THE IMPACT OF ACTION VIDEO GAME PLAY

ON ATTENTION AND COGNITIVE CONTROL

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By

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Abstract

Video games players (VGPs) regularly demonstrate marked success over non-video game players (NVGPs) on a variety of tasks that tap visuospatial attention. Localization of these benefits remains elusive. Drawing from experiments reported in this thesis and considering each in light of the current literature, it would appear that said benefits are the result of development of the mechanisms and processes involved in the representation of visuospatial information rather than due to a benefit of higher cognitive control mechanisms. This assertion is supported by a series of effects. First, experience with an action video game immediately prior to a measure of visuospatial attention showed no effect on performance. VGPs demonstrated only a general tendency to complete the task more rapidly than NVGPs. There was no indication that VGPs may have been engaging contextually-related control mechanisms to more efficiently search through displays. Second, VGPs did not experience a general task switching benefit during trials that included a high level of proactive interference, only outperforming NVGPs when provided with enough time and information to engage in endogenous task-set reconfiguration. Finally, previous work has demonstrated parietal slow wave ERP correlates of central executive activity in working memory, with greater amplitudes of these components indexing increased executive control demands. In the present work, VGPs showed distinctively smaller degrees of central-executive (CE) related ERP activity in a demanding visuospatial WM condition relative to NVGPs, while maintaining equivalent behavioural performance. Thus, VGPs appear to recruit smaller degrees of CE-related processing compared to NVGPs on difficult visuospatial tasks. Taken together, these findings suggest that the observed performance benefits for VGPs in visuospatial tasks are likely not due to improved cognitive control ability, but are more probably the result of a superior representational ability for visuospatial information.

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Chapter 3—Published Article (Acta Psychologica)

Research conducted in partial fulfillment of Doctoral degree requirements.

Authors: Karle, James; Watter, Scott; & Shedden, Judy

Contribution to Work by Dissertation Author (James Karle):

- Integrally involved in hypothesis development stage, supervised by Scott Watter.
- Selected paradigm and developed experimental design in concert with Scott Watter.
- Collected majority of subject data.
- Analyzed subject data.
- Responsible for final conclusions regarding data (with input from Scott Watter and Judy Shedden).
- Significantly involved in planning, writing, submission, and revision of final manuscript.

Chapter 4—Submitted Article

Research conducted in partial fulfillment of Doctoral degree requirements.

Authors: Karle, James; Watter, Scott; Kiss, Ivan; & Shedden, Judy.

Contribution to Work by Dissertation Author (James Karle):

- Integrally involved in hypothesis development stage in concert with Judy Shedden.

- Developed experimental design in concert with Judy Shedden.
- Collected majority of subject data.
- Analyzed subject data.
- Responsible for final conclusions regarding data (with input from Judy Shedden and Scott Watter).
- Significantly involved in planning, writing, submission, and revision of final manuscript.

Chapter 1: Introduction

Beginning in the late 1970s, video games have become increasingly pervasive, rivaling television as a primary form of entertainment within North American society. Video games have a long history (see Table 1) and come in a variety of forms, including arcade systems, games for console platforms (e.g. Xbox 360, PlayStation 3, Nintendo Wii), stand-alone games, and both downloadable and off-the-shelf (OTS) products designed for use with personal computers (Subrahmanyam, Kraut, Greenfield, & Gross, 2001).

Figure 1.1 about here

Like television and film, video games benefit from dynamic visual imagery but critically, video games are deeply immersive due to their high level of interactivity (Paik, 2001). This characteristic combines with the striking capacity of video games to satisfy intrinsic needs, such as autonomy, competence, and relatedness (Przybylski, Rigby, & Ryan, 2010). The impressive growth of video games as a medium of entertainment most likely can be attributed to the interaction between these unique characteristics. Approximately 70% of Canadian households have some form of entertainment device designed to play video games (Entertainment Software Association, 2009). Importantly, the traditionally defined demographic of video game player (VGP), that being adolescent and male, is changing rapidly. The average VGP is now between the ages of 18 and 49, with 40% of all VGPs being female and 26% over the age of 50 (Entertainment Software Association, 2009). VGPs remarkably are found across all age cohorts, from very young children to those individuals in late adulthood, making research into the effects video game play has on cognition, development, and health clearly relevant to an enormous variety of populations. Yet, despite the widespread use of video games as a form of entertainment and the many hours of practice engaged in by players, when contrasted against comparable media such as television and movies, there is a surprising dearth of well-controlled and reliable psychological research on the immediate and long-term socio-emotional and cognitive consequences of video game expertise. The general trend in this field of research seems to involve a wide spectrum of interest, each of which is probed by only a handful of studies, the exception being the socio-emotional psychological consequences of video game play. The latter case has received significant attention but remains deadlocked by conflicting findings. From the wider perspective, it is obvious that research into the consequences of video game expertise is still a very young field by comparison to other disciplines and this may account for the contradictory findings and the lack of research depth in any one particular area.

1.1 Socio-Emotional Psychology of Video Games

The preponderance of research, especially the pioneering efforts, on the consequences of video game play is motivated by a polemic that rages over the potentially negative social psychological effects of this electronic form of entertainment. The principal concern is that video games not only lack any pedagogical/andragogical benefit (i.e. are a form of mindless activity) but also actually engender violent and/or addictive behaviour in those who play them. To some degree, the suggestion that video games provoke negative behavioural patterns in players has received a certain amount of support. Estimates range from 13 to 26% of adolescents who play video games exhibit hallmark behavioural patterns of addiction (e.g. sacrificing food, clothing, other forms of entertainment for game play opportunities; Egli & Meyers, 1984; McClure & Mears, 1984). Furthermore, many of the games that interest VGPs are inherently violent in nature. Buchman and Funk (1996) found that 50% of the games preferred by fourth through eighth graders involved some form of fantasy or realistic violence. In a meta-analytic review, Anderson and Bushman (2001) argued that exposure to violent video game play leads to a host of negative behavioural costs, including increased violent play behaviour and decreased pro-social behaviour in children, as well as increased aggressive behaviour, physiological arousal, and aggression-related ideation in adults. Considering the number of children and adults who play violent video games, these findings are a source of considerable concern.

Despite the above research, the study of the negative effects of violent video game play is a relatively new field and much of the findings are contradictory or confused by methodological concerns. For example, significant portions of the research completed to date has utilized classifications of violent video games that are experimenter-defined, rather than empirically established, as has been true of the field of research on the impact of violent television viewing (Dill and Dill, 1998; Griffiths, 1999). In addition, it is often the case in these studies that children, due to ethical concerns, are divided into control and experimental conditions based on previous violent game play. This naturally forwards the valid criticism that such findings as decreased pro-social behaviour and increased violent play behaviour may be the result of a selected population effect (i.e. children with violent behavioural tendencies prefer violent games) rather than violent games developing violent behaviour in the children that play them. Indeed, Wiegman & van Schie (1998) observed that children who like aggressive games are rated as more aggressive by their peers, suggesting that a child's preference for violent games may be an important variable. This picture is further distorted by the fact that not all studies on the consequences of violent video game play have demonstrated deleterious side effects. From a sample of 16-year-old high school students, Durkin and Barber (2002) found no evidence of negative outcomes among game players and, surprisingly, established that on several measures such as family closeness, activity involvement, positive mental health, and positive school engagement, game players scored more favorably than did non-video game playing peers. As well, Ferguson (2007) completed a meta-analytic review of the literature and found that there was little or no evidence to support the argument that the playing of violent video games causally influences aggressive behaviour.

Added to these concerns is the simple fact that much of the work on the addictiveness of video games is simply dated. Nearly all of the work in this area was completed in the mid 1980s (e.g. Egli & Meyers, 1984; McClure & Mears, 1984) and typically involved an analysis of adolescent behaviour within the arcade culture. While arcades still exist, the widespread availability of home entertainment systems designed for video game play has led to the steady decline of the arcade culture, such that most arcades have closed their doors. The coin-driven nature of arcade games and the significant reinforcing aspects of social interaction that occurred within these environments (e.g. peer pressure) may have engendered, in part, the reported addictive behavioural patterns exhibited by some game players at arcades. While video games are again becoming increasingly socially attractive to game players with the advent of online multiplayer games—indeed, social interaction is the strongest predictor of actual time spent playing online action games (Jansz and Tanis, 2007)—there are enough differences between the arcades of the past and the contemporary strain of video games that a need exists for more current research to support or deny the conclusions forwarded by Egli and Meyers (1984); that being, approximately one-quarter of adolescents will demonstrate addictive behaviour in reference to video game play. Moreover, the definition of addiction requires clarification. Video games are highly reinforcing, contain many of the critical elements for successful learning and, as will be discussed below, likely encourage the development of varied skill-sets in the player that may be beneficial to other aspects of daily life. In essence, are expert gamers addicted to learning? Is an expert hockey player or gymnast an addict? These issues certainly cloud a topic of importance.

What cannot be denied is that there is at least some evidence suggestive of negative socio-emotional psychological consequences. As such, such tentative data would argue for further research on the subject with an aim to categorize and minimize (or eliminate) the harmful impact of game play or if that is impossible, to inform those populations particularly sensitive to the deleterious effects of certain game genres so that exposure can be controlled individually or through parental involvement. This sentiment is expanded upon by Ferguson (2007), where he argues that the violent video game debate should be reframed in terms of the positive and negative consequences of engaging in this medium of entertainment. This perspective seems to have germinated, as video game research has been recently conceptualized as largely divisible into two branches: concern-focused (identifying negative effects) and intervention-focused (delineating and harnessing positive effects for various practical benefits; Przybylski, Rigby, & Ryan, 2010).

1.2 Cognition and Video Games

It seems likely that there is no immediate and simple answer to the question of whether or not video games are clearly “good” or “bad” for those who play them but rather that like most activities, there are both costs and benefits associated with significant investment of time and resources. This proposal appears to be valid when considered in light of the information already reviewed and the fact that a number of studies have demonstrated a variety of cognitive and motor benefits for those who regularly engage in the video game play. This author would suggest that the core goals of the field that studies the various non-socially oriented consequences of video game play are determining: the effect game play has on cognitive and motor development; the causal nature of changes to various cognitive skill-sets associated with game play; the permanence of these changes; the generalizability of these changes to other settings and environments (i.e. transfer of learning); the application of positive effects to influence psychological and physical well-being. These last two points are of some importance as they forward an often overlooked issue: the bridging of theoretical knowledge collected through basic empirical research to the application of those data in the real world. In essence, should empirical work establish that the gains developed through video game experience are trainable—a probable assumption based on the material that will be discussed below—it is essential to ascertain methods of applying this information to various practical problems and issues.

1.2.1 Motor Skills

VGPs have been shown to have increased success at tasks that tap various motor skills. In reference to non-video game player (NVGP) controls, VGPs have heightened motor responses in terms of eye-hand coordination (Griffith, Voloschin, Gibb, & Bailey, 1983). Participants completed a photoelectric rotary-pursuit task, using a wand to follow a moving light stimulus around the perimeter of three shapes (circle, triangle, square) across a series of speeds (defined as rotations per minute, ranging from 10 to 50). VGPs outperformed their non-video game playing contemporaries on the triangle and square forms and at all but the slowest speeds on the circle. Interestingly, the amount of time spent playing video games, computed in terms of months of experience and average number of hours spent playing per week, did not correlate with success on the task. The authors took this to indicate that it was unlikely that video games train eye-hand coordination, but rather these games appeal to individuals who have exceptionally developed eye-hand coordination (Griffith et al. 1983). Orosy-Fildes and Allan (1989) later demonstrated experience with a video game decreases choice reaction time. All participants received training on the basic task, completing pre-test and post-test measurements of performance. The experimental group spent a mere 15 minutes between these sessions playing a video game. This small amount of practice led to a significant decrease in the choice reaction time of the experimental group.

Several concerns can be leveled at both of these experiments. The study completed by Griffith and colleagues (1983) lacked a training component, making it equivocal that experience playing video games is not responsible for the benefits observed in eye-hand coordination. Indeed, the authors based their assessment of whether or not video game play influences eye-hand coordination on a correlation between performance on the experimental task and a self-report measure of time spent playing video games. Self-report measures have been broadly demonstrated to suffer from issues of reliability (cf. Bradburn, Rips, & Shevell, 1987; Capaldi, 1996). Importantly, being a common but not tightly scheduled activity, it seems likely that the exact number of hours spent playing per week would be poorly recalled from memory by the majority of players. As such, the approach used by Griffith and colleagues (1983) to determine the weight game play has on motor development may have been produced spurious results. Without establishing a causal link between game play experience and the improvement of a particular skill-set, the fact then remains that any finding can be either the result of expertise with video games or the result of selected population effects (or both). Suggesting that individuals are attracted to activities that tap abilities they are naturally skilled at is far less intriguing than the concept that experience with the task shapes those abilities. Should video game play develop cognitive skill-sets, it immediately becomes a simple matter of pragmatism to delineate the cost and benefits to players for their edification and safety. More importantly, the possible applications of beneficial cognitive development through game experience can be easily imagined. A short list might include aiding development in children, remediation of cognitive decline in fluid cognition experienced after age 25, addressing developmental difficulties (e.g. amblyopia), and encouraging specific skill-sets useful to established populations such as paramilitary (e.g. police forces, private security groups) and military organizations where improvements in various cognitive and motor processes could provide an essential edge.

Continuing with the concerns leveled at the two motor studies, while Orosy-Fildes and Allan (1989) did have their participants engage in video game training, they themselves admitted that it is possible any manual dexterity task might provide similar results. This does not invalidate their findings but makes them potentially less impressive when considering the application of video game technology to generate improvements in a particular ability, one of the main goals of the field. Further, as the authors (Orosy-Fildes and Allan, 1989) ran a choice reaction time task and did not contrast it with a simple reaction time measure of performance, there is some uncertainty as to the localization of the differential performance in the processing stream. The utilized design does not allow for benefits to be clearly associated with one or more stages of processing, from perception through to response provision, particularly with respect to the efficacy of categorization of the stimulus and speed of motor output. As well, considering the limited duration of video game practice during the experiment, the benefits demonstrated may be short-lived. Participants were not later examined to ascertain retention in an effort to access this practical issue.

