to-centre spacing thresholds and videogame playing hours, an unexpected result in the opposite direction of our hypothesis.

These results not only fail to extend previous work that appeared to show robust differences between VGPs and NVGPs across two separate conditions, but also fail to replicate them (i.e. VGPs were expected to display enhanced spatial resolution and potentially improved visual acuity across the 3T and single T conditions respectively.) One addition to the methodology from that of previous research (Toet & Levi, 1992; Green & Bavelier, 2007) that may have been responsible is in the randomised presentation of the stimuli to a single location in both visual fields as opposed to a single visual field. This addition may have forced participants to use more attentional processes than in previous use of the task and thus increased task demands and difficulty. Participants may have struggled to spread attentional resources across such a large visual area to each potential target location without prompt or priming before then focusing on the task itself. Indeed, previous research has identified that although attention can improve speed and accuracy in visual acuity tasks, peripheral cuing can further improve participants performance in identifying the gap in a Landolt-square stimulus (whereby participants are presented with a square stimulus with a small gap in one side, and are tasked to accurately answer which side of the square is broken) (Carrasco, Williams, Yeshurun, 2002) and in “broken line” tasks (whereby participants are required to answer whether a line presented for a short duration at different visual locations and eccentricities is solid or made up of smaller individual dashes) (Yeshrun & Carrasco, 1999). One explanation for such performance enhancement through precueing is through an improved sensory representation at the cued location by enhancing spatial resolution (Yeshrun& Carrasco, 1998). Performance on correctly identifying vernier acuity (our ability to discern whether two or more stimuli are aligned in visual space) has also been shown to improve when spatial precueing indicates the target location to observers (Nakayama & Mackeben, 1989; Mackaben & Nakayama, 1993).

Despite previous research observing enhancements in attention at several viewing angles in the visual eccentricity in VGPs (Green & Bavelier, 2003, 2006b; Dye & Bavelier, 2010), even with additional task demands in the form of a concurrent central task (Green & Bavelier, 2006b), the current task may have remained too difficult to identify small differences due to its attentional and psychophysical demands. However, the current experiment difficulty varied in a stepwise fashion as performance increased/decreased, allowing differences to be observed if they were present.

On the other hand, one may be forgiven for expecting differences in the current experiment due to the separate findings of modulated attention and visual resolution in the periphery, and for example, as VGPs have enhanced attention in the periphery, they may find targeting the stimuli and thus completing the crowding task easier than NVGPs. However this did not appear to be the case.

Another explanation may for the null results may be in the covert design of the current study, i.e. that participants were unaware of the videogame playing aspect of the experiment until after the experimental trials had been completed. This covert design was implemented to prevent demand characteristics and other placebo effects as described by Boot et al., (2011), in which VGPs and NVGPs may perform better or worse (respectively) due to having an understanding of the underlying research question.

A final point must be drawn to the current finding that, contradictory to Green and Bavelier (2007), I found NVGPs were able to discriminate smaller T shapes in the single T condition when compared to VGPs. Although all participants had normal or corrected to normal vision, this may indicate the VGPs used in this study overall had worse vision than their NVGP counterparts. It should be noted that the 3 T task was individually tailored to each participant's level of visual acuity, however and therefore differences in visual acuity should not affect results from the 3T condition. Future research should ensure that this is controlled.

Several explanations including group composition, covert design and methodological additions leading to increased difficulty may be responsible for these null findings. If the covert design were responsible, the issues raised by Boot et al., (2008; 2011) such as task demands and placebo effects may hold true. On the other hand, is the increased difficulty of the task from the additional randomized stimuli positioning may have reduced findings of between group differences. Although attention has been directly linked to improved performance on acuity tasks (Yeshrun& Carrasco, 1999), and VGPs have displayed enhancements in visual attention at multiple eccentricities in previous research (Green &Bavelier, 2003, 2006b; Dye &Bavelier, 2010; Wu et al., 2012), such enhancements did not appear sufficient enough to identify differences in crowding threshold between VGPs and NVGPs on this version of the task. In conclusion, the current study fails to replicate the findings of Green and Bavelier (2007) and no significant differences in visual resolution between VGPs and NVGPs were observed; whereas NVGPs displayed greater visual acuity compared to VGPs.

Chapter 8. General Discussion

In this thesis, I have aimed to identify whether habitual videogame play affects the cognitive processing of visual stimuli, and where this modulation occurs in the processing stream. As stated at the end of Chapter 1, cognitive modulation refers to differences in ERP components that theoretically could be altered through exposure to highly salient visual environments and fast temporal responses as typically found in many videogames. Through the use of electroencephalography, I explored neural correlates of bottom-up and top-down attentional processes in addition to neural correlates of working memory capacity and motor priming with the aim of identifying where in the processing stream such differences may occur. Alongside identification of neural differences, it is important to identify whether cognitive modulation as observed through ERP methods is sufficient to elicit significant behavioural differences, as behavioural experiments has been the most common form of literature in videogame playing thus far. In addition to this, I have overcome some of the methodological confounds of past literature as outlined by Boot et al., (2011) through using covert designs and event related potential recording to avoid demand characteristics and reliance on behavioural correlates of underlying neuronal changes. Below I discuss the findings of the six experiments, with specific consideration of whether each chapter lends itself to supporting or weakening the hypothesis that videogames modulate cognitive processing and where in the process this occurs. In addition to this, I will consider each experiment in terms of its methodological strengths and weaknesses, before concluding this thesis with a brief discussion of future avenues of research and the implications that the research presented here may have in day to day life.

Perceptual Load – Attentional resources and control in the periphery

The perceptual load experiment (Chapter 2) aimed to extend previously robust findings (Green & Bavelier, 2003; 2006b) and examine whether results differed through using a covert recruitment method. VGPs were observed to display significantly greater accuracy when compared to NVGPs, however although VGPs and NVGPs displayed slightly different patterns in terms of reaction times (at each distractor eccentricity), none of these differences were significantly different between the two groups.

As accuracy was not reported in previous in Green and Bavelier's (2003) paper, the observed finding of improved accuracy overall is incomparable. However, the current study failed to identify between-group differences in the flanker compatibility effect (reaction time), a strong effect previously identified. Indeed, the main effect of flanker position indicated that flankers closest to the fovea, and theoretically of highest saliency were not processed as quickly as near flankers, a result incongruent with previous literature (Green & Bavelier, 2003).

Further to the above result, no main effect of congruency was noted, indicating that both forms of distractor (congruent and incongruent) were processed in the same way. Previous results have shown incongruent stimuli to increase reaction times, making responses slower, and for congruent stimuli to have a facilitatory effect on processing and thus faster reaction times (Green & Bavelier, 2003). No such difference was observed here.

One explanation for the lack of between-group differences could be that of the covert recruitment method used. In this case, we aimed to eliminate potential demand characteristics and placebo effects that might have affected group performance as identified previous by Boot et al., (2008). However, this still fails to explain why no distractor congruency effect, or distractor eccentricity effect was identified.

In summary, VGPs appeared to be more accurate than NVGPs at completing the task. However, as theoretically necessary within-subject measures were not found, the task cannot confidently be regarded as a measure of distractor processing or attentional control. Consequently, Chapter 3 further investigated the role of attentional control and distractor processing in a modified Eriksen flanker task combined with ERP recordings in order to better test the role of selective attention, attentional control, and motor response mapping.

Flanker Task – Erroneous response and motor priming

In order to further test for cognitive modulation of distractor processing in VGPs, an Eriksen flanker task was employed in combination with the use of ERP. From a behavioural standpoint, no between-group differences were observed. This may have been due to the ease of the task. If this is indeed the case, a more difficult task might be more likely to demonstrate significant behavioural between-group differences. Another potential explanation for failing to find any between-group behavioural differences might stem from the removal of behavioural demand characteristics through the use of a covert recruitment method. However, due to previous literature not using the flanker paradigm in this format, there is not current data to compare my results to.