These are minor concerns when compared to the fact that there were no controls for Hawthorne-like effects on performance or differential motivation between the two groups. Experimental participants interacted with the experimenters while completing an arousing and potentially interesting training session with a video game between tests of choice reaction time, where the controls waited quietly in an adjoining room for 15 minutes and received no attention from the experimenters. It has been clearly demonstrated that the simple act of an experimenter attending to a participant or the awareness of the participant that they are being experimented upon leads to variation in obtained data unrelated to any experimental manipulation. For example, participants who received more extensive follow-up as part of a clinical trial analyzing the efficacy of Gingko biloba for treating mild dementia demonstrated better performance on a subsequent cognitive assessment battery, as compared to minimal follow-up controls (McCarney, Warner, Iliffe, van Hasele, et al., 2007). In the current study (Orosy-Fildes and Allan, 1989), the experimental group may have been more motivated or engaged during the post-test period of the experiment as a result of the video game training session, leading to a finding of decreased reaction time spuriously attributed to training of the motor system but in reality, brought on by increased vigilance ("paying attention" in the vernacular) and commitment on the part of the subject. This is a delicate but an unquestionably important issue. Orosy-Fildes and Allan (1989) assert the ability of experience with video games to automatically develop (improve) a cognitive-motor network, and yet the alternative explanation of their findings is that some volitional strategy such as a desire to "pay attention" or "try harder" or simply the experimenter interacting with the participant inflated performance in the experimental group. Considering the core interests of this field that studies the impact of video game on players, the first of these two hypotheses is far more intriguing; which of them is primarily involved in these findings remains unanswerable with such a confounded design.

1.2.2 Memory Effects

Evidence that playing video games changes or improves the functionality of memory encoding and/or retrieval is currently sparse. As will be described below, action VGPs demonstrate significant success at visuospatial processing, much more so than their non-game playing counterparts. Building on these findings, it was theorized that expert visuospatial processors (i.e. VGPs) might be better able to evoke details from visual memory (Ferguson, Cruz, & Rueda, 2008). On a series of visuospatial recall tasks, the performance of those who played violent video games was associated with higher visual memory recall. The authors point out that this experiment was correlational by design and thus the findings cannot indicate a causal relation between improved visual memory and violent video game play. In a purely cognitive-oriented study, Boot and colleagues (Boot, Kramer, Simons, Fabiani, & Gratton, 2008) have demonstrated that expert VGPs are better able to detect changes to objects stored in visual short-term memory when compared against NVGPs.

Another study that examines some form of memory is one completed by this author (Karle, Watter, Kiss, & Shedden, submitted), where both VGPs and NVGPs completed a working memory task in verbal and spatial modalities while high-density electroencephalography (EEG) was recorded. While this data will be presented in Chapter 4, a short description seems appropriate here. In brief, differential processing between the two groups was not recorded using behavioural measures. However, there were significant differences between the two groups when examining electrophysiological activity across the scalp. While there were a variety of areas of interest that differed between NVGPs and VGPs, this article focused on one cluster of electrodes located central parietally. This study was one of the first to use event-related potential (ERP) to study differences between VGPs and NVGPs. (see Bartholow, Bushman, & Sestir, 2006 for ERPs, aggression, and video game play). Of further interest is the fact that had only behavioural measures been taken, no differences would have been detected, suggesting the use of ERP and other neurophysiological measures (e.g. PET, fMRI, MEG) may be valuable tools for continued research on the impact of video game expertise. It should be noted that a limitation of the study (Karle, Watter, Kiss, & Shedden, submitted) was the lack of a training component. Due to the costly nature of both ERP and video game training experiments, this element will be completed in a future study. See Chapter 4 for a full description of the method, results, and conclusions regarding these data.

1.2.3 General Learning and Problem Solving

While details on how video games may change memory processes remain limited, there is some evidence that aspects of higher cognitive processing such as problem-solving may be affected by expertise with video games. For example, greater video game experience impacts learner performance in video game-based instructional environments, with improved performance during testing regardless of difficulty levels involved (Orvis, Horn, & Belanich, 2008). It has also been demonstrated that frequency of video game play influences the likelihood of insight (sudden recognition of a new method of solving an impasse or development of a new strategy) and player comments relating to game strategy (observations on behaviours used in-game that describe an action or inaction with reference to the consequences), with frequent VGPs outperforming infrequent VGPs on both counts (Blumberg, Rosenthal, & Randall, 2008). Further, both VGPs and NVGPs placed increased emphasis on problem-solving skills over the course of the 20-minute game session, as demonstrated by greater mention of insight, game strategies, and goal comments, suggesting that video game play may encourage the activation of those mechanisms that underlie problem-solving skills (Blumberg et al., 2008). Interestingly, frequent VGPs outperformed infrequent VGPs on the test game on several measures of performance despite the game being novel to both groups. This is consistent with previous findings (Blumberg, 1998; Blumberg, 2000). Blumberg and colleagues (2008) suggest that frequent VGPs are capable of activating a general “game play” schema that allows for significant success at the test game despite lack of foreknowledge about the rules and restrictions involved in the game. This author suggests it is possible that instantiation of this schema allows frequent VGPs to conceptualize relatively novel events in terms of familiar categories and their associated responses. This pattern of responding, though not perfectly matched to the task and thus liable to error, provides a rough link between previously developed knowledge sets and the current environment, leading to increased success in terms of overall game performance. Indeed, framing this suggestion in terms of cognitive load theory supports such a conclusion. According to this theory, individuals with greater experience possess sets of schemas specific to a particular general domain and their use places fewer demands on working memory, thus allowing learners to progress more successful through complex instructional environments (Kalyuga, Chandler, & Sweller, 2001).

A concern that can be leveled at the study by Blumberg and colleagues (2008) is reflected in the age disparity between the two experimental populations. Frequent VGPs were five years younger than the infrequent VGPs (28.4 vs. 33.6 years respectively), placing the former group on the cusp of the period when cognitive decline is purported to begin (cf. Di Lollo, Arnett, & Kruk, 1982; Hertzog, Williams, & Walsh, 1976; Kline & Szafran, 1975; Walsh, 1976) while the latter will have experienced 5 to 8 years' worth of accrued deficits. The test game used (Sonic the Hedgehog 2) is a very fast paced game, requiring rapid visual processing and responses to game stimuli. As the infrequent VGPs would have on average experienced more decline in both motor and attentional processing, it is possible that the difference in performance observed by Blumberg and colleagues (2008) may be attributable to a general slowing of cognition in the infrequent VGPs, rather than a causal influence of video game play experience.

An earlier study by Blumberg and Sokol (2004) engaged children between the ages of 6 and 11 years, examining the differential use of internal- and external-based strategies concerned with learning how to play video games. Internal strategies are behaviours that do not make use of the support of another individual, typically involving the reviewing of instruction manuals provided with a game or engaging in trial-and-error. Opposed to these approaches to learning are external strategies, examples of which include observing the performance of—or asking for instruction from—another, more experienced individual. It was determined that older children and those that frequently play video games subscribed to internal-based strategies when learning to play a novel video game. As per findings by Blumberg (1998, 2000), frequent VGPs outperformed infrequent VGPs on measures of success at game play. These studies (Blumberg et al., 2008; Blumberg and Sokol, 2004) are of particular interest for their focus on children, as the majority of video game research uses young adults as participants, typically gathered from university populations. Unfortunately, like many other studies in the field of video game research, the findings of Blumberg and colleagues (Blumberg et al., 2008; Blumberg and Sokol, 2004) and Orvis and colleagues (2008) are compromised by the lack of training conditions comparing the performance of two groups of NVGPs, one of which experiences a period of practice on a video game while the other engages in some suitable control task between pre- and post-test sessions. Without such a condition, it is impossible to determine if the differential patterns of problem-solving and learning listed above are causally linked to video game expertise. Considering that Blumberg and colleagues (2008) reference the prospective applied benefits of video game expertise by suggesting "…that learning in the context of video games has the potential to inform instruction in academic settings" likely through the encouragement of specific patterns of problem-solving, this is a particularly conspicuous though not uncommon oversight. However, it should be noted that while in some instances it is particularly important to demonstrate causality, it is not always necessary to obtain meaningful and useful data that explicate differences between VGPs and NVGPs. For example, when we consider the findings demonstrated by Blumberg and colleagues (2008), the knowledge that children with some video game expertise engage in differential problem-solving strategies as compared to non-video game playing controls should be of considerable value to educators when attempting to develop lesson plans that acknowledge such individual differences.

Motivated by the intriguing structural similarities between video games and computer-based instruction, a study completed by Pillay (2002) addresses the issue of clearly linking experience with video games and changes to learning behaviour. Three groups of children were involved, two of which played one of two recreational computer games, while the third acted as a control. Each group was assessed both quantitatively (response time and accuracy) and qualitatively (cognitive strategies) on a set of educational tasks. The results suggest that playing a recreational computer game may improve performance on future computer-based educational tasks. However, the generalizability of this learning may be linked with how closely the computer game matches the educational software. More recent data support this assessment, demonstrating that only specific prior game experiences that have a number of characteristics in common with the training game will be positively predictive of learner outcomes (Orvis, Orvis, Belanich & Mullin, 2005). Using Blumberg and colleagues' (2008) schema-driven performance hypothesis described above, both of these findings can be explained with reference to the similarity between a schema developed through prior experience (training) and the current task requirements. As congruency between contextual demands increases, so does performance.

Of particular interest to the current segment, Pillay (2002) demonstrates that the type of learning or cognitive strategies developed by game experience depends on the genre. Games that can be structurally defined as linear cause-and-effect in style are associated with means-end analysis type strategies, while adventure games encourage inferential and proactive thinking (Pillay, 2002). While this study found intriguing results that are arguably causally linked to experience playing a video game, it is marred by a previously mentioned confound. Specifically, while the experimental groups played the recreational computer game prior to completing the educational software portion of the experiment, no appropriate activity was substituted for game play in the control condition. Thus, a portion of or all of the success demonstrated by the experimental groups on the educational measures could be the result of motivation and/or arousal brought on by the immediately prior engaging video game play experience. This seems a plausible alternate hypothesis as experience with video games has been found to predict motivational learning outcomes, including training motivation, time spent playing an instructional game, and training satisfaction (Orvis, Horn, & Belanich, 2006; Orvis, Orvis, Belanich, & Mullin, 2005; 2007).

1.2.4 Impact on Spatial Reasoning

While higher reasoning may be sensitive to the influence of expertise with video games, there is also evidence that lower-level processes involved in attention and spatial reasoning can be modified through experience with video games. Dorval and Pepin (1986) found that NVGPs who trained on a video game over a period of 8 sessions demonstrated superior spatial visualization skills, being more adept at mentally rotating, manipulating, and twisting 2D and 3D objects than controls who did not receive training. McClurg and Chaillé (1987) further demonstrated that training on a video game that places significant demands on spatial reasoning leads to improvements on post-test measures of performance on the mental rotation test (MRT). Two video games were used, each assigned to an experimental group and a third group acted as a control. Following pre-test assessment of performance on the MRT, the experimental groups engaged in video game training twice a week for 45 minutes per session over the course of 6 weeks. This was followed by a post-test of performance on the MRT. Controls were pre- and post-tested but received no treatment during the 6 week training period. Both experimental groups differed significantly from the control group on the MRT but did not differ from each other. An association between skill at the mental paper-folding test (MPFT) and action video game expertise has also been demonstrated (Greenfield, Brannon, & Lohr, 1994). However, a follow-up experiment that involved training on an action video game failed to demonstrate a causal link between skill at the MPFT and game play expertise. The authors (Greenfield et al., 1994) argue that the training period was too short and structural equation modeling predicts that long-term training on an action video game will have a beneficial effect on skill at the MPFT. A similar but more recent study reflects these earlier findings with a correlation between experience with action-simulation video games and performance on the MRT (Quaiser-Pohl, Geiser, & Lehmann, 2006). Three groups were tested, action-simulation players, logic-and-skill training game players, and NVGPs. Only action-simulation players differed from the other two groups, which did not differ from each other. This is an interesting finding as it suggests that the genre of video game may differentially influence performance across cognitive abilities. As has been described, linear games (logic games) encourage means-end analysis type strategies (Pillay, 2002) in players but, as the present study indicates, has no effect on a measure of spatial performance. Considering the diversity of video game genres currently available and the variety of demands they place on the game player, it seems potentially fruitful to use a broad selection of genres when testing the impact of video game play on cognitive performance. Of course, such an approach, as is the case of training conditions, can be excessively demanding of resources, both in terms of fiscal and temporal commitments making such additions appealing but often impractical. However, a long-term research trajectory engaged in by one or more labs could effectively isolate the unique abilities of specific game genres to influence cognitive and motor development in the player.

It is important to note that each of the studies described above (Dorval and Pepin, 1986; Greenfield, Brannon, & Lohr, 1994; McClurg and Chaillé, 1987; Quaiser-Pohl, Geiser, & Lehmann, 2006) manages to avoid one of the major pitfalls that plagues the field, that being the failure to provide a training condition to determine causality of the experimental effect, but each overlooks the importance of controlling for the influences of motivation and arousal. All of these studies provide an experimental group with varying degrees of practice on a video game. The performance on some measure of spatial reasoning of the experimental group is then compared against that of a control, which does not receive any game experience between pre- and post-test. Critically, this control either does nothing between testing periods or engages in their regular daily routines. In either case, an appropriate activity to control for issues of motivation and arousal (and other Hawthorne-like effects), was not implemented confounding the results of each study. This is a major theme that can be observed in much of the early work in the field of video game studies, though it continues to occur occasionally with current research.

Importantly, several studies have been completed that potentially explicate the influence of motivation and arousal when testing the impact of experience with video games on spatial reasoning. One such study tested changes in spatial performance after practice on a video game that placed significant demands on spatial reasoning against a control computer-based word game that required verbal processing with no spatial component (Subrahmanyam and Greenfield, 1994). Experience on the spatially-oriented video game was significantly more effective at improving spatial reasoning than experience with the word game. Interestingly, children that entered the experiment with comparably poorer spatial skills than their counterparts showed the greatest improvement in performance, which the authors took to suggest that educational programs involving training on spatially-demanding video games may be useful to reduce or eliminate individual differences in spatial reasoning performance (Subrahmanyam and Greenfield, 1994). Applications of video game research are described in some detail below but this finding predicts a series of exciting possible applied avenues for video game training. However, the findings of Subrahmanyam and Greenfield (1994) are tempered by several potential confounds. Firstly, several non-standard measures of spatial reasoning were employed, bringing into question how effectively these findings can be related and contrasted against other studies in the field that use more traditional measures of spatial reasoning (e.g. MRT). Moreover, the suggestion that the two experimental games are conceptually similar is specious. The spatially demanding game was a video game in the truest sense of the word, in that it involved dynamic processing of stimuli, while the second game was a computer game comprised of static words as study and test items. Research has demonstrated in humans a strong, reliable preference for dynamic stimuli from an early age (e.g. Shaddy and Colombo, 2004). When these data are combined with the fact that the level of dynamic complexity of a TV program correlates positively with both vigilance and recognition memory when using ecologically valid measures (Welch and Watt, 1982), it can been argued that the dynamic stimulus processing required of television, film, and video games is a critical reason for the success of these modern media over radio and books, media that lack this trait. Something similar may be occurring in the current study (Subrahmanyam and Greenfield, 1994), with the dynamic stimuli presented in the video game leading to greater engagement (e.g. vigilance, immersion, etc.) on the part of the experimental group. This elevated engagement could lead to increased success on the measures of spatial reasoning used in the study. These significant findings would then allow for the potentially spurious conclusion that experience with a spatially demanding video game, but not a computer word game, improves spatial reasoning. A more controlled comparison would include a word game that is also a video game, involving dynamic imagery of some form.