Again, VGPs showed differential processing of stimuli dependent on visual angle. Specifically, VGPs' N2c, a neural correlate of erroneous response reversal at the perceptual discrimination stage, was modulated by flanker distance. Again, NVGPs showed no such interaction with flanker distance, indicating videogame play may modulate how attention is deployed in the visual periphery and as such, provides VGPs with the attentional resources to process further flanker distances.

VGPs also showed differences in the P3 component, in keeping with previous electrophysiological videogame literature (Wu et al., 2012). Indeed, past identification of greater amplitude P3 was thought to reflect top-down attentional allocation, specifically when inhibiting distracting items (Wu et al., 2012). Indeed, modulated P3 amplitude was found to correlate with videogame hours per week during incongruent trials, and may reflect a similar process as previously identified in inhibiting the processing of incongruent flanking stimuli.

Interestingly, significant between group differences were observed in the lateralized readiness potential (LRP), a neural correlate of motor response priming. Indeed, the LRP typically has a single positive peak, however during incongruent trials, an initial negative peak is typically observed prior to a positive deflection. This is thought to reflect initial encoding of an incorrect response due to processing of incongruent flanking stimuli. VGPs displayed a significantly reduced initial negative peak compared to NVGPs, indicating more effective inhibition of a primed incorrect response.

In summary, although no behavioural differences between the two groups were observed, I found modulation of ERP correlates of selective attention, executive control, and motor priming stages of the processing stream.

Visual Search – The N2pc and attention to distractors

The visual search experiment conducted in Chapter 4 was the first and only experiment in this thesis that showed significant differences in reaction time between VGPs and NVGPs, an effect thought to be robust (Dye et al., 2009). From this behavioural result, I may support the conclusion that VGPs' ability to identify targets and subsequently react is modulated.

ERP waveforms indicated NVGPs show significantly more negative N2pc waveforms during distractor trials, a neural correlate of distractor inhibition. This indicated NVGPs struggle to prevent attentional capture of an irrelevant pop-out singleton whereas VGPs may be more able to control their attentional capture so as not to attend to distracting pop-outs. Furthermore, NVGPs elicited earlier P3 components. This may reflect a prioritization of object categorization or be a result of modulated earlier components such as the difference in the N2pc. Despite this, VGPs once again displayed greater P3 amplitudes, again an indication that VGPs are able to allocate greater attentional resources to the same process, perhaps due to greater efficiency or an overall increase in available attentional resources.

It is important to note that although differences in the neurological processing of visual stimuli were identified between the groups, often dependent on trial types, these differences did not necessarily translate into significant behavioural differences. Therefore, although we observed by our definition, 'cognitive modulation', the extent to this modulation does not appear to be sufficient in driving behavioural differences between the groups.

Simple Visual Search – The distractor positivity and target negativity

The simple visual search task used in Chapter 5 originally devised by Hickey et al., (2009) aimed to split the N2pc into its component parts, the target negativity and distractor positivity. Some differences in early sensory ERPs were observed, for example NVGPs displayed earlier P1 components and greater N1 components. The N1 has been observed as a correlate of visual discrimination, which indeed would make sense during a discrimination based visual search. These differences may reflect small differences in early sensory gating, and preattentive processes such as simple visual discrimination. One might be able to argue that VGPs possess greater control over these preattentive processes compared to NVGPs, or that videogame play more effectively modulates later, more top-down processes at the expense of these earlier sensory processes. Despite this, it is important to note this task was not designed to elicit and measure these potentials, and therefore such conclusions should be made with caution.

Most importantly, VGPs elicited reduced distractor positivity, and NVGPs greater target negativity. This information helps us to address the specific processes modulated by videogame playing and conforms some of the between-subject ERP differences in other studies within this thesis, specifically chapters 3 and 4. Here, videogame players appeared to rely more so on processes relating to distractor inhibition and processing as opposed to target prioritisation, a similar process to that of the N2c and LRP in chapter 3,and the N2pc (of which the target and distractor positivity are subcomponents) in chapter 4.

Working Memory – Capacity and the Contralateral Delay Activity

An important route for investigation was that of working memory, and to investigate whether modulation in working memory capacity was, at least in part, associated with attentional modulation in VGPs. Despite some findings indicating that videogame playing may modulate visual working memory (Boot et al., 2008), my more extensive approach utilizing both EEG and covert recruitment failed to observe any significant effect of videogame play on either behaviour or on electrophysiological waveforms. From this, the data begins to suggest that any modulation in ERP waveforms occurs at the later stages of stimulus processing, specifically selective attention, executive control, and motor control as opposed to working memory.

T-Task – Visuospatial acuity and resolution

A study by Green and Bavelier (2003) observed that VGPs had enhanced spatial resolution in the periphery up to 25 visual degrees. As several of the experiments in this thesis measured visual attention in the periphery, it was prudent to further examine whether spatial resolution is also modulated by videogame play. Similar to the perceptual load study (Chapter 2) I extended previous methodology up to 45 visual degrees. Whereas the task used in chapter 2 appeared to have failed to elicit the appropriate processes from the participants, and therefore expected within-subject effects had failed to be elicited, the observed results of this task simply failed to identify any differences between VGPs and NVGPs – even at peripheral distances examined in previous literature (Green and Bavelier, 2007). One potential explanation for this would be the recruitment method, and whereas past literature could overtly recruit the most habitual of videogame players, our sampling method remained covert and thus contained a broad spectrum of videogame playing behaviours. However, a more likely explanation is the addition of random presentation specifically that our trials were randomly presented on the left or right visual hemifield, making the task more difficult and potentially reducing the chance of observing between group differences.

Synthesis and Conclusion

To summarise, the series of experiments conducted in this thesis provide a mix of results, both providing support for previous literature, and finding null effects where other literature has previously been thought robust. Videogame playing does appear to modulate cognition, in that significant ERP differences have been observed between VGPs and NVGPs across several domains. This cognitive modulation appears to be later in the processing stream, specifically in selective attention, executive control, and motor priming. More so, each of these processes has in some way been related to the processing of distractors; chapters 4 and 5 both elicited significant differences in the peak activity of the N2pc and distractor positivity between VGPs and NVGPs, both correlates of selective attention. Whereas chapter 3 elicited significant between-group differences in the peak activity of the N2c, a neural correlate of erroneous response priming (executive control) and the peak activity of the LRP, a correlate of motor response priming. Between groups differences were also observed in early sensory ERPs, however it is important to note that the task eliciting these waveforms was not designed to do so, and as such the findings of such differences may be due to other confounding variables relating to the task.

Importantly, few behavioural differences were observed in this thesis. This was especially surprising given the almost exact replication of the perceptual load task (Chapter 2) (Green and Bavelier 2003) , and the visual resolution task (Chapter 7) (Green and Bavelier, 2007) – two task previously thought very capable of being able to elicit between-group differences. Indeed, not only did the behavioural only tasks in this thesis fail to elicit previously observed between-group differences, but I failed to observe the behavioural counterparts to several of the significant ERP differences outlined in the paragraph above. Indeed, this would lead me to both conclude that cognitive modulation does occur, but its effects on actual behaviour are perhaps weaker than much of the previous literature has suggested.