Though a collection of confounds do mar the findings in the spatial reasoning literature, generally these studies do evidence the positive impact of video game play on cognitive development. And yet, like many fields of study findings are frequently contradicted. A successful experiment performed by Okagaki and Frensch (1994) demonstrated that mental rotation and spatial visualization times tested by computerized spatial performance measures improved significantly after training on *Tetris*, a three dimensional puzzle game that involves fitting shapes made up of four connected squares (called tetraminoes) together. This game is well accepted in the field as placing significant demands on spatial processing and mental rotation abilities. A more recent study completed by Sims and Mayer (2002) found that skilled *Tetris* players outperformed non-*Tetris* players only on tests of mental rotation that employed tetraminoes, not on other tests of spatial ability. Performance by *Tetris* players on this task was qualitatively similar to their counterparts, with rotation of tetraminoes being completed in a similar but more rapid manner. Sims and Mayer (2002) employed a training condition where non-*Tetris* players received 12 hours of game experience with *Tetris*. This had no quantitative impact on tests of spatial reasoning when compared against matched controls. Interestingly, a qualitative difference was detected, where the experimental group was recorded using a different rotational strategy when faced with tetraminoes, as compared to other shapes. The authors suggest that their findings indicate that expertise is highly domain specific and thus, training on spatially demanding games will not transfer broadly (Sims and Mayer, 2002). The contradictory findings in studies that use training components to modify spatial reasoning foreshadows similar findings that will be discussed in the attention segment below (Green and Bavelier, 2003; Boot et. al., 2008).

It is potentially edifying that training effects are non-robust. This is of critical importance to one of the main goals of the field of video game research, that being the successful application of empirical findings to immediate problems faced by a variety of populations. It seems reasonable to postulate that specific game genres may convey particular benefits (and potentially particular deficits) in various forms of processing. For example, we know that dynamic puzzle games do not provide benefits to spatial attention, temporal attention, or attentional capacity (Green and Bavelier, 2003, 2006a, 2006b). However, as the results described above allude to, they may engender benefits in spatial reasoning. Transfer of learning is essential to the success of this area of interest and such success will likely rely on a match between the accrued benefits from video game play and the demands of the real world context.

1.2.5 Attention and Video games

Early research touched only lightly on the potential impact of video game expertise on attentional processing. This fact is surprising, as most video games developed and marketed from the mid 1980s to the present bombard players with excessively dense fields (both spatially and temporally) of dynamic stimuli. This is especially true of the most commonly played games such as first-person shooters, racing games, and real-time strategy games. Each of these styles or genres of games potentially places massive strain on the perceptual and attentional processing systems. And yet, up until the mid 1990s, nearly 20 years after video games began to work their way into the collective infrastructure of North American entertainment, much of the research focused on motor control and higher forms of cognition. In their seminal work, Greenfield, deWinstanley, Kilpatrick, and Kaye (1994) first evaluated the performance of expert and novice VGPs on a divided attention task where response times were measured for targets of varying probabilities at two locations. While the two groups did not differ in the condition where target probability was high, expert VGPs did not demonstrate the attentional cost that novice VGPs manifested when target probability was low (Greenfield et al., 1994). Of considerable importance is that an experimental group received 5 hours of training on an action video game. This small amount of practice led to a significant difference in performance between the control and experimental groups on post-test measures of divided attention (Greenfield et al, 1994). Like so many other studies from that period, no stand-in task was assigned to the control group to account for such confounding variables as motivation or arousal.

In the new millennium, research began in earnest into the effect video game play has on the development and function of attention. Over the space of approximately 6 years, at least 11 articles were written on the subject. Much of this momentum can be attributed to the work completed by Green and Bavelier (2003, 2006a, 2006b, 2007). They set a standard in the field by ensuring that nearly each effect of differential visuospatial attentional processing discovered between VGPs and their non-game playing contemporaries was accompanied by a training condition to determine causality while also controlling for motivation and arousal confounds. It will be recalled that it is necessary to demonstrate that those who do not play video games can be shown to approximate the performance of

VGPs on measures of cognitive performance after some period of training with video games. Failure to do so leaves unaccounted for the possibility that the enhanced cognitive abilities of VGPs could simply be due to a predisposition that leads to successful performance on both video games and cognitive tasks used in these studies. In essence, VGPs may have a predilection for video games because they excel at them as a result of some preexisting skill-set(s) that the video games of interest place a premium on, rather than the games themselves engendering improved performance (though see comments earlier in this Introduction regarding the value of correlational research).

The initial study completed by Green and Bavelier (2003) was motivated by the well known finding that consistently exposing an organism to an altered visual environment leads to changes in the visual system. The authors suggest that considering both the ubiquity of video game play and the significant demands action video games place on perceptual and attentional processing, it is likely that expertise with this genre of games should lead to development of visuospatial selective attention. In order to test this hypothesis, Green and Bavelier (2003) gathered measures of performance from VGPs and NVGPs on a variety of tasks that tap three components of attention: capacity of the attentional system, spatial attention, and temporal attention. Attentional capacity was examined using a modified Eriksen flanker task (i.e. flanker compatibility task) and an enumeration task. The traditional finding with this modified Eriksen flanker task can be described as follows: the greater the load placed on the visual system through increasing the number of distracting items, the less influence an incompatible to-be-ignored distractor stimulus will have on performance. NVGPs clearly replicate this basic finding. With respect to VGPs, the to-be-ignored item interferes with performance on the task, regardless of the number of load items, suggesting that VGPs have spare attentional resources to process the to-be-ignored stimulus despite increasing demands placed on the visual system (Green and Bavlier, 2003). The enumeration procedure produces a similar differential with respect to attentional capacity, with VGPs being able to subitize (or instantly perceive) more items than NVGPs. It should be noted that it has been demonstrated that this effect is not the result of an improved ability to instantly apprehend numerosity of the display, but is in fact a consequence of significant improvement to the serial process of counting (Green and Bavelier, 2006a). The spatial distribution of attention was examined through employing the useful field of view (UFOV) task. Not only did VGPs outperform NVGPs on this task but surprisingly, they also did so outside of their typical range of practice (10 to 20 vs. 30 degrees of eccentricity; Green and Bavlier, 2003). Temporal attention was assessed by tapping a robust phenomenon in perceptual research known as “attentional blink”. Should a first target be followed in close succession by a second target, typically measured in terms of a few hundred milliseconds, performance on detecting the second target will be poor, with increasing accuracy the greater the stimulus onset asynchrony (SOA). VGPs outperformed NVGPs on this task at all but the longest

SOAs. This finding was taken to indicate VGPs have improved control of attentional resources across time.

To ensure that these effects were indeed the result of experience with action video games, a training condition was included (Green and Bavelier, 2003). Two groups of NVGPs were randomly assigned to one of two conditions. The first group received training on an action video game while the second practiced on *Tetris*, previous described in this manuscript as a video game requiring significant spatial reasoning while placing few demands on attentional processing. Importantly, the “control” group for this experiment was also involved in training on a visually dynamic task, thus controlling for Hawthorne-like effects and motivational and arousal confounds. The addition of this control group has managed to address a significant oversight in the field. Green and Bavelier (2003) observed those who trained on an action video game consistently and significantly outperformed their counterparts on three measures of attention, which included the UFOV, an enumeration procedure, and a test of the attentional blink. These findings provide strong evidence for a causal link between action video game play and improvements in visuospatial selective attention. Of considerable interest is the fact that the training that led to these differential effects was merely 10 hours in length. This suggests that expertise may not be a requirement; even limited exposure to action video games may be sufficient to provide benefits to visual processing. Of course, the generalizability of these benefits to other settings and their durability over time has yet to be ascertained, though there is some evidence to suggest that increased success at the UFOV as the result of training on an action video game can last in excess of 5 months (Feng, Spence, and Pratt, 2007). Green and Bavelier (2006a, 2007) went on to expand on their initial findings, replicating a number of these effects. As well, they demonstrated the superiority of VGPs over NVGPs on another measure of attentional capacity, the multiple object tracking task (MOT), and also a significant reduction in the phenomenon known as crowding, which is a measure of the smallest distance a distractor can be from a target without hindering target identification. This latter effect is suggested to be descriptive of the spatial resolution of vision. In both cases, training on an action video game by NVGPs led to significant post-test improvements that were not mirrored in control groups trained on *Tetris*. However, it should be noted that training benefits observed in these two studies differed from earlier findings in that the required time spent training be increased from 10 to 30 hours of practice, a still minor amount of experience when considered in light of the fact that many avid VGPs expend this number of hours playing video games in as little as 4 weeks.

The fact that game experience accounted for at least part, if not all, of Green and Bavelier's (2003, 2006a, 2006b, 2007) findings spurred other research groups to develop related projects aimed at illuminating the impact of video games on visuospatial attention. Changes to attentional capacity have been found in children (Trick, Jaspers-Fayer, & Sethi, 2005), where those who play action video games have demonstrably improved capabilities when simultaneously tracking positions of target-items embedded in fields of distractors. This finding suggests that even developing populations can benefit from experience with action video games. A marginal effect was found for those who engage in action oriented sports (e.g. hockey, football). This finding raises the question of the superiority of action video games to modify visual processing. One might argue that video games are uniquely endowed to encourage development of attentional processing. While this is certainly possible, considering the intense demands action sports place on the visual system, it is perhaps an issue of the phenomenon of transfer appropriate processing; in that, the testing environment (a computer terminal) closely mimics the context in which most children play video games. Due to the high level of congruity between the two contexts, performance is significantly improved, a phenomenon demonstrated across a variety of memory and learning paradigms (Chun and Jiang, 1998; Donald, Bransford, & Franks, 1977; Godden and Baddeley, 1975; issues of contextual control will be further discussed in Chapter 2). It is important to note that the lack of a training study recruiting non-video game playing controls prevents any statement on the power of these games to modify visuospatial selective attention in the young. When one considers the potential of a video game to either permanently enhance or speed the development of visual processing in children or the value of an OTS video game to remediate developmental difficulties in perception and attention, a training study of this sort should certainly be pursued. It is likely to succeed in light of the data presented by Green and Bavelier (2006a). The relatively inexpensive and portable nature of OTS video games, combined with their highly engaging nature which encourages student / patient compliance with training regimes should make these potentially applied tools very attractive to educators and physicians.

Castel, Pratt, and Drummond (2005) expanded the literature on video games and attention by comparing the similarities between VGPs and NVGPs on tasks that tapped into their abilities to inhibit the return of attention to previously scanned locations and how efficiently each population could visually search both simple and demanding arrays. In all instances, VGPs clearly outperformed NVGPs on the experimental task, responding more rapidly to target stimuli. Though the lack of a training study prevents causal conclusions, the interesting and unique contribution of these series of experiments is the analysis of how each group may pursue completion of these attentionally demanding tasks. Green and Bavelier (2003) have speculated that some or all of the differential effects in visuospatial attention demonstrated between video game and non-video game playing populations may be the result of speeded perceptual processing or more successful management of multiple tasks at the level of the central executive. Castel and colleagues (2005) sought to speak to these two possibilities by examining their data for qualitatively different patterns of performance. In essence, the success demonstrated by VGPs may be the result of completing the exact same stages of processing from perception to motor output simply at a faster rate than matched NVGP controls. Alternately, VGPs may have different and more efficient strategies or types of processing that lead to optimal performance on attentional tasks. While VGPs were consistently faster at the tasks in this study (Castel et al., 2005), demonstrated by between-group main effects, the pattern of the data gathered from population for each paradigm was nearly exactly matched. This suggests that VGPs have a quantitative advantage over NVGPs, experiencing speeded performance at one or more stages of processing. Castel et al. (2005) argue that VGPs enjoy success at visual processing due to faster stimulus-response mapping, which leads to rapid response execution to targets. To predict results later described in this manuscript, a quantitative interpretation of the impact video game expertise has on cognition and specifically attention, may be warranted.

A meta-analytic review of the positive and negative effects of violent video games (Ferguson, 2007) demonstrates that experience with violent video games is associated with improvements in visuospatial cognition. This is unsurprising considering that the studies used in the visuospatial portion of the review were largely the same as those detailed in this chapter and that violent games share many of the characteristics and attributes of action video games. A significant portion of the research performed to date has been concern-focused, examining the addictive, aggression-causing, and violence-desensitizing nature of video games—all clearly potential negative consequences—with a complete ignorance of the likely positive consequences. In light of the series of intriguing positive visuospatial effects video game expertise may engender, Ferguson (2007) suggests that it is time to reframe the debate over the influence of violent video games on players in terms of the possible costs and benefits of the medium. However, Ferguson (2007) cautions that the body of literature detailing visuospatial cognitive findings is limited and requires significant expansion before true causal inferences are defensible.

This statement is echoed by failures to completely replicate extant findings in the literature. Boot and colleagues (Boot, Kramer, Simons, Fabiani, & Gratton, 2008) demonstrated superior performance by VGPs over NVGPs on a series of tasks tapping attention, memory, and executive control. Importantly, there were several critical deviations from earlier findings in the literature. First, several of the seminal attentional effects produced by Green and Bavelier (2003, 2006a, 2006b) were not replicated. VGPs did not outperform NVGPs on the UFOV (called the functional field of view in this study) nor on tests of the attentional blink. Further, processing success at all eccentricities in the UFOV task was not replicated. The ability to immediately apprehend more items than NVGPs was not demonstrated, as expected by previous findings (Green and Bavelier, 2003; 2006a). In fact, the only attentional VGP superiority effect replicated by Boot and his colleagues (2008) was performance on multiple object tracking (MOT). The second deviation from earlier findings involved a complete absence of increases in performance on a variety of cognitive tasks after 20 hours of training by NVGPs on an attentionally demanding action video game (Boot et al., 2008). The authors (Boot et al., 2008) suggest that the differences observed to date between

VGPs and NVGPs in cognitive processing are the result of either far more extensive experience with video games than previously thought or that some pre-existing skill-set leads to success at game play and therefore, the population is self-selected. It should be noted that Green and Bavelier's later findings (2006a, 2006b, 2007) are based on 30 hours of training on video games, suggesting that training-induced effects generated from short durations of practice (e.g. 10 hours) are not reliable or robust. However, this assertion is complicated by the fact that performance on the UFOV by NVGPs after training for 10 hours on an action video game has been replicated by Feng et al. (2007). One possible explanation of these conflicting findings is that NVGPs may initially appear to be a more heterogeneous population than VGPs, who have the shared experience of extensive video game play providing a common connection. However, considering NVGPs are often recruited generally from a restricted population of some form (e.g. university undergraduate population, professionals at a particular work place, etc.), the population may share characteristics in common. If these shared attributes are incompatible with the skill-sets being trained during the experiment, this could negatively influence the demonstration of a significant difference. This seems unlikely but it may be of some value to take detailed histories from participants in training studies to search for possible correlations. Furthermore, as will be demonstrated in Chapter 2, many individuals who self-report to be NVGPs are actually infrequent VGPs, confusing the purity of the sample populations.