Future research

As far as additional cognitive functions are concerned, the scientific community has several bases covered in relation to their modulation by videogame playing. As a community, we have substantially investigated attention (Green & Bavelier, 2003), memory (Boot et al., 2008), problem solving (Adachi & Willoughby, 2013), learning and literacy (2003), among others. Future research can further our knowledge into these specific cognitive domains through improved methodologies, specifically the controversy of some null findings found in this thesis (perhaps due to covert recruitment), as well as looking to the more longitudinal effects of videogame play.

From a methodological stand-point, several improvements could be made for future research, regardless of the specific cognitive domain being investigated. For example, although EEG provides excellent temporal data regarding processes elicited from the cortex, the spatial resolution, and ability to measure processes occurring in subcortical areas of the brain are inefficient. A combined EEG and MRI set-up would provide excellent spatial and temporal resolution for future testing, allowing more detailed observation of whether the neural generators of specific components change between groups.

The core design of these studies can also be improved in future research. Unfortunately due to time and financial constraints only a cross-sectional design was possible in this research (issues of which I have detailed in Chapter 1). Despite this, future studies should utilise training designs and furthermore, endeavour to test participants longitudinally, in order to demonstrate causality and measure the longevity of potential enhancements caused by training.

Although covert recruitment ensured demand characteristics did not confound results, it comes with its own issues. Hiding a quality measure of past videogame playing behaviours within a pseudo-measure is impossible, and thus extensive post-experiment questionnaires were the only reliable method of acquiring the information needed whilst keeping recruitment covert. Unfortunately, this lack of control over recruitment prior to data collection meant that individuals frequently fell between groups (playing some videogames, but not a lot or very little), and thus were removed from analysis. Analysing data through correlational models instead of ANOVA provided one method of reducing this issue, but requires greater participant numbers to reach a suitable level of statistical power.

Indeed, in the advent of e-sports and the “professional gamer”, there are growing numbers of individuals that live together, practice videogames eight hours per day or more in preparation for international tournaments. These individuals could provide valuable insight in determining the extent videogames can alter cognition (although it is important to note that self-selection might cause individuals with greater natural reaction times to find themselves in these positions). The majority of past literature has relied on lower level criteria such as six hours per week to be deemed a gamer, or a training programme of 10 hours; though importantly these levels of criteria have been sufficient to observe modulations in cognition. It may be particularly interesting to question the extent 8 hours per day of videogaming may have in comparison to eight hours per week.

Furthermore, the age at which children can begin playing these games is becoming younger and younger as videogames become more popular. The importance of these experiences at a stage of life when the brains of children are highly plastic is relatively un-tested. The notion that videogames alter cognition is strongly supported in adults; if we are capable of altering attention in an individual that already possesses years of experience and subsequent neuroplasticity, how will this affect still developing children?

Implications

The potential implications of this research is very much dependent on the intended recipient. More specifically, whether it is used to enhance certain cognitive functions, or to attenuate cognitive decline.

As discussed in Chapter 1, several militaries organisations utilise videogames in different ways, from a recruitment tool (Prensky, 2003) to training regimen (Gopher et al., 1994). Overall, this makes a lot of sense, for example, recruiting individuals to fly drones based on past videogame experience (Subbaraman, 2013). Not only will these individuals be capable of using videogame style controls and perceiving a 3D world on a 2D screen, but they should also possess the modulated cognitive abilities to be able to perform tasks more easily in high-stress situations. Indeed, videogame training may provide military personnel with an important improvement in spatial skills (Feng et al., 2007), allowing for better tactical control on the battlefield, improved selective attention (Dye & Bavelier, 2004) and distractor inhibition (Chapter 3) allowing soldiers to focus more easily on the task at hand. Skills such as an enhanced ability to detect unusual signals/movement (West et al., 2008) may allow soldiers to identify enemies in camouflage due to unusual means of movement in visual space.

Greater attentional resources and improved inhibitive abilities may also support individuals within certain job sectors, and even in daily activities such as driving. Indeed, previous research has linked past videogame experience with performance improvements in both surgeons (Rosser et al., 2007) and nurses (Petit dit Dariel et al., 2013) due to improved motor skills and decision making, respectively. Despite this, a job role such as surgeon requiring constant information from his/her team whilst being able to focus on the task at hand would greatly benefit from increases in available attentional resources. Whether the information is necessary or not, greater attentional resources would allow for this information to be attended to, and enhanced inhibition would allow irrelevant information to be discarded with relative ease. However, these cognitive enhancements would not only provide such niche job roles as surgeons with benefits, but also improve everyday driving skills. Enhanced attentional resources would allow drivers to detect more potential threats in the visual field whilst simultaneously being able to inhibit those not deemed a threat to safety.

Whether age-related cognitive decline begins shortly after maturity (Allen, Bruss, Brown, & Damasio, 2005) or toward later life (Aartsen, Smiths, van Tilburg, Knopscheer, & Deeg, 2002), enhancements in cognition gained from videogame playing may help attenuate these declines. Indeed, this notion of ‘brain training’ has been tested previously with mixed results (Smith, Housen, Yaffe, Ruff, Kennison, Mahncke, Zelinski, 2009; Papp, Walsh, & Snyder, 2009), and when training has seen improvements, these have frequently failed to transfer outside of the current task (Owen, Hampshire, Grahn, Stenton, Dajani, Burns, Howard, & Ballard, 2010). It is this transfer to external tasks that has so far made commercial videogames so attractive to research, that without a specific goal to improve cognitive functioning, videogames often successfully modulate cognition in several domains regardless. The use of videogames may still provide the elderly or patients with degenerative cognitive decline a method to attenuate these declines. Indeed, from an electrophysiological standpoint, previous research has observed reduced P3 amplitudes and delayed P3 onset in patients with early Alzheimer’s disease (Polich, 1996), an ERP I have observed modulation in Chapter 4 and also seen in previous research (Mishra et al., 2011; Wu et al., 2012).

In summary, this thesis continues to provide evidence that commercial videogames may modulate cognition such as increasing attentional resources, improving attentional inhibition and motor inhibition, and in-turn these modulations transfer outside of the tasks they were trained in. However, more research is still required to understand the longevity of these enhancements, how far into the visual periphery these enhancements reach, and the effect of videogames on the very young and elderly. Furthermore, precise methodological designs are required to fully understand the underlying neural mechanisms that are modulated by videogames which will in turn provide us with the information needed to fully utilize training programmes and interventions in the future.

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Chapter 10. Appendices

Chapter 3 – Incorrect Response Priming

N2c Mean (Incongruent Only). Initial bivariate correlation indicated significantly less negative N2c mean activity the greater the number of hours played at frontal electrodes during medium distance incongruent trials, r = .361, *p* (two-tailed) < .05. No other significant correlations were observed.

A mixed-design ANOVA including only data from incongruent trials for each electrode site (Fz, Cz, Pz, Oz) and flanker distance (small, medium, large) as within subject variables alongside videogame playing behaviour (videogame player, non-videogame player) as the between subject variable. A significant main effect of electrode site was observed (F(1.849, 62.850) = 34.792, *p*< .001). Paired t-tests indicated Fz yielded significantly more negative N2c mean activity than Cz(t(35) = -4.441, *p*< .001), Pz (t(35) = -8.094, *p*< .001) and Oz (t(35) < -5.733, *p* = .001). No other main effects were observed, however a significant interaction between electrode site * distance (F(3.076, 104.586) < .05), and electrode site * distance * videogame playing behaviour (F(3.076, 104.586) = .05).