Surprisingly, many of the attentional effects demonstrated repeatedly by Green and Bavelier (2003, 2006a, 2006b) were not replicated in the study by Boot and his colleagues (2008). To predict findings by this author discussed in Chapter 2, replicating the VGP visual search superiority effect observed by Castel et al. (2005) required a more stringent categorical definition of VGP than is traditionally used, requiring 7 rather than 4 hours of game play per week to be considered an expert VGP. As discussed above, one suggestion to explain these discrepancies is by referencing population differences between testing locations for VGPs. For example, researchers may advertise for VGPs who play 4 or more hours per week but the available population may on average play 10 hours a week and excessively favour action games over all others, where at another location, individuals meet the bare minimum of recruitment requirements and/or have a preference for games that place more extensive demands on memory, spatial reasoning, or executive control. Such a hypothesis would account for the lack of significant findings on attentional tasks and the significant effects on tasks of spatial reasoning recorded by Boot and colleagues (2008), as well as the significant attentional effects repeatedly demonstrated by Green and Bavelier (2003, 2006a, 2006b). This seems a plausible explanation as peers directly and indirectly influence each other with respect to which video games are most frequently played, suggesting the characteristics of a local VGP population could differ significantly from region to region. Alternately, one might subscribe to a perspective arguing that attentional effects are indeed valid and reliable but that they become increasingly robust across accumulated hours of training. Subject monitoring may also play a role. Green has indicated that ensuring game play remains consistently challenging but not aversively difficult is important to generating training induced changes in visuospatial processing (Shawn Green, personal communication, January 22, 2007). Regardless, both the differential training and VGP superiority effects demonstrated across research groups is a cause for some concern and yet, such contradictory findings could potentially elucidate the critical factors that influence and drive these effects. As such, further research will be of considerable value.

1.2.6 The Neuroscience Behind Video Games

Not all the research completed has implemented behavioural measures to assess the differences between video game and non-video game populations. In fact, with the advent and increasing accessibility of electro- and neurophysiological techniques such as positron emission tomography (PET), functional magnetic resonance imaging (fMRI), event-related potentials (ERP), magneto-encephalography (MEG) and repeated transcranial magnetic stimulation (rTMS), the variety of measures at researchers disposal to evaluate differential effects in video game players and perhaps localize these differences to cortical substrates is greatly expanded. However, the amount of research via these tools has been relatively limited, following similar lines to the currently published behavioural research. That is, most of the neurological research into the consequences of video game play has focused on issues faced by social psychologists and the remainder has been limited and spread across a series of cognitive domains with little depth. Indeed, the relative youth of this field can be demonstrated by the fact that work presented in this thesis that assesses differential ERPs between VGPs and NVGPs during a working memory task will likely be one of the first ERP studies to touch on cognitive differences between these two populations and one of only two ERP based studies examining the impact of video game expertise completed to date. This lack of both breadth and depth of neurophysiological research is likely due to various limiting factors, such as the relatively short period that these tools have been broadly available to researchers and the high operating expense of such equipment. Even the simplest of techniques are significantly more expensive in terms of temporal and monetary commitment when compared against basic behavioural research, making these studies often impractical. This fact paired with the general requirement of a training component to show causality makes the required outlay of resources deeply restrictive for a single laboratory, often necessitating collaborations across several research groups.

During action video game play, Koepp and colleagues (1998) demonstrated a dramatic increase in dopamine on par with the amount released during intravenous injection of amphetamines in areas thought to control reward and learning. Green and Bavelier (2006c) have suggested it is possible that the large surges of dopamine that are experienced by the player during a game session may lead to faster and more widespread learning in various systems. This could potentially provide a neural substrate account for the attentional benefits associated with video game expertise. Concurrently, these findings could provide neurological evidence for the addictive nature of video games.

Two subsequent studies examined the neurological underpinnings of issues faced by those studying the socio-emotional consequences of video game experience. Based on previous work that suggests exposure to media violence leads to aggression through desensitization of viewers to real world violence, Bartholow and colleagues (2006) theorize that desensitization to violent images should be reflected in a reduce P300, which is considered to index an aversive motivational system amongst other things. Analysis of the ERPs recorded demonstrated a reduction in P300 amplitudes in response to violent images in those who play violent video games when compared against VGPs who play non-violent games. Mathiak & Weber (2006) used fMRI to record neural activity during violent video game play. Their experimental focus was actually on whether or not the records of brain activity during game play might reflect neuronal correlates of real-life behavior, rather than on the neural implications of violent video game play. The authors (Mathiak & Weber, 2006) suggest that frequent training of aggressive neuronal patterns could lead to the potentially detrimental development of aggressive problem-solving behaviours, attributing other's behaviours to hostile intensions, and approval of aggressive behaviours in everyday life. Importantly, it should be remembered that these comments are all supposition and as described, the video game in this study was not purposefully examined for the neurological effects it had on the player.

1.2.7. Gender Effects

While the predominant VGP is male, there are significant numbers of females playing video games, making the determination of gender-linked consequences of video game play an important line of research. As mentioned above, the number of females playing video games is dramatically increasing. Anecdotally, this author has noticed a significant change over the past 5 years in the number of female students in his classes that raise their hands when asked if they play video games or played video games when younger. Indeed, now the typical response involves the entirety of the class raising their hands to signal current or past video game play.

Localizing the influence of video game experience on gender has been elusive. Studies examining a variety of cognitive functions have found no gender differences associated with video game expertise (e.g. Blumberg and Sokol, 2004; Dorval and Pepin, 1986; Green and Bavelier, 2006a; Greenfield, Brannon, & Lohr, 1994; McClurg and Chaillé, 1987), though some have found factors that link with gender. Unsurprisingly, males and females seem to play different games. Boys generally are overrepresented in action and simulation game categories, with girls involved in logic and skill training games or not playing games at all (Qauiser-Pohl, Geiser, & Lehman, 2006). Boys generally have more experience with video games and this influences performance on novel video games used in studies (Greenfield, deWinstanley, Kilpatrick, & Kaye, 1994; Subrahmanyam & Greenfield, 1994). This is supported by the fact that more boys than girls reached criterion on a video game involving shooting down starships (Greenfield, Brannon, & Lohr, 1994). Females typically report engaging in less video game play, being less motivated to play socially, and being less orientated to video game genres featuring competition and three-dimensional rotation (Lucas and Sherry, 2004). However, while Subrahmanyam and Greenfield (1994) found no interaction between gender and spatial reasoning after practice with various video games, the authors argue that because participants who begin with poor spatial scores improve the most and generally females score more poorly on tests of spatial reasoning, it is likely that a more powerful study and extended training would demonstrate a marked narrowing of the gender gap in spatial reasoning directly attributable to practice with a spatially demanding video game.

This argument has found support in a recent study that tested both spatial attention and mental rotation in males and females (Feng, Spence, & Pratt, 2007). Interestingly, a previously unknown gender difference in the spatial distribution of attention was discovered. By using the UFOV, it was demonstrated that males and VGPs were more successful at the test of spatial attention. In a well controlled training study, two groups of participants practiced on either an action video game or a 3D puzzle game. When compared against the 3D puzzle game, experience with the action video game resulted in parity of performance on the UFOV between genders. While gender differences did not disappear in terms of performance on the mental rotation task (MRT), the gap between males and females was much reduced after experience with the action video game and not for the 3D puzzle game. These findings required only 10 hours of training and females maintained their level of performance on the UFOV after 5 months without practice. In line with Subrahmanyam and Greenfield (1994), females on average demonstrated poorer performance at pre-test but demonstrated greater improvement from training than their male counterparts. This finding may be due to the fact that males are near or at ceiling (i.e. maximal performance) on these tests after a period of training. Interestingly, two of the males in the study completed by Feng and colleagues (2007) continued to play the action training game in the interim between the post-test and 5 month follow-up. The follow up was unplanned and so participants were not provided with instructions to play or not play video games during this period. While this is a very small number of participants, the two males showed improvement in performance between post-test and follow-up on the UFOV, meaning ceiling had not been reached.

It would appear that on the average, males and females experience fairly similar consequences of video game play. And yet, now may be the time to re-evaluate this suggestion. With each passing year, the number of woman that play video games is increasing, with women 18 years of age and older comprising 34% of the gaming population (Entertainment Software Assocation, 2009). As well, the disparity between genders in terms of what genres of games they play is beginning to dissipate. Finding enough females to match male participants in any experiment is a significant difficulty regularly faced by researchers in the field of cognition and video games. In fact, many researchers simply use males because finding action video game playing females is so difficult. However, with the progressive change in the demography of video game players, this seems a perfect time to retest the findings of the 1980s and 1990s for gender differences, while also addressing extant training and motivational confounds.

1.3 Current Research

As this introduction makes apparent, the impact that video games have on socio-emotional, cognitive, and motor development and function are complex and multifaceted. In support of Ferguson (2007) and others (Przybylski, Rigby, & Ryan, 2010), it now seems appropriate that the violent video game debate be reframed in terms of the positive and negative consequences of engagement in this medium. Indeed, there is an ever increasing number of identified accruable benefits from the practice of video game play. One simply needs to review the comprehensive work of Green and colleagues (cf. 2003, 2006a, 2006b, 2007) to see the many advantages action video game play brings to attentional and perceptual performance. The experiments presented in this thesis were completed in an effort to expand on such findings in the extant literature and to identify the locus of the benefits seen in these and other studies (e.g. Castel et al. 2005; Feng et al. 2007).

In the first of these experiments (see Chapter 2), we searched for contextual control over the deployment of selective attention. Within the existing video game literature, an analysis found that testing and training environments were generally analogous in physical layout and method of interface (Green and Bavelier, 2003, 2006a, 2006b; Feng et al, 2007; and more recently Li, Polat, Scalzo, & Bavelier, 2010). We postulated that some degree of the visuospatial processing superiority effects demonstrated by VGPs over NVGPs could be accounted for by contextual influences. In essence, our hypothesis was that VGPs may have been capable of modulating control of selective attention according to the demands of context. Alternately, VGPs may have had attentional systems that were generally more finely tuned, leading to consistent benefits in performance that would be independent of contextual influences. While we were able to replicate a previously demonstrated benefit to visual search by VGPs over NVPGs (Castel et al. 2005), we were unable to demonstrate contextual control of visuospatial processing.

In Chapter 3, we more explicitly tested the hypothesis that the attentional benefits demonstrated in our work and the current literature (Castel et al., 2005; Green and Bavelier, 2003, 2006a, 2006b, 2007; and more recently Chisholm, Hickey, Theeuwes, & Kingstone, 2010) could be localized to improvements in executive function and cognitive control. In order to do this, we employed several task-switching paradigms. VGPs demonstrated generally shorter response latencies when compared against NVGPs. When significant time was available to make use of informative cues and task-set overlap was minimal, VGPs were able to reduce their task-switching costs. Further testing demonstrated that increasing the overlap between task-sets led to the removal of any task-switching benefits. These findings suggested that VGPs have no task switching-related benefit to cognitive control. It seemed likely that VGPs were more capable of the volitional deployment of selective attention when task interference is low.

Our findings in Chapter 3 left us with two means of interpreting the data. Specifically, visuospatial superiority effects demonstrated by action VGPs over their NVGP contemporaries may be attributable to improvements in the mechanisms and processes associated with more basic systems, such as attention and perception, or due to more efficient and better use of executive functions influencing cognitive control. The research reported in Chapter 4 was guided by a desire to differentiate between these two hypotheses. While completing a running memory task designed to assess elements of both verbal and spatial working memory (WM), event-related potentials (ERP) were recorded. Behavioural performance was similar across groups. As well, ERP data indicated that both VGPs and NVGPs demonstrated load-sensitive WM effects in response to stimuli that were to-be-remembered. ERP effects remained analogous on both easy and hard verbal WM tasks and during a comparably easy spatial WM condition. However, in the hard spatial WM condition, patterns of electrophysiological activity diverged across the two groups. When constant updating of spatial information was required, ERP indices of cognitive control demonstrated less cortical involvement by VGPs over NVGPs. We interpret these data to suggest that NVGPs engaged in more effortful strategic processing when demands are placed on spatial WM. With respect to our two hypotheses, such an interpretation suggests that VGPs may benefit from a superior ability in representing visuospatial information rather than more efficient or better control of the mechanisms that direct the deployment of selective attention.

As a final note, please be aware that this document is a *sandwich* thesis. As stated within the Preface, Chapter 3 is a published article and Chapter 4 is a submitted manuscript. Due to the nature of this thesis, there are instances of significant overlap in the literature reviews located within this Introduction and those of the published and submitted pieces. I have made efforts to reduce overlap by truncating portions of the introduction found in Chapter 2 but it is advised that the reader be prepared for some redundant material.

Chapter 2: Searching for Contextual Control of Visuospatial Processing in Video Game Players[1]

2.1 Introduction

It is clear that those who regularly play action video games demonstrate an advantage over non-video game players (NVGPs) with respect to visuospatial processing. This assertion is supported by the wide variety of attentional tasks on which video game players (VGPs) outperform their non-video game playing contemporaries, including multiple object tracking (Green and Bavelier, 2006a; Trick, Jaspers-Fayer, & Sethi, 2005); flanker compatibility task and useful field of view (Green and Bavelier, 2003; 2006b); inhibition of return and visual search (Castel, Pratt, & Drummond, 2005); and, divided attention (Greenfield, deWinstanley, Kilpatrick, & Kaye, 1994). What remains unclear is whether or not these benefits in attentional processing are driven by the immediate context or represent abilities that are permanently active in VGPs. It is interesting to note that in nearly all previous studies, the context in which VGPs have been tested closely approximates the game play context. This naturally leads one to consider the possibility that some or all of the benefits that VGPs demonstrate are tied to recent or immediate contextual demands in which laboratory testing occurs. This has practical implications, in that there is a trend in the current application *zeitgeist* arguing for the use of off-the-shelf video games to remediate cognitive

[1] Unpublished Research

decline or as training devices for special populations (e.g. military pilots, the aged, or visually impaired; cf. Clark, Lanphear, & Riddick, 1987; Gopher, Weil, & Bareket, 1994). Though NVGPs have been trained to approximate VGP performance on the above mentioned tasks (Green and Bavelier, 2003, 2006a, 2006b, 2007), an immediate concern is that such learning is deeply linked to contextual cues or information. Therefore, effects observed in laboratory settings may not transfer beyond the training environment (or outside those of a very similar composition).

The present study aimed to determine if the visuospatial processing superiority effects demonstrated by VGPs over NVGPs are sensitive to the demands of recent contextual information. This hypothesis suggests at least two possible explanations of extant data. First, the enhanced visuospatial processing abilities of VGPs are always active, regardless of the context. Alternately, VGPs might enjoy some small benefit to visuospatial processing but the larger portion of their achievement is influenced by contextual information, with this population ramping up control mechanisms that allow for such success as demanded by an environment very much like the one in which they play video games. Supporting this latter argument, there is some suggestion in the literature that context plays an important role in success at a variety of tasks. For example, in a seminal article, Godden and Baddeley (1975) were able to show what they labeled context-dependent memory. In a free recall experiment, participants learned lists of words either underwater or on land and were either tested for recall underwater or on land. The authors found that recall was best when the context of learning matched that of test. More recently, the importance of context has been demonstrated in a variety of visual attention tasks, with visual search being of most interest to the current study (Brady & Chun, 2007; Chun & Jiang, 1998; Kunar, Flusberg, Horowitz, & Wolfe, 2007; Rausei, Makovski, & Jiang, 2007). For instance, Chun and Jiang (1998) demonstrated in a series of experiments that global context, or the spatial layout of stimuli in visual search displays, influences how participants carry out visual search. Labeled contextual cuing, targets in learned configurations are more readily detected than novel configurations.

Based on the above findings, a modified version of the visual search task used by Castel and colleagues (Castel, Pratt, & Drummond, 2005) was employed to address contextual influences on visuospatial processing in VGPs. It was postulated that VGPs may generally deploy visuospatial attention in a more efficient manner when compared to non-video game playing contemporaries but that this benefit can be influenced by the type of video game played immediately prior to testing. Experience with an action video game, previously shown to be causally-linked to improvement on tasks that tap visuospatial attention (Green and Bavelier, 2006a; 2006b; 2007), should benefit performance on an immediately subsequent test of visual search, while playing a dynamic puzzle game should lead to no such improvement. It should be noted that the design previously employed by Castel and colleagues (2005) was an identification task, where the current methodology employed target detection, allowing for the measurement of performance by both VGPs and NVGPs during target present and target absent trials. These arguably involve different processes and, therefore, were thought to be worth examination.

2.2 Method

2.2.1 Participants

Ninety-four English-speaking undergraduate students enrolled in an Introduction to Psychology or Introduction to Cognition course at McMaster University participated in this experiment in exchange for course credit. Of the total number of participants, six were excluded from analysis due to failure to complete the experiment or data corruption. The eighty-eight remaining participants were comprised of fifty-two VGPs and thirty-six NVGPs (self-identified through response to an advertisement calling for experimental participation from each population). As a function of the relative dearth of female VGPs, participants were exclusively male. All participants reported normal or corrected-to-normal vision and supplied informed consent prior to undergoing the experimental session. Upon conclusion of the experimental procedure, all participants completed a questionnaire, which assessed VGP status through explicit questions such as whether or not the participant played video games; if so, with what frequency and duration (see Appendix A for an example of the questionnaire). The data collected from this questionnaire were employed as a means to ensure that the VGP status self-reported by participants at the beginning of the experiment was indeed valid and also to allow for a more refined division of the participants into the two populations of interest. At recruitment, the definition of a VGP involved no less than 4 hours of game play per week, with at least 1 hour per session over the previous 6 months. NVGPs were defined as those who had never played a video game, but were also accepted into this category if they had not played in the past 6 months.

Analysis of the post-experiment questionnaire demonstrated that 11 of the self-reported NVGPs actually were intermittent players of video games, who engaged in 4 or less hours per week and, thus, were removed from comparison. As our goal was to maximize the opportunity to observe differences between the two experimental groups, we equated the number of participants in each group by making the definition of VGP more stringent than at recruitment. VGPs with less than 7 hours per week of action video game play were eliminated from analysis. There is some precedent for this more restricted definition, with VGPs having been defined as those involved in 7 hours of game play per week over a two year period (Boot, Kramer, Simons, Fabiani, Gratton, 2008). This extreme samples approach allowed for the comparison of true NVGPs against expert VGPs, thereby improving the likelihood that a difference between the two groups would be detected. It is important to note that the group selection criteria made no reference to the participants' scores on the visuospatial attention task employed in this experiment but only on their self-reported questionnaire data.

The number of overall participants was limited by the difficulty in recruiting true NVGPs, as few males in our modern society refrain entirely from playing video games or were moderate to heavy game players at some other time in their lives (e.g. teenage years). Since there is no research indicating whether or not benefits engendered by video games much earlier in development carry over into later parts of life, the latter group of individuals may skew any data collected as they are not true NVGPs. Rather, they would form some third population; for example, they may be labeled "previous video game experts". Indeed, Feng and colleagues (2007) demonstrated retention of visuospatial processing benefits in NVGPs trained on video games for 10 hours. Improved task performance was still present 5 months after video game training, suggesting that previous video game experts may have the ability to negatively influence the quality of data collected from NVGP. While previous experts and carry-over benefits are worthy of future study, inclusion in a comparative analysis between NVGPs and VGPs would simply detract from collecting meaningful data. Analysis of collected data was carried out on this restricted and numerically-equated sample (NVGP = 25; VGP = 25).

2.2.2 Apparatus and Stimuli

All stimuli were presented to participants on a 17-inch colour CRT monitor connected to an IBM™-compatible microcomputer running Presentation® software (version 9.90, www.neurobs.com), which recorded manual responses and presented experimental stimuli. All responses were made on a QWERTY format keyboard. Throughout the experiment, participants were seated in a dimly lit room approximately 68 cm from the monitor.

Visual displays consisted of a varied number of letter stimuli, presented in white on a black background. Using Courier New font, the target item was a lowercase letter “b” and distracting items consisted of the letters “p, y, g, j, l, h, and k” (0.75° x 0.5° of subtension). A red fixation cross (0.1° x 0.1°) was centrally located on an imaginary 10 x 10 grid, where each cell was 1.0° high and 0.75° wide. Participants were asked to initially focus on the fixation marker but were permitted to move their eyes around the field to search for the target.

Blocks of video game play were completed on a separate computer from the testing unit, though in the same room and in close proximity. Games were presented on a 19-inch colour CRT monitor. Participants sat approximately 60 cm from the screen and used both a mouse and keyboard when playing the action-oriented game (*Unreal Tournament 2004*®) and used only the keyboard for the dynamic puzzle game (*Tetris*®).

2.2.3 Procedure

The experiment consisted of two visual search conditions, one easy and one hard, presented in a mixed-block design. Engaging in a two-alternative forced-choice detection task, participants determined presence or absence of the target item. In easy searches, participants searched for the target item amongst uniform “k” distracting items. For hard searches, distractors were heterogeneous, consisting of “p, y, g, j, l and h”. Target and distracting items were randomly located within the 10 x 10 grid, generating 100 possible locations for these stimuli. Target presence was determined randomly. There were four display sizes, comprised of 4, 10, 18, and 26 distracting items.

Each trial consisted of the following steps. The fixation cross was presented and remained on until response provision. After 500 ms, the test array appeared, consisting of distractor items and, on approximately half of trials, the target was present. Participants indicated presence or absence of the target by pressing the “z” (target present) or “/” (target absent) key. The trial ended following a response from the participant or after 6000 ms if no response had been provided. The next experimental trial began after 1000 ms. Each block consisted of 300 trials, with VGPs experiencing three blocks (pretest, post-test 1, post-test 2) and NVGPs completing one (see Figure 2.1). Counterbalanced across participants, VGPs first played an action-oriented video game (*Unreal Tournament 2004*®) and then a dynamic puzzle game (*Tetris*®) for 20 minutes after each set of visual search trials except the last. *Unreal Tournament 2004*® previously has been argued to place significant demands on attentional processes and mechanisms while avoiding certain memory-based scripts associated with other story-driven action video games (e.g. *Medal of Honor*®; Green and Bavelier, 2006a; 2006b; 2007). *Tetris* controls for the effect of visuo-motor coordination but more importantly, does not require the rapid, concurrent visual processing of multiple objects as experienced during action video game play (Green and Bavelier, 2003; 2006a; 2006b; 2007). To ensure this latter point, the "preview next block" option was deactivated. NVGPs did not complete the video game training sessions and so only completed the pre-test component of the experiment allowing for comparison of initial visual search performance prior to context manipulation across groups.

Prior to game play, participants were instructed on the rules and controls particular to each game to ensure general competence. Observation demonstrated that VGPs quickly adjusted to the game environments used in the experiment, likely due to experience with similar games of the two genres used in this experiment or previous experience with the particular games. With previous studies that involved training on video games, effects were indicated to be maximal if the game difficulty was maintained at the upper limit of the players' capabilities (Shawn Green, personal communication, January 22, 2007). To ensure that the games remained engaging and challenging to the participant and thus, encouraging as much transfer of contextually-oriented control processes, difficulty was titrated in *Unreal Tournament 2004* through using the in-game setting that adapts the skill of computer controlled opponents in accordance with the player's game performance. In *Tetris*, players only experienced increased difficulty if they successfully completed game levels, with each successive level more challenging than the last. This ensured that *Tetris* players would most likely reach ceiling performance within the limits of the 20-minute game session, though these data were not recorded. Participants were directed between sets of visual search and game play by an experimenter, who also checked in periodically to ensure that participants were playing the games and were not having technical or instructional difficulties.

2.3 Results

Prior to analysis, all anticipatory errors [response times (RTs) shorter than 150 ms] were removed, along with inordinately long RTs of 6000 ms or greater. The remaining RTs were subjected to a trimming procedure that removed trials with RTs beyond 2.5 standard deviations from the mean; less than 2% of trials were excluded from analysis.

In order to examine differences between the NVGPs and VGPs, a mixed analysis of variance was carried out on correct response times (RTs) for the following factors: Gamer Status (VGP x NVGP; between-subjects variable); Presence (Target Present x Target Absent); Difficulty (Homogeneous x Heterogeneous Distractors); and, Display Size (4 x 10 x 18 x 26). As mentioned above, VGPs completed three blocks of behavioural testing, a pretest and two post-tests following each game training session. Since NVGPs did not complete the training sessions with the two test video games, their one block of behavioural data gathered from the visual search task was compared to the pretest block of data collected from the VGPs. This process allowed for an appropriate comparison across groups, as these data were collected at the beginning of the experiment—indeed, it was the entirety of the experiment for NVGPs—and each group experienced the same type and number of trials within this block.

The traditional within-subject main effects associated with visual search were found, with Presence [Present = 1022 ms vs. Absent = 1460 ms; $F(1, 48) = 152.06$, $p < 0.001$]; Difficulty [Hard = 1622 ms vs. Easy = 860 ms; $F(1, 48) = 447.96$, $p < 0.001$]; and, Display [4 = 807 ms vs. 10 = 1106 ms vs. 18 = 1400 ms vs. 26 = 1649 ms; $F(3, 144) = 336.84$, $p < 0.001$)] all achieving significance (see Table 2.1). Furthermore, the between-subjects main effect of Gamer Status was also significant, demonstrating that VGPs responded, on average, more quickly than NVGP [1163 ms vs. 1317 ms; $F(1, 48) = 4.67$, $p < 0.05$], conceptually replicating the visual search superiority effect demonstrated by Castel and colleagues (2005). None of the Gamer Status interactions were significant.

The error rate data mirrored RTs, demonstrating significant main effects for Presence [Present = 5.7% vs. Absent = 0.9%; $F(1, 48) = 82.8$, $p < 0.001$], Difficulty [Hard = 5.0% vs. Easy = 1.5%; $F(1, 48) = 58.95$, $p < 0.001$], and Display [4 = 2.2% vs. 10 = 2.0% vs. 18 = 3.8% vs. 26 = 5.1%; $F(3, 144) = 18.85$, $p < 0.001$)] but no other effects reached significance, including the between-subjects effect of Gamer Status, with the latter finding replicating data observed by Castel and colleagues (2005).

A repeated analysis of variance was computed on the VGPs alone, in an effort to analyze any differences in visual search performance brought about by playing the two test games (*Unreal Tournament 2004* and *Tetris*). Order of game play was counter-balanced across participants and had no significant impact on the data and so, this factor was collapsed over for analysis. Correct RTs were examined for the following factors: Game (*Unreal Tournament 2004* x *Tetris*), Presence (Target Present x Target Absent), Difficulty (Homogeneous x Heterogeneous Distractors), and Display Size (4 x 10 x 18 x 26). The expected main effects associated with visual search were found, with Presence [Present = 916 ms vs. Absent = 1295 ms; $F(1, 23) = 88.69$, $p < 0.001$], Difficulty [Hard = 1473 ms vs. Easy = 739 ms; $F(1, 23) = 284.58$, $p < 0.001$], and Display [4 = 713 ms vs. 10 = 979 ms vs. 18 = 1255 ms vs. 26 = 1475 ms; $F(3, 69) = 255.30$, $p < 0.001$)] all achieving significance(see Table 2.2). However, the critical main effect of Game and all interactions by Game were non-significant ($F>1$).

Error data mimicked RT data and are therefore not reported here. The expected main effects associated with visual search were demonstrate, with Presence [Present = 5.6% vs. Absent = 1.0%; $F(1, 23) = 39.14$, $p < 0.001$], Difficulty [Hard = 5.1% vs. Easy = 1.5%; $F(1, 23) = 41.07$, $p < 0.001$], and Display [4 = 2.2% vs. 10 = 2.3% vs. 18 = 3.7% vs. 26 = 5.0%; $F(3, 69) = 13.86$, $p < 0.001$)] all achieving significance. As with RT data, the critical main effect of Game and all interactions by Game were non-significant ($F>1$).

Importantly, the critical main effect of Game and the related interactions did not achieve significance. This suggests that playing an action video game (or a dynamic puzzle game for that matter) immediately prior to a visual search task does not enhance visuospatial processing for VGPs. As order effects were found to be unimportant and no effect of Game was observed, an analysis of each game against pretest performance is not explored in this manuscript. The pretest block was provided only as a relatively pure comparison of initial performance between NVGPs and VGPs, so as to confirm previous findings (e.g. Castel et al, 2005). Further, had an effect of Game context been observed, the possibility of simple practice effects would have been addressed using the pretest block as a point of reference.