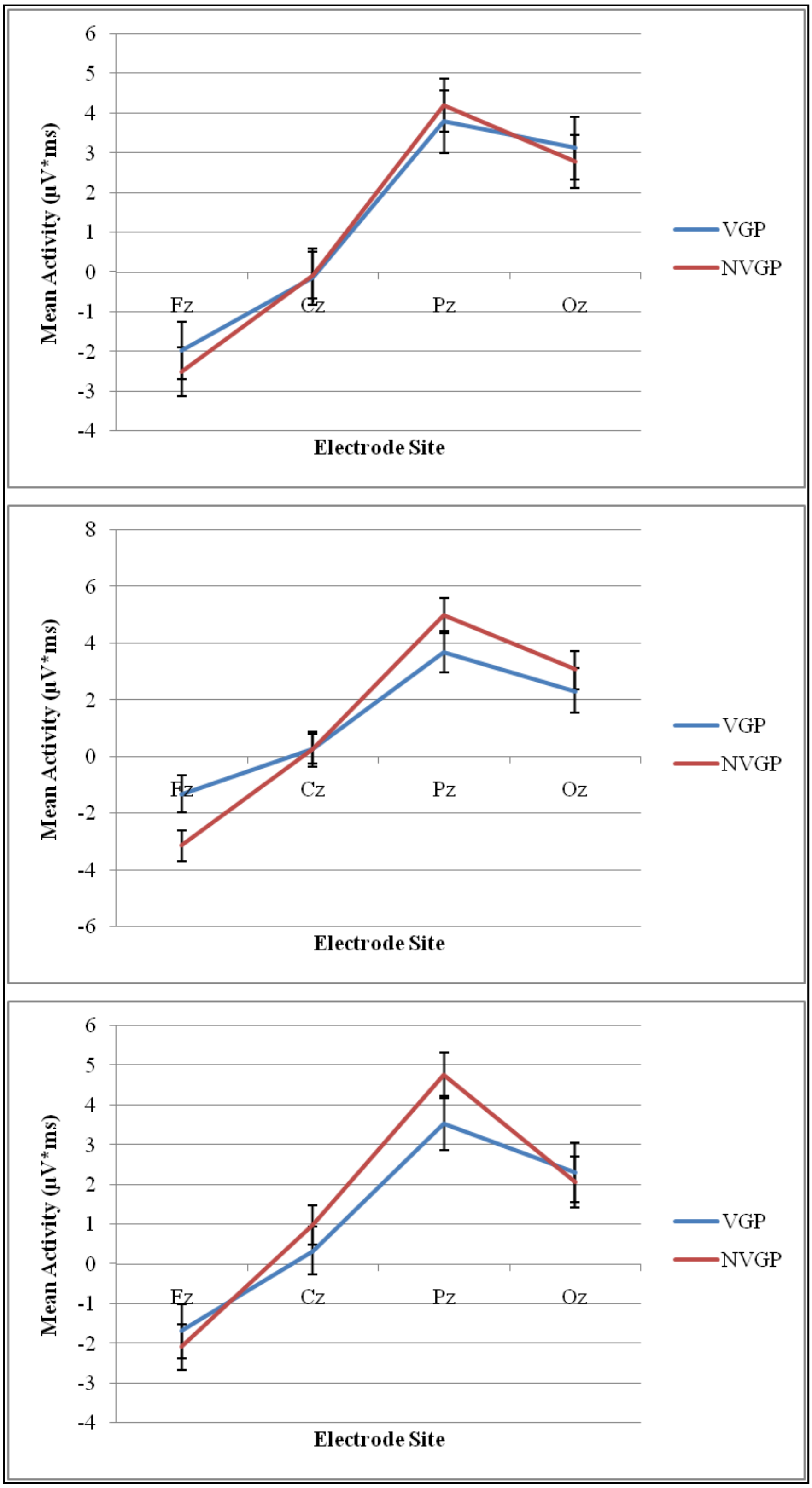

Fig. Appendix 1. Incongruent Mean Activity data at each electrode site for small, medium and large flanker distances respectively as a function of videogame playing groups.

Data entered into a one-way ANOVA indicated the only significant between group difference showed NVGP yielded significantly more negative mean activity during medium flanker trials at Fz (F(1, 34) = 4.588, *p*< .05). No other between-group comparisons approached significance at the remaining three electrode sites for any of the flanker distances.

P3 Mean Activity. Initial correlations computed between numbers of hours played and each trial type/distance combination at each electrode indicated a single significant effect. The number of hours played significantly correlated with an increased P3 during incongruent trials with medium spaced flanking stimuli at the frontal electrode site (r = .329, *p* (two-tailed) < .05.

A mixed-design ANOVA included electrode site (Fz, Cz, Pz, Oz), trial type (congruent, incongruent, neutral) and flanker distance (small, medium, large) were input as within-subject variables alongside videogame playing group (videogame player, non-videogame player) as the between-subject variable. A main effect of electrode site (F(1.944, 66.087) = 22.191, *p*< .001) and trial type (F(1.433, 48.727) = 28.572, *p*< .001) was observed. Paired t-tests indicate Pz yielded P3 components with significantly greater mean activity over the remaining electrode sites (Fz: t(35) = 6.030, *p*< .001; Cz: t(35) = 5.192, *p*< .001; Oz: t(35) = 7.600, *p*< .001), an expected result regarding the posterior P3 elicitation believed to stem from neural generators in the fronto-parietal attentional network (Polich, 2007). Additionally, paired t-tests indicate incongruent trials elicited significantly greater P3 waveforms than both congruent (t(35) = 6.563, *p*< .001) and neutral trials (t(35) = 3.733, *p*< .01). Neutral trials yielded the second greatest P3 waveform, significantly greater than congruent trials (t(35) = 6.183, *p*< .01). Importantly, a main effect of the between subject variable videogame playing group was noted (F(1, 34) = 4.674, *p*<

.05) indicating videogame players produced significantly larger P3 mean activity than non-videogame players.

Significant interactions between electrode site * distance (F(3.025, 102.862) = 10.798, *p*< .001), electrode site * congruency (F(2.947, 100.188) = 8..365, *p* = .000) and distance * congruency (F(4, 136) = 3.781, *p*< .01) were all observed. No interactions with group were observed.

Planned comparisons indicated small flanker distances elicited significantly smaller P3 mean activity at the frontal electrode when compared to medium (t(35) = -4.114, *p*<.001) and large flanker distances (t(35) = -3.919, *p*< .001). However, this pattern was reversed at both posterior (t(35) = 3.042) , *p*< .01; t(35) = 2.695, *p*< .05) and occipital electrode sites (t(35) = 2.754, *p*< .01; t(35) = 2.940, *p*< .01) indicating increased P3 mean activity (when compared to medium and large flanker distances, respectively) (See figure 7).

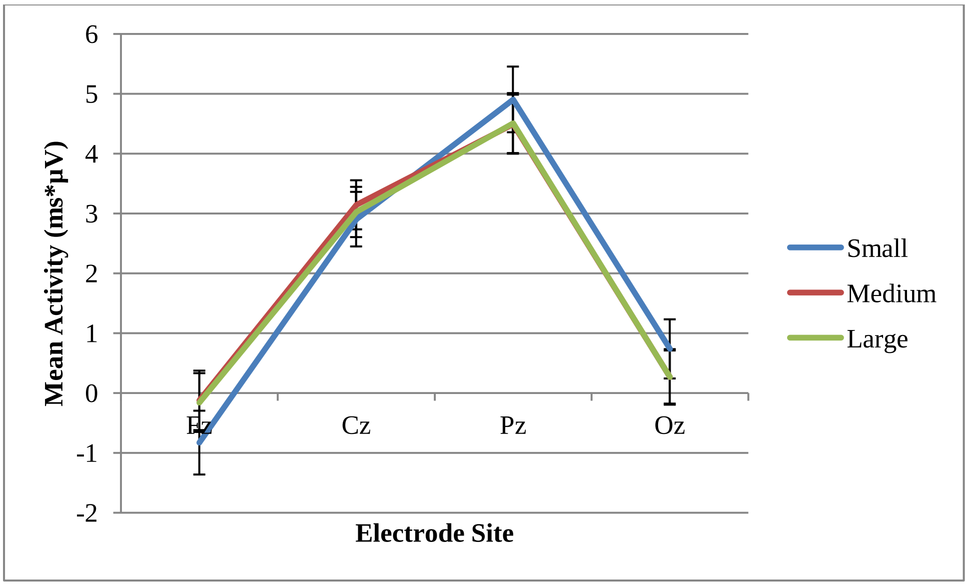

Fig. Appendix 2. P3 Mean activity at each electrode site as a function of distance.

Paired t-tests showed incongruent trials elicited significantly larger mean activities at Fz when compared to neutral trials (t(35) = 4.098, *p*< .001), than both congruent (t(35) = 6.196, *p*< .001) and neutral trials at Cz (t(35) = 4.902, *p*< .001) and congruent trials at Pz (t(35) = 4.615, *p*< .001). However, this pattern is eliminated at the occipital electrode site.

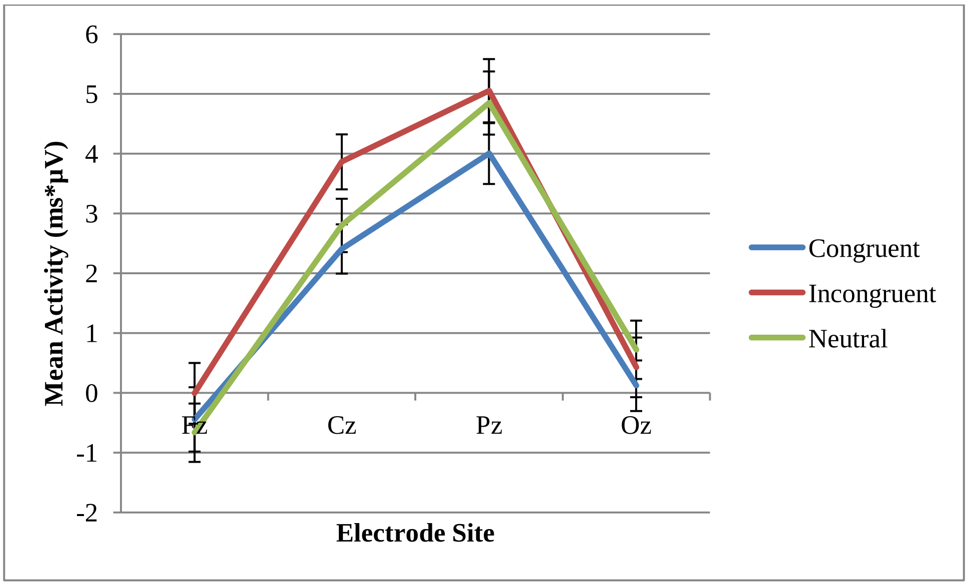

Fig. Appendix 3. P3 Mean activity at each electrode site as a function of trial type.

Paired t-tests indicated small flanker distances during congruent trials elicited significantly larger P3 mean activity when compared to medium flanker distances (t(35) = 2.076, *p*< .05). This pattern was then reversed during incongruent flanker trials with medium flanker distances producing significantly larger mean activity than small distances (t(35) = 2.553, *p*< .05). No significant differences between flanker distances were observed during neutral trials.

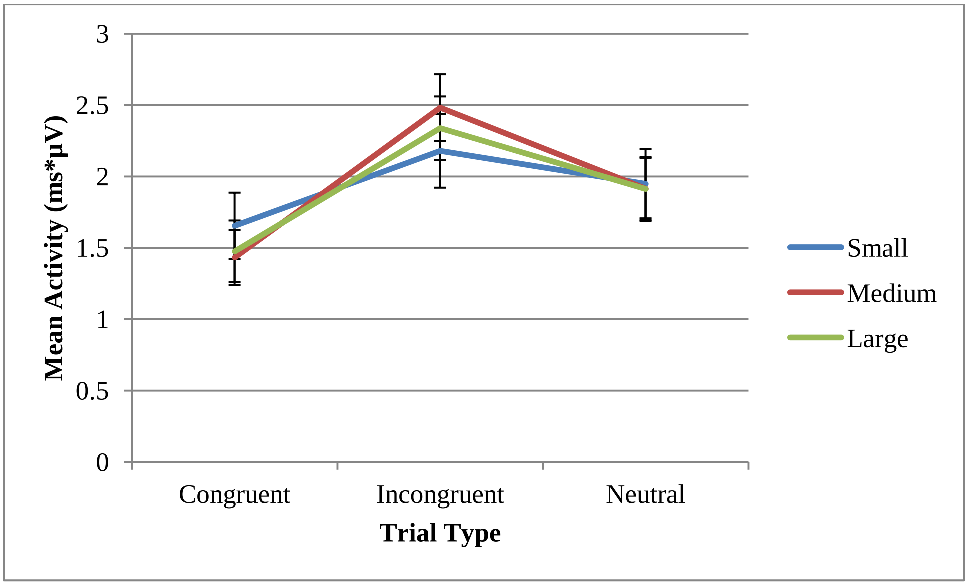

Fig. Appendix 4. P3 Mean activity for each trial type as a function of flanker distance.

LRP Mean Activity. Initial correlational analyses for LRP mean activity at each congruency/distance combination with videogame hours per week was computed. No significant relationships were observed.

A mixed-design ANOVA with congruency (congruent, incongruent, neutral) and flanker distance (small, medium, large) as within-subject variables alongside videogame playing behaviour (videogame player, non-videogame player) as the between-subject variable was computed for the late window.

A main effect of congruency was observed (F(1.629, 55.383) = 109.610, *p*< .001) and interaction between congruency and distance (F(4, 136) = 4.578, *p*< .01). An approaching significant interaction between congruency and videogame playing behaviour was also observed (F(1.629, 55.583) = 2.964, *p* = .07).

Planned comparisons indicated incongruent trials elicited significantly more positive mean activity when compared to congruent (t(35) = 12.255, *p* < .001) and neutral trials (t(35) = 8.775, *p*< .001). Congruent trials elicited the most negative mean activity, significantly more negative than neutral trials (t(35) = -8.496, *p*< .001).

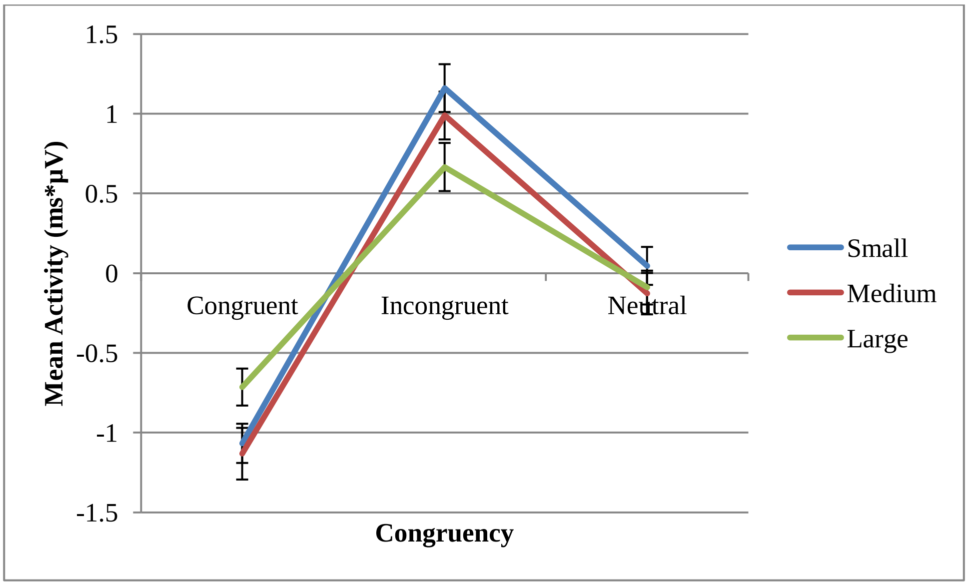

Fig. Appendix 5. Mean Activity data for each trial congruency as a function of flanker distance.