2.4 Discussion

The current experiment was designed to evaluate the influence of recent contextual information on visuospatial processing in VGPs. Replicating earlier work (Castel et al., 2005), it was demonstrated that VGPs responded more rapidly than NVGPs during a visual search task, especially on target present trials. Of most interest to the current study is the lack of any effect that *type* of recent video game play has on visuospatial processing. Specifically, neither experience with an action-oriented game (*Unreal Tournament 2004*) that has been shown to place demands on visuospatial attention nor a dynamic puzzle game (*Tetris*) influenced success on a subsequent test of visual search. It would appear, then, that manipulation of contextual information, specifically the type of game played prior to testing performance on visual search, does not influence visuospatial processing. Irrespective of the information available in the visual display, VGPs consistently outperform NVGPs, suggesting that the visuospatial processing benefits that they enjoy are permanently active. The current data propose that the visuospatial superiority effects demonstrated by VGPs over their non-video game playing contemporaries are the result of a durable form of learning at the level of perceptual and attentional systems, rather than a transient ramping up of higher order mechanisms and processes that are contextually-dependent in nature (we explore and provide some further support for this hypothesis in Chapters 3 and 4 of this thesis). This view advocates that the success VPGs demonstrate on tasks that tap visuospatial attention will likely transfer broadly, to higher fidelity, real world scenarios. Such a position provides further support for the use of video games as remediation or learning tools by medical organizations and educational facilities.

While our data support a context-independent interpretation of the benefits demonstrated by VGPs on tasks of visuospatial attention, several caveats ought to be mentioned regarding our current findings and conclusions. Most readily, our conclusions are based on the absence of an effect. It is well known that the failure to detect an effect does not mean there is an absence of an effect. Rather, it might be that the task used in the current experiment was inappropriate to detect the effect of interest. Perhaps VGPs are experts at discrimination rather than detection. This would suggest a return to the original design employed by Castel and colleagues (2005) or possibly a within-subjects comparison of VGPs performing both discrimination and detection tasks. As well, in the current experimental design, participants moved from one computer to the other when performing visual search and game play. Due to technical issues, games were presented on a computer separate from the test computer. This minimal change in context might have been sufficient to obscure changes in visuospatial processing brought on by game play. Furthermore, the vast majority of VGPs who participated in this study indicated that they play for 1 hour or more per session of game play. During this study, the VGPs played each game for a short period of 20 minutes. This disparity might be of some importance, with VGPs taking more than the short interval of game play provided in this experiment to transiently ramp up control mechanisms which support superior visuospatial processing. Interestingly, the test context is much like that which PC VGPs experience but somewhat different from the context in which console VGPs play games (i.e. keyboard and mouse plus monitor vs. TV and gamepad, respectively). It may be necessary to parse our subject pool into expert PC and console players. In this case, one would predict that the effect of action game play immediately prior to a test of visual search would be demonstrated most strongly by the PC VGPs. Another analysis that could be carried out with the current dataset would be to break down the visual search data into deciles. It is possible that visuospatial processing does indeed ramp up during action video game play but dissipates quickly and thus would only be apparent in the earliest trials of visual search after action video game play. Lastly, while over fifty VGPs were included in this experiment, there were few observations per cell, making it possible that low power is responsible for the failure to detect transient changes in visuospatial processing.

To some degree, these results generate more questions than answers. It should be noted that the current design was somewhat different than the original, in that detection rather than discrimination was required of participants in the present experiment. As well, Castel and colleagues (2005) utilized a blocked design for visual search, with hard and easy searches occurring in distinct sets. That being said, Castel et al (2005) found the effect with a mere ten participants in each condition, where that number was nearly tripled in the current study. It is possible that the task type is critical when attempting to demonstrate the effect of interest. Action video game players spend much of their time making discriminations between targets, to determine if they are friend, foe, or neutral for the purpose of allowing higher processing (i.e. should one attack this target and if so, with what type of weapon?). However, considering the breadth of tasks that tap visuospatial processing that have shown VGPs outperforming NVGPs (cf. Feng, Spence, & Pratt, 2007; Green and Bavelier, 2003; 2006a, 2006b; Greenfield, deWinstanley, Kilpatrick, & Kaye, 1994), it would be surprising if this were true. Should this be the case, it might suggest that the superiority of VGPs over NVGPs on tasks that tap visuospatial processing may not be as robust as once thought. Indeed, Boot and colleagues (2008) have had much difficulty replicating findings in the literature. Specifically, they were able to demonstrate that expert VGPs could track objects moving at greater speeds, better detected changes to objects stored in visual short-term memory, switched more quickly from one task to another, and mentally rotated objects more efficiently when compared to NVGPs (Boot et al., 2008). However, despite increasing the standard training period from 10 to 20 hours and adding an extra genre (real-time strategy) to the testing regimen, NVGPs who experienced training only improved on a single measure (mental rotation; Boot et al., 2008). It would be illuminating if small differences between tasks were critical to generating the levels of performance demonstrated by VGPs and the extant training effects found in the literature, potentially revealing the key cognitive mechanisms that underlie observed performance differentials. Regardless, this present work clearly demonstrates superior performance by VGPs over NVGPs on a test of visual search and suggests that this visuospatial processing benefit is unrelated to the influences of immediate contextual information. We make attempts to localize the benefits demonstrated by VGPs in visuospatial attention tasks in Chapters 3 and 4 of this thesis.

Chapter 3

PUBLICATION INFORMATION:

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CHAPTER SUMMARY:

The purpose of the experiments detailed in this chapter was to expand on the work presented in Chapter 2 of this dissertation. When considered in light of the number of studies that show visuospatial attentional benefits for expert / action video game players and our inability to demonstrate any related contextual control of visual search, we decided to purposefully look for effects in higher cognitive processing that might explicate the extant attentional data. Task-switching paradigms have traditionally been considered to be effective methods of accessing various elements of cognitive control. We make use of two such paradigms in this chapter. To predict our findings, VGPs were generally able to reduce their response latencies in comparison to their NVGPs contemporaries. In Experiment 1, when confronted with a situation containing minimally overlapping task-set rules, and when they had significant time to make use of informative cues, video game players were able to additionally reduce their task-switching costs. A second experiment demonstrated that when task overlap—and therefore proactive interference—was increased, this task switching benefit disappeared (though overall faster performance remained for VGPs).

Our findings suggest that VGPs have no generalized benefit in task switching-related cognitive control. Rather, VGPs seem to be more capable of voluntarily deploying selective attention to use available information when task interference is minimal. These data suggest one of two possible conclusions. First, VGPs may have better or more efficient control of higher level processes that manage the deployment of selective attention. Alternately, VGPs may be more capable of visuospatial processing due to better or more efficient processing in lower level perceptual and attentional mechanisms. In this latter instance, the same amount of high-level control would lead to superior performance on tasks that tap visuospatial processing.

RUNNING HEAD: TASK SWITCHING IN VIDEO GAMERS

Task Switching in Video Game Players:

Benefits of Selective Attention But Not Resistance to Proactive Interference

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ABSTRACT

Research into the perceptual and cognitive effects of playing video games is an area of increasing interest for many investigators. Over the past decade, expert video games players (VGPs) have been shown to display superior performance compared to non-video game players (NVGPs) on a range of visuospatial and attentional tasks. A benefit of video game expertise has recently been shown for task switching, suggesting that VGPs also have superior cognitive control abilities compared to NVGPs. In two experiments, we examined which aspects of task switching performance this VGP benefit may be localized to. With minimal trial-to-trial interference from minimally overlapping task set rules, VGPs demonstrated a task switching benefit compared to NVGPs. However, this benefit disappeared when proactive interference between tasks was increased, with substantial stimulus and response overlap in task set rules. We suggest that VGPs have no generalized benefit in task switching-related cognitive control processes compared to NVGPs, with switch cost reductions due instead to a specific benefit in controlling selective attention.

Keywords: task switching; selective attention; executive control; video games

PsyclNFO classification:

2300 Human Experimental Psychology

2340 Cognitive Processes

2346 Attention

1. INTRODUCTION

As playing video games has become an increasingly popular and widespread activity over the past several decades, research into the potential perceptual and cognitive effects of video game play has similarly developed. Following initial video game-related research focusing on transfer of training (e.g., Fabiani, Buckley, Gratton, Coles, Donchin & Logie, 1989; Gopher, Weil & Bareket, 1994), an increasing number of authors have become interested in investigating how expert video game players (VGPs) may differ from non-video game players (NVGPs), in terms of specific underlying mental processes. Visual perception and attention have been particularly well represented in studies to date. Superior ability has been reported for VGPs compared to NVGPs in divided visual attention (Greenfield, deWinstanley, Kilpatrick, & Kaye, 1994) and spatial attention via the useful field of view task (Feng, Spence & Pratt, 2007). Similar findings have been demonstrated in children, including benefits in selective attention (Blumberg, 1998), and attentional capacity via multiple object tracking (Trick, Jaspers-Fayer, & Sethi, 2005).

Support for these findings can be found in a series of studies conducted by Green and Bavelier (2003, 2006a, 2006b, 2007), who have consistently demonstrated that VGPs outperform NVGPs on a variety of tasks that tap visuospatial attentional processing, and that such benefits appear to be trainable to a non-game playing population. In their earlier work, Green and Bavelier (2003) demonstrated VGP performance benefits in an attentional blink task, with better

T1 identification and T2 detection compared to NVGPs. From these data, they suggested that expert video game players may have greater control over task switching in addition to better temporal attentional processing. Through their subsequent work with multiple object tracking (2006a, 2006b), and visual crowding (2007), Green and Bavelier argued that their findings indicated that VGPs' superior performance on complex visual processing tasks was likely the result of changes in fundamental characteristics of the visual system brought about by extensive gameplay experience, and that it remained to be determined if there were also improvements to higher-order processing and cognitive control mechanisms. Castel, Pratt and Drummond (2005) also found performance benefits for VGPs versus NVGPs using cuing and visual search paradigms. While VGPs were faster overall, and showed some benefit for more efficient self-directed visual search, they showed very similar patterns of lower-level effects, such as cuing and inhibition of return. From these data, Castel, Pratt & Drummond (2005) suggested that VGPs may instead have a benefit in higher-level executive control processes, allowing for more efficient control and allocation of selective attention, and the ability to more rapidly establish stimulus-response mappings.

Recently, several authors have more directly examined whether video gaming expertise may be related to differences in cognitive control, specifically processes involved in task switching. Task switching paradigms typically measure the effects of various factors on *task switching cost*, defined as the difference between performing a task for a second time in sequence (repeat trials) compared to performing a task for the first time in sequence following a previous different task (switch trials). Andrews and Murphy (2006) used an alternating-runs (AABB task sequence) task switching paradigm based on methods from Rogers and Monsell (1995), and demonstrated that VGPs showed smaller task switching costs than NVGPs when response-to-stimulus durations were relatively short (150 msec in their study). Boot, Kramer, Simons, Fabiani and Gratton (2008) investigated a range of cognitive abilities in a training study comparing VGP and NVGP participants, with executive control assessments including task switching and working memory operation span. They found no difference in operation span between gaming groups or as a result of training novices on a range of video games for 20 or more hours. Expert gamers showed smaller switch costs compared to novices, but video game training did not affect switch costs.

Our present study sought to more carefully distinguish what aspects of task switching and related cognitive control processes might selectively differ between expert video game players and non-video game players. We conducted two experiments to more closely examine VGP versus NVGP differences with respect to factors known to influence task switching processes, including the amount of time and information available prior to stimulus onset during which endogenously driven task set reconfiguration can be performed, and the degree of stimulus and response overlap between tasks.

In Experiment 1 we manipulated a range of stimulus, response and cuing parameters, to parametrically vary the difficulty of preparing for and responding to a given trial, in addition to a basic task switching manipulation. Cuing and trial timing parameters were manipulated so that even when response mappings were difficult, substantial endogenous preparation for a particular trial was possible given an informative cue and a longer cue-to-stimulus interval in some conditions. Although Experiment 1 employed randomized shifts between two sets of semantically distinct stimuli (letters A, B, C, and digits 1, 2, 3), we reduced the degree of overlap of task set rules, and hence the likely extent of trial-to-trial interference, by having no stimulus or response overlap between tasks, and having a direct univalent 1-to-1 mapping of each individual stimulus to a separate manual response. In effect, this task could have been conceptualized as a single task requiring mapping of six distinct stimuli to six distinct responses, with no requirement for any real switch of task set rules. This design also allowed us to assess VGP versus NVGP differences in a range of other effortful, selective attention-demanding processes, independent of task switching behaviour.

For Experiment 2, we employed a different task switching paradigm based on Arbuthnott and Frank's (2000) method for demonstrating additional reaction time costs for task alternation as compared with simple task switching—for example, longer reaction times on the final Task C in a C-B-C task sequence compared with an A-B-C task sequence. These findings have generally been taken as evidence for active inhibition of recently abandoned task set representations, a phenomenon that has come to be termed Backward Inhibition (Arbuthnott, 2005; Arbuthnott & Woodward, 2002; Mayr & Keele, 2000). In this experiment, we employed tasks with extensively overlapping task set rules, where the same six stimuli were remapped to two alternative responses for each task. As such, this required endogenous reconfiguration of task set based only on a pre-stimulus cue, in the face of likely substantial task switching-related proactive interference (Wylie & Allport, 2000).

Throughout this study, we were interested to see what aspects of task switching performance might differentiate video game experts from non-video game players, and whether other aspects of performance close to but separate from task switching itself might be revealed as more distinguishing of VGP and NVGP groups. To anticipate our results somewhat, results from Experiment 1 demonstrated selectively better performance for VGP participants in a small set of conditions, reflecting a superior ability to actively prepare for an upcoming task when time and information were available, including relatively greater reductions in task switching costs under these conditions. However, while Experiment 2 showed faster performance for VGP versus NVGP groups in general, video gamers showed no selective benefit at all with regard to task switching costs. We consider these results with respect to likely component processes involved in task switching performance, including effortful selective attention-dependent preparation for upcoming task performance, and processes involved with resolving proactive interference arising from successive performance of different but overlapping tasks.

2. EXPERIMENT 1

Experiment 1 asked participants to make speeded responses to one of six single-character stimuli, under a range of intermixed stimulus, response, cuing and timing conditions. We expected to find a range of typical effects on performance for all participants—for example, we expected all participants to be slower when stimuli were harder to perceive, when more complex response mappings were used, and when response-to-stimulus durations were particularly short. We assessed our data with a particular focus on how our participant group variable (video game players versus non-video game players) interacted with other effects in these data, to assess what particular aspects of selective attention-demanding performance might be influenced by video gaming expertise.

2.1. Method

2.1.1. Participants

Fifty-six individuals from McMaster University's undergraduate student population participated in the experiment in exchange for course credit. All participants were male, and reported normal or corrected to normal vision. Our recruitment notice requested participants with either very little video game experience (only infrequent casual play at most, preferably none) or substantial and recent video game experience with immersive, first-person games (at least four hours per week, and at least one hour per session, for six months or more), which we confirmed in a post-experiment questionnaire. Several self-identified non-gaming participants were excluded from initial analyses based on their reporting considerable video game experience on their debriefing questionnaire.

We analysed data for 30 participants identified as action video game players (VGPs) and for 26 participants identified as non-video game players (NVGPs), with no difference in age between groups (19.2 years versus 18.3 years, $t(25) = 1.11$, p = n.s.).