Paired t-tests indicate congruent small (t(35) = -2.320, *p*< .05) and medium trials (t(35) = -2.759, *p*< .01) elicited significantly more negative mean activity when compared to congruent large trials. This pattern was then reversed during incongruent trials as small trials elicited significantly more positive activity when compared to large trials (t(35) = -2.389, *p*< .05). No significant differences were observed at neutral trials.

Although only approaching significance, independent t-tests of the between-subject and congruency interaction indicated videogame players elicited less positive mean activity during incongruent trials (t(34) = -1.839, *p* = .075) and more negative mean activity during neutral trials (t(34) = -1.999, *p* = .054).

To examine facilitation congruent and neutral trials were examined together in mixed design-ANOVAs. In order to examine interference, incongruent and neutral trials were examined in an identical mixed-design ANOVA. Peak latency was measured at the time point of the greatest negative peak in the late window (250 – 350ms) window, facilitation would emerge as earlier latency in congruent trials compared to neutral trials, whereas interference as delayed peak onset compared to neutral trials.

*LRP Latency (Congruent and Neutral).*A mixed-design ANOVA including only congruent and neutral trials with distance (small, medium, large) as the other within-subject variable alongside videogame playing behaviour (videogame player, non-videogame player) was computed. No significant main effects or interactions were observed.

Chapter 4 – Attention to distractors

N2pc Mean Activity. An initial correlation including all participants indicated a strong relationship between the number of hours participants played videogames and the mean activity of the N2pc waveform elicited at posterior electrodes P7/P8 during distractor trials, r = .433, (two tailed) *p* < .005. No other electrode site and array combinations approached significant relationships with videogame playing behaviours. Further correlational analyses using just male participant data indicated no significant relationships between N2pc mean activity and videogame playing behaviour.

The mixed-design ANOVA yielded no main effect of array type (F(1, 34) = .462, *p* = .501) or array type between-subject interaction. A main effect of electrode pair yielded a significant main effect (F(2, 68) = 5.453, *p* < .01) indicating N2pc waveforms elicited at different sites differed in mean activity. Paired-sample t-tests indicated P7/P8 electrodes measured significantly larger N2pc waveforms than posterior-occipital sites, *t*(35) = -2.339, *p*< .05. Despite no significant main effect of videogame playing group (F(1, 34) = 1.442, *p* = .238) a significant array type * electrode pair * videogame group three-way interaction was observed, F(1.608, 54.668) = 3.602, *p* < .05 (see Figure .). Array type and electrode pair combinations entered separately into one-way ANOVAs indicated videogame players had significantly less negative N2pc mean activities during distractor trials at electrode sites P7/P8 (F(1, 34) = 4.371, *p*< .05) and P3/P4 (F(1, 34) = 10.723, *p*< .005).

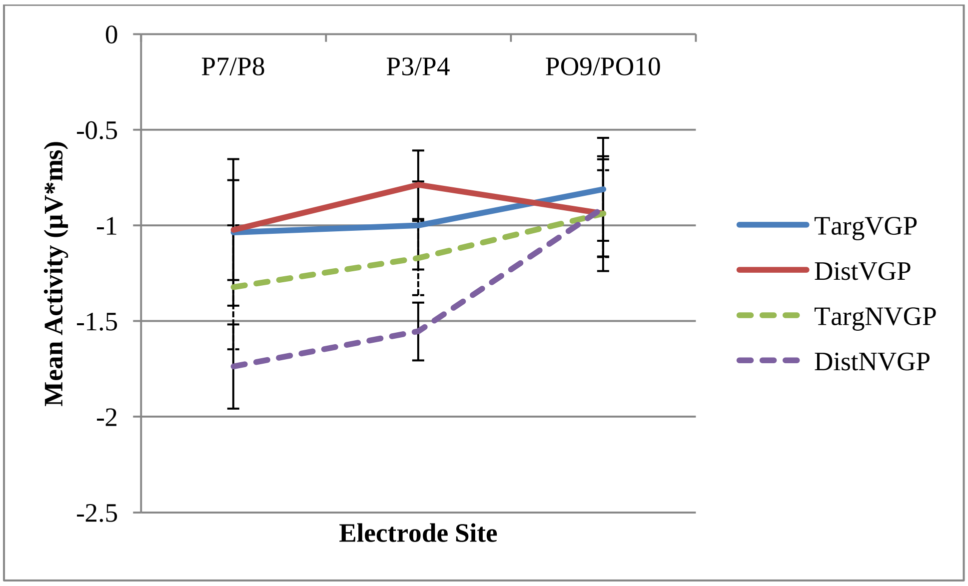

Figure Appendix 6. N2pc mean activity elicited at each electrode pair as a function of array type and videogame playing group.

P3 Mean Activity. Correlational analyses including all participants (and afterwards including only males) for each electrode and array type combination yielded no significant relationship. One approaching effect indicated larger P3 mean activities at the occipital electrode site during distractor trials the higher the number of hours participants played videogames, r = .315, *p* (two-tailed) = .062.

A mixed-design ANOVA included electrode site (Fz, Cz, Pz, Oz) and array type (target, distractor and homogenous) as the within-subject variables, videogame playing group (VGP, NVGP) remained the between-subject variable. A main effect of electrode site was observed (F(1.874, 61.849) = 27.083, *p*< .000), paired t-tests indicated most electrode sites differed significantly from neighbouring sites. Most importantly, the P3 elicited at the posterior electrode (Pz) was significantly greater than frontal (t(34) = -6.369, *p* < .000), central (t(34) = -6.187, *p*< .000) and occipital electrode sites (t(35) = 8.525, *p*< .000). A main effect of array type was also observed, F (2, 66) = 13.294, *p*< .000 (See Figure .).

An array type * electrode site interaction was also observed (F(3.603, 118.902) = 65.292, *p*< .000), paired t-tests indicate this interaction is primarily driven by significantly larger homogenous activity at frontal and central sites (Fz: t(34) = 9.471), *p*< .000; Cz: t(35) = 3.642, *p*< .000) alongside significantly lower activity at posterior sites (Pz: t(35) = -6.112, *p*< .000; Oz: t(35) = -13.848, *p*< .000) (all comparisons to target array data).

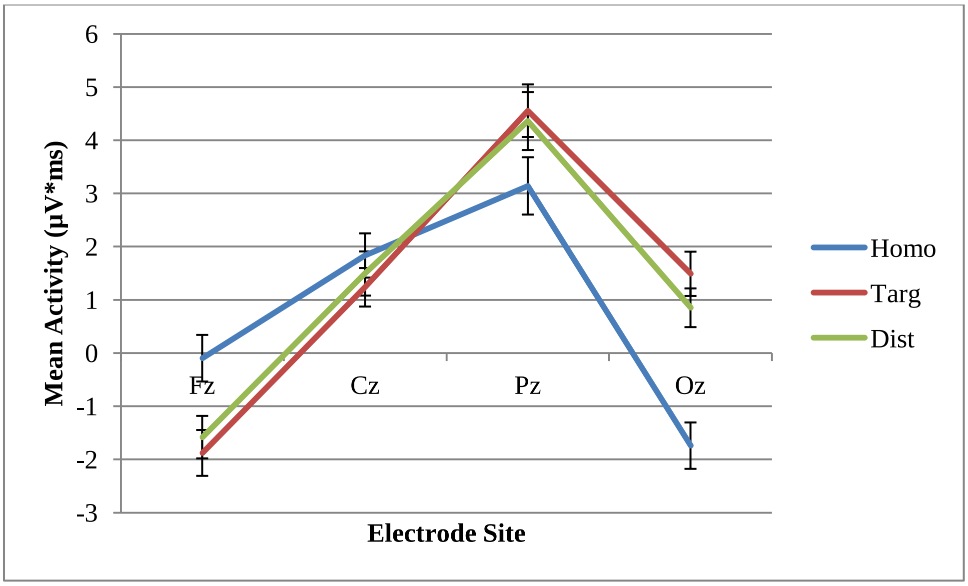

Figure Appendix 7. P3 Mean Activity across all electrode sites as a function of array type.

Despite no main-effect of the between-subject variable(F(1, 33) = .374, *p* = .545), an approaching significant interaction was observed between array type * electrode site * videogame group (F(3.603, 118.902) = 2.504, *p* = .052). Further analysis indicated videogame players elicited significantly larger mean activities at occipital electrodes during distractor trials (F(1, 34) = 9.451, *p* = .004) and an approaching significant increase during target trials (F(1, 34) = 3.699 = .063) in comparison to non-videogame players (See Figure).

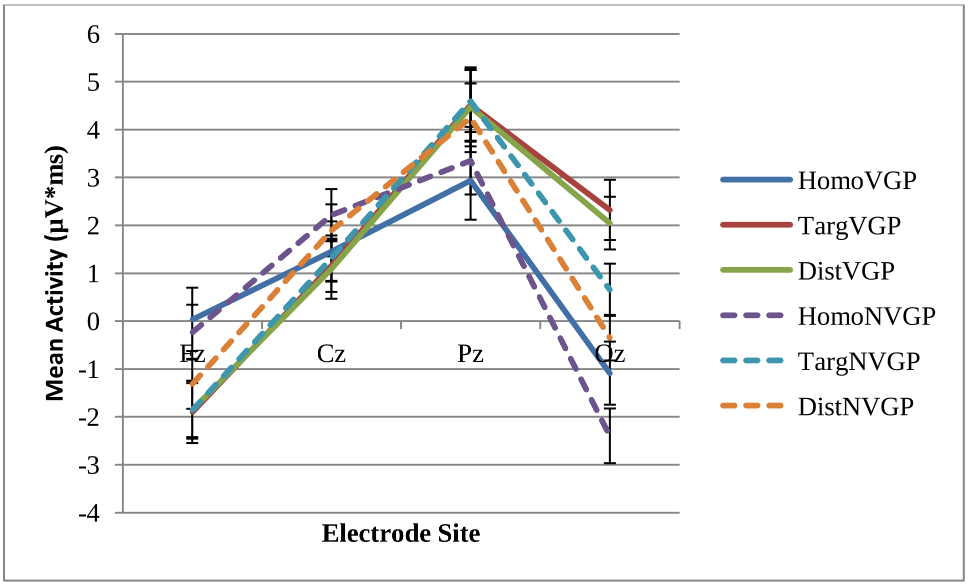

Figure Appendix 8. P3 Mean Activity elicited at each electrode site as a function of array type and videogame playing group.

Chapter 5 – Target acquisition or distractor inhibition

P1 Latency. Data was extracted from trials with lateralized target and contralateral distractor items in both upper and lower hemifields between 70 and 175ms after trial presentation. Time windows were identified using visual inspection of grand average waveforms. Data was entered into a Target (Luminous Square vs. Isoluminant Line) * Laterality (Ipsilateral vs. Contralateral) * Hemifield (Lower vs. Upper) Target Side (Left Hemifield vs. Right Hemifield) vs. Videogaming Behaviour (VGP vs. NVGP).

A main effect of laterality indicates significantly earlier P1 waveforms elicited at contralateral electrode sites (F(1050.587, 168.992) = 6.217, *p*< .05) and a main effect of hemifield (F(18909, 1019.295) = 18.551, *p*< .000) shows earlier P1 waveforms in the lower visual hemifield. A significant interaction between target and laterality was observed (F(54441.969, 856.488) = 63.564, *p*< .000), secondary analysis showed during square target trials, P1 amplitudes were elicited significantly earlier at contralateral electrode sites (t(39) = -7.968, *p*< .000), whereas during line target trials, waveforms elicited at ipsilateral electrode sites were significantly earlier (t(39) = 7.000, *p*<.000).

An approaching significant target side by videogame playing interaction was observed (F(1411, 347.348) = 4.065, *p* = .051), secondary analysis indicated VGPs elicited significantly later P1 components when the target stimulus was presented in the right visual field (t(38) = 2.580, *p*< .05) and a similar trend although not significant when the target stimulus were presented in the left visual field. A significant target * hemifield * videogame playing group was observed (F(2562.355, 387.404) = 6.614, *p*< .05), although secondary analysis indicated a general trend for delayed P1 latencies in VGPs, however only line trials presented in the lower visual hemifield were significant (t(38) = 2.533, *p*< .05) and approaching significance during square target trials in the upper hemifield (t(38) = 2.015, *p* = .051).

Importantly, a significant main effect of videogame playing group (F(20867.154, 4619.021) = 4.518, *p*< .05) was observed, with means indicating VGPs P1 latencies were delayed by approximately 11ms when compared to NVGPs.

P1 Amplitude. A main effect of hemifield was observed (F(34.974, 6.486) = 5.392, *p*< .05), indicating greater P1 amplitudes elicited to stimuli presented in the upper hemifield. A significant target by laterality interaction was also observed (F(169.085, 3.382) = 49.995, *p*< .000), paired t-tests indicated during square target trials ipsilateral electrode sites elicited significantly greater amplitudes than contralateral waveforms (t(39) = -6.130, *p*< .000) whereas line target trials elicited at ipsilateral waveforms were significantly reduced compared to contralateral waveforms (t(39) = 6.355, *p*< .000). No other significant main effects or interactions were observed.

*N1 Latency.*Data was extracted from trials with lateralized target and contralateral distractor items in both upper and lower hemifields between 160 – 250ms after trial presentation. Time windows were identified using visual inspection of grand average waveforms. Data was entered into a mixed design ANOVA identical to that used for P1 latency and amplitude analyses.

A main effect of laterality was observed (F(3.484.502, 177.447) = 19.637, *p*< .000) indicating significantly N1 waveforms elicited at contralateral electrode sites when compared to ipsilateral electrode sites. A main effect of hemifields (F(7828.629, 268.560) = 29.150, *p*< .000) indicated later N1 components elicited in the upper hemifields than lower hemifields. A main effect of Target Side was also observed (F(1087.97.782) = 11.125, *p*< .05) indicated slower N1 elicitation when stimuli was presented in the left visual field when compared to the right visual field. A Target * Laterality interaction was observed (F(32838.890, 489.218) = 67.125, *p*< .000), paired samples t-tests indicated contralateral waveforms for luminous square trials elicited significantly earlier N1 latencies, however the opposite remained true for trials in which the isoluminant line was the target stimulus (t(39) = -4.747, *p*< .000; t(39) = -9.986, *p*< .000, respectively). Contralateral waveforms elicited during Square trials were significantly earlier than Line trials (t(39) = -6.737, *p*< .000) whereas ipsilateral waveforms elicited significantly earlier N1 latencies to Line trials (t(39) = 7.358, *p*<.000).

A target * hemifields * videogame playing group interaction came close to reaching significance (F(805.219, 210.406) = 3.827, *p* = .058). Further investigation yielded no significant between group differences. No significant main effect of group was observed.