2.1.2. Apparatus and Stimuli

Stimuli were the letters A, B and C, and the digits 1, 2 and 3, in Arial font and coloured medium grey, sized to subtend a vertical visual angle of approximately 2°. These stimuli were presented against a 7° vertical by 9° horizontal rectangular background area that was either high-contrast (white background with light grey random noise) or low-contrast (white background with black random noise) with the stimuli, creating "easy" versus "hard" stimulus perceptual conditions. These composite character-plus-background stimuli were presented against a constant dark grey background. A task cue was also presented on every trial, as a thin white, green or red rectangular frame surrounding the whole character-plus-background stimulus, approximately 0.5° visual angle larger both horizontally and vertically. All stimulus elements were centered on the screen relative to each other and the display itself. On a single trial, a task cue was presented for 100 msec or 1000 msec, which was then joined on screen by a character-plus-background stimulus that persisted until a response was made. The next trial began with a task cue following a constant 100 msec inter-trial interval. Erroneous responses elicited an immediate auditory feedback signal (100 msec, 100 Hz square wave). Character-plus-background stimuli were created as bitmap images in Adobe Photoshop, and then presented on a 19 inch ViewSonic P95f CRT monitor (1024 x 768 pixels, 85 Hz), via a Pentium 4 computer running Presentation® (v.12.0, www.neurobs.com) experimental software under a Windows XP operating system.

2.1.3. Procedure

Our procedure had a simple notional task for our participants—to respond with the correct one of three keys with their left hand to indicate an A, B or C stimulus, or to respond with the correct one of three keys with their right hand to indicate a 1, 2 or 3 stimulus. Our experimental procedure manipulated five within-participants independent variables, each with two levels. First, stimulus perceptual difficulty was manipulated with high-contrast (easy) versus low-contrast (hard) stimuli as described above. Second, response mapping difficulty was manipulated with typical left-to-right response mappings of stimuli A, B and C to ring, middle and index fingers of the left hand respectively, and stimuli 1, 2 and 3 to index, middle and ring fingers of the right hand respectively (easy response mapping), versus an atypical left-to-right response mapping of stimuli B, C and A to ring, middle and index fingers of the left hand respectively, and stimuli 2, 3 and 1 to index, middle and ring fingers of the right hand respectively (hard response mapping). Third, task switching status was calculated based on whether the current trial was of the same letter versus number category as the previous trial or not, giving repeat versus switch trials respectively. Fourth, we manipulated the cue-to-target time interval to be either 100 msec (short) or 1000 msec (long). Fifth and finally, we manipulated the informativeness of the task cue to either indicate with 100% predictability whether the upcoming stimulus would be a letter (red cue) or a number (green cue), or to provide no predictive information (white cue).

Single-character stimuli were presented randomly on each trial, with the constraint that any particular letter or number could not repeat on a subsequent trial. Stimulus noise and task switching factors were presented randomly mixed within blocks. Cue-to-target interval, response mapping and cue informativeness were manipulated between blocks of trials, alternating every one, two and four blocks, respectively. Participants performed 48 blocks of 32 trials each, for a total of 1536 trials over an approximate 40 to 45 minute experimental session. Self-paced breaks were given in between every second block, when instructions for changes in response mapping were presented on screen, along with information about their mean reaction time and error rate for the previous 64 trials. Participants did not receive block-by-block instructions regarding changes of cue-to-target interval or cue informativeness, but were informed at the beginning of the experiment as to the cue colour-task relationships that would sometimes be present. This design gave six complete iterations of each response mapping x cue-to-target interval x cue informativeness block type, with the starting level of each of these factors counterbalanced across participants.

2.2. Results

One participant from each gaming group was excluded from analysis based on excessively errorful performance (greater than 20 % errors overall).

Trials with responses faster than 250 msec or slower than 2000 msec were excluded from analysis, representing 0.4 % of all correct trials, distributed equally between video gaming groups. Trials immediately following an error trial were also excluded from reaction time analyses. Mean reaction time data for correct trials are presented in Figure 3.1. A repeated-measures analysis of variance (ANOVA) was conducted with within-subjects factors of stimulus perceptibility (easy, hard), response mapping (easy, hard), task switching (repeat, switch), cue informativeness (cued, uncued), and cue-to-target interval (100 msec, 1000 msec), with video gaming status (VGP, NVGP) as a single between-subjects factor. Our primary goal was to assess how video gaming status interacted with the set of effects and interactions amongst conditions in our dataset.

Figure 3.1 about here

A number of effects were evident across our dataset for all participants. High-contrast (easy) stimuli showed faster reaction times than low-contrast (hard) stimuli, responses were faster under typical (easy) response mapping than atypical (hard) mapping, repeat tasks were faster than switch tasks, and cued trials were faster than uncued trials, all supported by main effects, *F*s > 44.00, *p*s < 0.001. In addition, a substantial series of 2-way and 3-way interactions involving subsets of stimulus perceptibility, response mapping, task switching, cue-to-target timing and cue informativeness factors suggested systematic influences on all participants' ability to actively prepare for and perform speeded responses. For example, both groups of participants showed reduced task switching costs (the difference between repeat and switch trial reaction times) with long cue-to-target intervals, $F(1,52) = 17.09$, $p < 0.001$, with this effect more pronounced when informative cues were available, $F(1,52) = 8.36$, $p < 0.01$. Similarly, task switching costs were systematically reduced under simple versus difficult response mapping conditions, $F(1,52) = 317.44$, $p < 0.001$, with this effect more pronounced at long cue-to-target intervals, $F(1,52) = 22.28$, $p < 0.001$, and with informative cues, $F(1,52) = 5.28$, $p < 0.05$.

While a range of effects was observed across all participants, a selective number of interactions were additionally observed with video gaming status. Expert video gamers appeared to be able to additionally reduce their reaction times under certain combinations of task conditions, beyond the performance of non-video game players. VGPs reduced their reaction times to a greater degree than NVGPs with long cue-to-target intervals, supported by the interaction of gaming group with cue-to-target interval, $F(1,52) = 4.38$, $p < 0.05$, and when informative task cues were available, supported by the interaction of gaming group with cue informativeness, $F(1,52) = 21.62$, $p < 0.001$. Gamers showed additional reductions in RTs compared to non-video game players when these informative task cues were available on trials with long cue-to-target intervals, reflected by the 3-way interaction of these factors, $F(1,52) = 7.44$, $p < 0.01$. Under long cue-to-target conditions, VGPs also demonstrated additional reductions in switch costs compared to NVGPs when stimulus perceptibility was easy, $F(1,52) = 4.64$, $p < 0.05$. These effects were observed to modify the marginal two-way interaction of task switching and gaming group, $F(1,52) = 3.33$, $p = 0.074$, and the marginal main between-subjects effect of gaming group, $F(1,52) = 3.78$, $p = 0.057$.

Considering the generally faster reaction times of VGPs compared to NVGPs, it is possible that the observed smaller switch costs for VGPs could be due simply to the difference in baseline RT between groups. To examine this possibility, we calculated switch costs as a proportion of mean repeat trial RT in each condition for each participant, and then reanalyzed these normalized switch cost data as above (minus the repeat versus switch task factor). We observed a significant interaction of video gaming status with cue-to-target interval and stimulus perceptibility, $F(1,52) = 4.18$, $p < 0.05$, matching the interaction of these factors with the repeat versus switch task factor in our mean RT analyses above. This suggests that reductions in switch costs for VGPs versus NVGPs is not simply due to baseline differences in RT between groups.

Error rate data were analysed via repeated-measures ANOVA with the same factors and levels as our mean reaction time data. Overall, errors displayed similar patterns of effects to reaction time data, although these error data were relatively more variable with fewer significant effects. For brevity, we omit a detailed presentation of these data here. Aside from a main effect of long cue-to-target interval trials producing more errors than short cue-to-target trials (*M* =

7.12 % vs. 5.90 %, respectively) across all participants, $F(1,52) = 13.57$, $p < 0.01$, there was little evidence of speed-accuracy tradeoff. A number of other main effects were observed across all participants, with fewer errors for cued versus uncued trials ($M = 6.19$ % vs. 6.83 %), $F(1,52) = 9.17$, $p < 0.01$, for repeat versus switch trials ($M = 5.46$ % vs. 7.56 %), $F(1.52) = 41.65$, $p < 0.001$, and with easy versus hard response mappings ($M = 4.30$ % vs. 8.73 %), $F(1,52) = 73.29$, $p <$ 0.001. A number of interactions mirrored a subset of those seen for reaction time data, including greater numbers of errors on switch tasks with difficult response mapping, $F(1,52) = 6.45$, $p < 0.001$. This effect was slightly but significantly more pronounced in long cue-to-target trials, $F(1,52) = 10.18$, $p < 0.01$, again reflecting some degree of speed-accuracy tradeoff under different trial timings. This interaction of cue-to-target interval, task switching and response mapping difficulty interacted further with gaming group, $F(1,52) = 4.05$, $p < 0.05$, with VGPs showing a relatively smaller degree of speed-accuracy tradeoff than NVGPs, with systematically smaller error rates across this pattern of effects despite faster reaction times. While a number of other marginal effects were observed in interaction with video gaming group status, including a marginal main effect of numerically less errorful performance by video gamers compared to non-video game players, no other effects reached significance.

2.3. Discussion

Experiment 1 was designed to measure the extent to which participants could actively prepare for and respond to a basic choice response task under a range of stimulus, response, and cuing conditions, including a basic task switching manipulation. A large set of main effects and interactions were observed with these manipulations across all participants, as was expected. The observation of these effects suggests that our task manipulations were effective, and that we could reliably measure even small differences in performance (for example, the small but significant main effect of stimulus contrast across our data).

In addition to these findings, we observed a small but coherent set of interactions between our participant group variable and these within-subjects effects, suggesting a subset of conditions under which action video game experts showed selectively better task performance. While all participants were faster with informative cues and long cue-to-target intervals, video gamers appeared to be selectively and additionally better than non-video game players in being able to use informative cue information given enough time, to speed their overall performance. Further, with long preparation times and easily perceptible stimuli, VGPs reduced their task switching costs relative to NVGPs. This reduction in task switching cost persisted when we normalized participants' switch costs relative to their individual mean repeat trial RTs, suggesting that the apparent task switching benefit for VGPs is not simply due to differences in baseline RTs between groups.

In considering the particular set of conditions under which VGPs additionally outperformed NVGPs in this experiment, the selectively better ability to use cue information to prepare for upcoming task performance suggests a relative benefit in the ability to endogenously deploy selective attention to task-relevant stimulus processing for VGPs. Along these lines, one might wonder about the degree to which similar selective attention processes might have been the primary influence on our observed task switching differences in this experiment. Task set switching may be considered as a combination of processes, involving (at least in part) processes involved in the endogenously driven instantiation of a given task set, akin to Rogers and Monsell's (1995) description of *active reconfiguration*, and likely including cognitive control processes to deal with proactive interference from previous tasks and stimuli (e.g. Wylie & Allport, 2000). The present experiment afforded almost no trial-to-trial interference—each task was consistently mapped to a separate hand, with congruent stimulus-response mappings between tasks maintained for both easy and hard response mapping conditions (i.e. stimuli A and 1 were always mapped to the same left-to-right response in each hand, and so on), with no task overlap or stimulus-task cuing ambiguity. One could even conceptualise this experiment as having only a single task, mapping each of six distinct stimuli in a 1-to-1 fashion to six distinct responses.

Our observed switch costs do demonstrate that participants seemed to represent letter and digit stimuli as two separate tasks, with a cost of switching between them; this said, the processes involved in this switching may not fully represent the set of cognitive control processes typically implicated in many task switching situations. We conducted Experiment 2 to examine whether the observed performance advantage in task switching for video game experts versus non-video game players would persist under conditions of more substantial proactive interference between tasks.

3. EXPERIMENT 2

Experiment 2 was based on the task switching procedure of Arbuthnott and Frank (2000), with three different tasks presented in a pseudorandom order to allow the comparison of repeat trials with simple switching from one trial to another, and the alternation from one trial to another and back again. This experiment was designed to have substantial task overlap, and hence cause substantial proactive interference from trial to trial, with six stimuli mapped to two alternative responses for each of three tasks, under three different sets of stimulus-response mapping rules. In contrast to typical response alternation paradigms, we again presented blocks of trials with both long (1000 msec) and short (100 msec) cue-to-target intervals, to explicitly assess whether participants could actively prepare for an upcoming trial given time to do so, and test whether VGPs would show a selective benefit under such conditions as they did in Experiment 1.

3.1. Method

3.1.1. Participants

Forty undergraduate students from McMaster University participated in exchange for course credit. All participants were male, and reported normal or corrected-to-normal vision. Participants were recruited as described in

Experiment 1, with 20 participants identified in each video gamer (VGP) and non-gamer (NVGP) group. Mean age was not different between VGP and NVGP groups (19.0 years versus 18.6 years, $t(19) = 1.13$, p = n.s.).

3.1.2. Apparatus and Stimuli

Stimuli were the digits 2, 3, 4, 6, 7 and 9, presented individually in the center of a computer display. One of three informative verbal task cues—“Odd/Even”, “Prime/Multiple”, or “Less/More”—was also presented on screen directly above the current stimulus digit on every trial, indicating which of three speeded classification tasks participants should perform on the stimulus digit. Stimuli and task cues were presented in the same sized Arial font, with each element subtending approximately 1° vertical visual angle, with approximately 1.5° visual angle separating the near edges of stimulus and task cues vertically. On a single trial, a task cue was presented for either 100 msec or 1000 msec, and was then joined on screen by a single stimulus digit that persisted until response. The next trial began with a task cue following a constant 100 msec inter-trial interval. Erroneous responses elicited an immediate auditory feedback signal (100 msec, 100 Hz square wave). The same computer apparatus was used as in Experiment 1.

3.1.3. Procedure

Stimulus digits were presented randomly on each trial, with the constraint that a presented digit could not repeat on the subsequent trial. Participants performed one of three possible tasks on each trial, classifying the presented single digit as either odd or even, as a prime number or not, or whether that digit was larger or smaller than 5. Task order was systematically constrained to present ordered sequences of five tasks, in order to produce consistent numbers of four different trial types: *repeat* trials, where a task A followed another task A; *1-switch* trials, where a task A followed a different task B; *2-switch* trials, where a task A followed two successive different tasks B and C; and *alternate* trials, where a task A followed a previous task A from two trials ago, with an intervening task B. All four of these trial types were embodied in 5-trial sequences with an AABCB trial order structure, where trials two through five represented repeat (A), 1-switch (B), 2-switch (C) and alternate (B) trials, respectively. We computed all six possible iterations of these 5-trial sequences for combinations of our three tasks, plus all six combinations for another 5-trial sequence that similarly gave these four trial types in a different order, ABACC.