*N1 Amplitude.*A main effect of laterality was observed, indicating significantly more negative contralateral waveforms (F(93.961, 3.159) = 29.748, *p*< .000). No main effect of target type, but a main effect of target hemifields presentation was observed, indicating more negative amplitudes when stimuli was presented in the right visual field (F(62.698, 3.596) = 17.434, *p*< .000). A significant interaction between target and laterality was observed (F(353.627, 10.377) = 34.079, *p*<.000), secondary analysis showed significantly more negative ipsilateral waveforms during square trials compared to contralateral wavefroms (t(39) = 2.298, *p*<.05). The opposite relationship proved significant during line target trials with waveforms elicited at contralateral sites being significantly more negative than those at ipsilateral sites (t(39) = -7.998, *p*< .000).

A significant laterality * videogame group was observed (F(29.849, 3.159) = 9.450, *p*< .005), secondary analysis indicated NVGPs elicited significantly more negative N1 potentials at contralateral electrode sites than VGPs (t(38) = 2.566, *p*< .05). No significant difference was observed at ipsilateral electrode sites. An approaching significant main effect of videogame playing group was observed (F(310.378, 78.039) = 3.977, *p* = .053), indicating a strong trend for significantly more negative N1 potentials in NVGPs than VGPs.

*P2 Latency.*Data was extracted from trials with lateralized target and contralateral distractor items in both upper and lower hemifields between 230-300ms after trial presentation. Time windows were identified using visual inspection of grand average waveforms. Data was entered into a mixed design ANOVA identical to that used for P1 latency and amplitude analyses.

A significant main effect of laterality showed delayed contralateral P2 latencies (F(6105.626, 337.355) = 18.099, *p*< .000) and a main effect of target side (F(2018.026, 239.884) = 8.413, *p*< .05), indicating delayed P2 latencies when the target stimulus was presented in the right visual field. A target * laterality interaction was observed (F(5465.426, 470.323) = 11.621, *p*< .005), paired t-tests showed no significant difference between ipsilateral and contralateral waveforms when the target stimulus was square, however contralateral waveforms were significantly delayed in comparison to ipsilateral waveforms during line target trials (t(39) = 5.374, *p*< .000). A laterality by target side interaction was also observed (F(2838.591, 412.977) = 6.873, *p*< .05), secondary analysis indicated no significant difference between contralateral waveforms between target sides, but a significant difference between waveforms elicited at ipsilateral electrode sites to the target, with right visual field presented stimuli eliciting delayed P2 waveforms at the ipsilateral electrode site (t(39) = -3.320, *p*< .005).

A laterality * target side * videogame playing group (F(3951.610, 412.977) = 9.569, *p*<.005), independent sample t-tests yielded no significant differences. When split by group, VGPs showed significant differences between ipsilateral and contralateral waveforms during left presented targets (t(16) = 4.4325, *p*<.000) but no difference in right presented trials. This pattern remained opposite for NVGPs, with significant differences between laterality for trials presented in the right visual field (t(22) = 3.013, *p*< .05) but not trials where the target was presented within the left visual field.

P2 Amplitude. A main effect of laterality indicated greater P2 amplitudes were recorded at electrodes ipsilateral to the target (F(95.548, 4.732) = 20.190, *p*< .000) whilst a main effect of hemifield indicated greater amplitudes in the lower visual hemifield (F(54.948, 7.479) = 7.347, *p*< .05). A main effect of target side was also observed (F(43.902, 5.865) = 7.485, *p*< .05), showing greater amplitudes were elicited when the target stimulus was presented in the left visual field. A target by laterality interaction (F(84.977, 3.263) = 20.045, *p*< .000) was observed, paired sample t-tests showed no difference between P2 waveforms contralateral or ipsilateral to the square target stimulus, but significantly greater ipsilateral than contralateral waveforms during line target trials (t(39) = -7.189, *p*< .000). A second within-subject interaction observed was a laterality * hemifield interaction (F(39.550, 2.635) = 15.008, *p*< .000), although paired sample t-tests showed no significant differences, the interaction appears to be driven from a difference between the two target trials when presented in the upper hemifield (indeed, this approached significance *p* = .055).

A between subject interaction was identified in the P2 maximum amplitude data; target * videogame playing group (F(34.924, 8.187) = 4.266, *p*< .05), independent sample t-tests show no significant between subject differences. When split into groups, paired samples t-tests also yield no significant results, indicating the interaction appears to be driven from a difference in amplitude during square trials (albeit N.S.) and little between-group difference during line trials. A second between subject interaction identified was target * hemifield* videogame playing group (F(16.133, 2.562) = 6.298, *p*< .05); again, independent sample testing yielded no between group significance. When split by group, VGPs showed significantly greater P2 amplitudes to square stimuli than line stimuli in the upper hemifield (

t(16) = 2.408, *p*< .05), however this relationship was not consistent when stimuli were presented in the lower visual hemifield. No significant differences were observed within the NVGP group.

N2 Latency. Data was extracted from trials with lateralized target and contralateral distractor items in both upper and lower hemifields between 250 – 320ms after trial presentation. Time windows were identified using visual inspection of grand average waveforms. Data was entered into a mixed design ANOVA identical to that used for P1 latency and amplitude analyses.

A main effect of laterality was observed (F(12018.165, 688.979) = 17.443, *p*<.000) showed delayed ipsilateral elicitation of the N2 compared to waveforms measured at contralateral electrode sites. An approaching significant main effect of target (F(3225.870, 792.644) = 4.070, *p* = .051) indicated slower N2 latency when the luminous square stimulus was the target stimulus.

A significant target * laterality interaction was observed (F(14587.335, 899.065) = 16.225, *p*< .000), secondary analysis found no significant difference between contralateral and ipsilateral waveforms during square trials, however contralateral elicitation to line trials proved showed much faster onset compared to contralateral electrode recordings (t(39) = -6.012, *p*< .000).

Despite no main effect of videogame playing group, a target side * videogame playing group was observed (F(7630.037, 811.059) = 9.408, *p*< .005); Secondary analysis showed VGPs displayed significantly delayed N2 onset for targets presented in the left visual field than right (t(16) = 2.858, *p*< .05). No significant N2 latency difference was observed in NVGPs between target visual field presentation.

N2 Amplitude. A main effect of target type indicated more negative N2 amplitudes were elicited when the isoluminant line was the target stimulus (F(35.464, 6.950) = p< .05). A main effect of laterality indicated significantly more negative contralateral waveforms (N2pc) (F(107.600, 5.949) = 18.086, p< .000). A main effect of hemifield was also observed (F(55.449, 6.913) = 8.021, p< .05) indicating greater N2 amplitudes elicited in the upper visual hemifield. No other main effects reached significance.

Unsurprisingly, a significant laterality * target type was elicited (F(271.132, 6.950) = 39.009, p< .000); however, only a significant difference between contralateral and ipsilateral waveforms were elicited in the line condition (t(39) = -7.195, p< .000), no significant difference was observed between laterality in the square condition.

A significant hemifield * videogame playing group interaction was also observed (F(51.474, 6.913) = 7.446, p< .05). Independent sample t-tests indicate NVGPs elicit greater N2 amplitudes in the lower hemifield than VGPs (t(38) = 2.107, p< .042). However, when relationships within groups were analyzed, VGPs showed significantly greater N2 amplitudes in the upper hemifield than lower hemifield (t (16) = -3.063, p< .05), no statistically significant differences between hemifields were observed in NVGPs.

No significant between group differences were observed in either P3 latency or P3 amplitude analysis. For information on the P3, please see Chapter 4.