We presented these twelve sets of five tasks in random order (preserving the 5-trial sequence structures), for a continuous block of 60 trials in apparently random order. The initial trials in these 5-trial sequences could have represented a 2-switch (trial type A), repeat (B), or alternate trial (C) following a prior AABCB sequence, or a 1-switch (A or B) or repeat (C) trial following a prior ABACC sequence, depending on the identity of the initial trial in the current sequence and trials 4 and 5 in the previous sequence, and were analyzed as such. Within a 60-trial block, the random presentation order of these predefined 5-trial sequences gave a slightly greater expected proportion of repeat and 1-switch trials (26.6 %

each) compared to 2-switch and alternate trials (23.4 % each), approximated as 12 trials per condition plus 33.3 % (repeat and 1-switch) or 16.7 % (2-switch and alternate) of the 11 initial-position trials, out of a total 59 eligible trials (the first trial of a 60-trial block is undefined). These small differences in experienced condition probabilities were the same for all participants.

Participants responded to each digit stimulus based on the task rules indicated by the pre-stimulus cue on each trial. Participants responded with their left versus right index, middle and ring fingers for Odd/Even, Prime/Multiple and Less/More (relative to the value 5) digit classifications, respectively. Task cues represented the consistent left/right mapping of the relevant category responses for each task, but did not indicate which pair of fingers was appropriate for a given task. Participants performed eight blocks of 60 trials, with a cue-to-target interval of 100 msec or 1000 msec alternated every block. Participants received self-paced breaks between every block, and were also given feedback on their mean reaction times and error rates for the previous block. Participants completed a single additional practice block prior to the main experiment, with 30 trials of each cue-to-target interval, which was not analysed. The order of cue-to-target interval alternation was counterbalanced across participants.

3.2. Results

In consideration of the overall longer reaction times in this experiment compared to Experiment 1, trials with responses faster than 300 msec or slower than 5000 msec were excluded from analysis, representing 0.1 % of all correct trials, distributed equally between video gaming groups. In addition to excluding error trials from reaction time analyses, we also excluded the two trials following an error trial, considering the dependence of our various task switching conditions on the preceding two trials. Mean reaction time data for trials from correct trial sequences are presented in Figure 3.2. As in Experiment 1, we expected to observe a number of general effects on performance across all participants due to our various task manipulations. We were particularly interested to test how video gaming status interacted with this set of task manipulation effects. We conducted a repeated-measures ANOVA with within-subjects factors of switch type (repeat, 1-switch, 2-switch, alternate), task (odd/even, prime/multiple, less/more), and cue-to-target interval (100 msec, 1000 msec), with video gaming status (VGP, NVGP) as a single between-subjects factor.

Figure 3.2 about here

From Figure 3.2, a number of effects were again evident across our dataset. A main effect of switch type was observed, $F(3, 114) = 167.47$, $p < 0.001$, reflecting at minimum a substantially faster performance for repeat versus other trials, with alternate trials appearing consistently slower than 1-switch or 2-switch trials across most conditions. A main effect of task type was observed, $F(2, 76) = 35.84$, $p < 0.001$, with faster responses for the less/more task compared with odd/even or prime/multiple tasks. A main effect of cue-to-target interval was also observed, $F(1, 38) = 151.92$, $p < 0.001$, with overall faster responses on trials with a long (1000 msec) cue-to-target interval. These main effects were modified by the interaction of switch type and cue-to-target interval, most readily observed as a relative reduction in switching costs (the difference between repeat and switch trials) with long cue-to-target preparation times, $F(3, 114) = 6.91$, $p < 0.001$. Switch type also interacted with task type, with relatively smaller switching costs observed for the less/more task, $F(6, 228) = 6.78$, $p < 0.001$. The interaction of cue-to-target interval with task type and the 3-way interaction between these factors and switch type were not significant, Fs < 1.2.

As in Experiment 1, we were interested to examine the potential interaction of these task effects with video gaming experience. A main effect of video gaming group was observed, $F(1, 38) = 7.12$, $p < 0.05$, reflecting overall faster reaction times for video gamers compared with non-video game players. However, no interactions whatsoever were observed between our gaming group variable and any of our task factors, all Fs < 1.1.

To better assess switching condition differences between alternation trials and 1- and 2-switch trials, typically described as Backward Inhibition effects (Arbuthnott & Frank, 2000; Mayr & Keele, 2000), we repeated our ANOVA for reaction time data with a 3-level factor of switch type, excluding repeat trial data. A significant main effect was observed for switch type, $F(2, 76) = 16.68$, $p < 0.001$, supporting the observation of greater reaction time costs for alternation trials as compared to 1-switch and 2-switch trials. The interaction of switch type with task type supported the observation that reaction time costs for alternation trials versus 1- and 2-switch trials were present in less/more and prime/multiple trials, but not apparent in odd/even trials, $F(4, 152) = 2.68$, $p < 0.05$. Strong main effects of task type, $F(2, 76) = 33.95$, $p < 0.001$, and cue-to-target interval, $F(1, 38) = 136.12$, $p < 0.001$, were still observed. However, the previously observed interaction of switch type with cue-to-target interval was absent here, $F < 1$, suggesting that this interaction was driven primarily by repeat trial performance becoming relatively faster with long cue-to-target intervals. Results for video gaming expertise were not altered, with a comparable main effect for video gaming group, $F(1, 38) = 6.74$, $p < 0.05$, and no interactions of gaming expertise with any of our task factors, Fs < 0.8.

Error rate data for Experiment 2 were calculated based on the individual trials on which participants made an incorrect response. The overall mean error rate for Experiment 2 was 4.23 %. Participants were less errorful overall on repeat trials compared to 1-switch, 2-switch and alternate trials (M = 3.22 %, 5.08 %, 4.05 % and 4.57 %, respectively), reflected by a main effect of switch type, $F(3, 114) = 5.15$, $p < 0.01$, and were less errorful overall for less/more trials compared to prime/multiple or odd/even trials (M = 3.06 %, 4.76 % and 4.87 %, respectively), $F(2, 76) = 6.67$, $p < 0.01$. Switch type and task type were observed to interact, with different tasks apparently more sensitive to error depending on task switching situation, $F(6, 228) = 5.10$, $p < 0.001$. There was no main effect of video gaming expertise, $F(1, 38) = 0.37$, $p = 0.54$. Mean error rates for NVGPs were 4.06 % and 3.94 %, and for VGPs were 3.88 % and 5.03 %, for short and long cue-to-target intervals, respectively. A marginal interaction of gaming group and cue-to-target interval, $F(1,38) = 3.55$, $p = 0.07$, reflected this approximately 1 % more errorful performance by VGPs in the long cue-to-target interval condition. No other interactions with gaming group approached significance, Fs < 1.

3.3. Discussion

Video game experts were again generally faster than non-video game players, and characteristic task switching and task alternation costs were observed for both groups. However, VGP participants showed no selective benefit for task switching compared to NVGPs, in contrast to Experiment 1. Further, while all participants showed a reduction in switch costs and overall reaction times with long cue-to-target intervals, the VGP group showed no selectively better ability to reduce their reaction times with a longer pre-stimulus preparation time, again in contrast to Experiment 1.

The addition of substantial task overlap in Experiment 2 appeared to remove any task switching-related benefit that VGP participants demonstrated over NVGP participants in Experiment 1. In Experiment 2, every trial had an informative cue, and so part of the overall faster performance observed for VGPs may have been facilitated by better cue-driven endogenous task preparation. On the basis of Experiment 1, we may have expected to see selectively better performance and relatively smaller switch costs for VGPs at long cue-to-target intervals given this cuing, but observed only equivalent effects across gaming groups.

Given the critical differences in design between our two experiments, we suggest that Experiment 2 likely involved substantially greater trial-to-trial proactive interference than was produced with the minimally-overlapping tasks in Experiment 1. While VGPs still showed substantial performance benefits compared to NVGPs, this benefit did not appear to extend to the cognitive control processes required to deal with the increased degree of switching-related proactive interference in Experiment 2. As such, we suggest that VGPs' apparent task switching benefit may be limited to a relative benefit in the control and allocation of selective attention, and not in other cognitive control processes underlying task switching.

4. GENERAL DISCUSSION

The present study compared performance of video gaming experts versus non-video game players in two different task switching situations. In Experiment 1, there was no overlap of stimuli or responses between tasks, and a direct univalent 1-to-1 mapping of all six stimuli to individual responses. In Experiment 2, six stimuli were mapped to two alternative responses in each of three different tasks, creating a substantial degree of overlap between task sets. We suggest that considerable cognitive control was required by participants to counter the substantial degree of trial-to-trial proactive interference in Experiment 2, but that this was negligible in Experiment 1. In Experiment 1, while all participants were able to respond faster and reduce their switching costs with informative cues, longer cue-to-target intervals, and simpler response mappings, VGP participants were able to additionally speed up their task performance and reduce switching costs relative to NVGPs under subsets of these particular conditions. In Experiment 2, longer cue-to-target intervals in the presence of informative task cues again allowed both VGPs and NVGPs to decrease their reaction times, and also to reduce their switching costs. However, in this situation, there was no apparent benefit of video gaming expertise on task switching performance.

Our primary interpretation of these findings is that the apparent advantage in task switching performance for video game experts compared to non-video game players is due to a superior ability to control selective attention, akin to some of the conclusions of Castel, Pratt & Drummond (2005). This kind of benefit in controlling selective attention could lead to generally observable task switching benefits in many situations, through modulation of effortful endogenously-driven *advance reconfiguration* processes of task set representations (Mayr & Kliegl, 2000; Meiran, Chorev & Sapir, 2000; Rogers and Monsell, 1995). In contrast, video gaming expertise appears not to afford any selective advantage in reducing the effects of proactive interference between task set representations (Wylie & Allport, 2000) on task switching costs, even when a substantial VGP advantage is observed for other aspects of speeded performance within the same trials. From these data, we suggest that there is no good evidence for a generalized task switching-related cognitive control benefit in expert video game players, and that the observed task switching benefits in this and other studies (Andrews & Murphy, 2006; Boot et al., 2008) are a result of a benefit in controlling selective attention.

Our present findings appear to be consistent with previous data showing a VGP benefit in task switching, though not necessarily consistent with previous conclusions regarding the cognitive basis for this benefit. Andrews and Murphy (2006) used a task switching paradigm closely following Rogers and Monsell (1995), with bivalent stimuli composed of both a number and a letter, with task cuing (vowel/consonant judgement on letters, or odd/even judgement on numbers) based on trial sequence and screen position cues. Andrews and Murphy (2006) observed a VGP benefit in task switching when stimuli were bivalent and congruent for a particular response (i.e., when the manual response for the irrelevant stimulus character under the other task was the same as the response for the current task-relevant stimulus character), and in a univalent situation when a neutral character (non-letter, non-number) was presented in place of the task-irrelevant stimulus character. In contrast, they observed no VGP benefit when stimuli were bivalent and incongruent (i.e., when the manual response for the irrelevant stimulus character under the other task was different to the response for the current task-relevant stimulus character). Andrews and Murphy's (2006) data appear to be consistent with a task switching benefit for VGPs under relatively low-interference conditions, with the disappearance of this benefit with increased interference from competing task set representations. Boot et al. (2008) also employed bivalent stimuli with their task switching paradigm, with parity or magnitude judgement tasks on single digit stimuli cued by background screen colour, although with responses for each task separated to different hands as in our present Experiment 1. Their observation of VGP benefits in task switching involved a situation with less task set overlap, and presumably a lesser degree of trial-to-trial proactive interference than in our Experiment 2.

We suggest that from previous studies and our present data, expert video game players display an advantage in controlling selective attention, similar to conclusions of Castel, Pratt and Drummond (2005). When switching task sets requires relatively little cognitive control to resolve interference from competing task sets, VGPs may be faster at instantiating new task sets due to a facilitation of endogenous reconfiguration processes due to a relative benefit in selective attention compared to NVGPs. We suggest that an increasing need for cognitive control processes to mediate the resolution of interference between overlapping task set representations would reduce the effect of this gaming-related attentional benefit on the speed of task set reconfiguration, to the point where no benefit would be observed with substantial degrees of interference between tasks. If expert gamers did indeed have a more generalized benefit in task switching-related cognitive control processes, one would expect to observe a VGP benefit in task switching to persist with increased task set overlap and resultant greater interference—the opposite of which seems to be the case in both our present data and data from previous task switching studies.

As in any study, there are a number of caveats that must be considered along with our experimental findings and their interpretation. One important question involves the source of between-groups differences – whether benefits in VGP versus NVGP performance are due to some self-selection to play video games because of initial differences in cognitive or other attributes, or whether the experience of playing video games is responsible for development of observed enhanced abilities. While exploring these causal distinctions was not a focus of our study, a number of interesting possibilities might be considered. For example, experience playing immersive first-person video games may specifically train individuals' ability to deploy selective attention, but not their ability to resist proactive interference from prior situations. Experience and training in demanding high-interference situations might result in a different set of abilities than currently appear to be typical of expert action video game players.

Several specific caveats with respect to our experimental design should also be noted. While we believe that the degree of task overlap and the resulting degree of proactive interference was the primary difference in task switching-related performance demands between Experiments 1 and 2, several other factors also varied. While both experiments used informative cues, Experiment 1 alternated between informative and uninformative cues every 4 blocks (128 trials). The observed VGP benefits in mean RT and task switching costs under informative cue conditions could have been due to NVGP's inability to flexibly make use of informative cues when only sometimes available, rather than a more basic difference in ability to use informative cues to speed performance. Similarly, differences in VGP benefits across experiments could have been more directly related to differences in flexibly adapting to changes in response mappings (alternating every 64 trials in Experiment 1, constant in Experiment 2). Both of these factors could have diminished apparent differences between VGPs and NVGPs in Experiment 2 compared to Experiment 1. To the extent that these issues may reflect differences in ability to endogenously direct selective attention, we would suggest that they would be further evidence toward our suggested conclusions – that VGPs appear to have a discrete benefit in deploying selective attention compared to NVGPs. We note also that our overall conclusions are based partly on the absence of task switching-related group differences in Experiment 2. While always a logical concern, we were reassured by our ability to observe large and systematic predicted effects in task switching, cue-to-target timing, and other factors in both VGP and NVGP groups, with no suggestion of gaming group interactions on task switching costs.

Finally, our discussion of task switching differences as arising from processes not selectively involved with task switching performance may seem counterintuitive, especially considering the typical framing of task switching as a fundamental function of cognitive control. Along with monitoring and updating of working memory ("Updating"), and the controlled, deliberate inhibition or suppression of prepotent responses ("Inhibition"), the shifting of mental set ("Shifting"), now increasingly studied as task switching, has been identified as a related but separable executive function via latent variable analysis (Friedman, Miyake, Corley, Young, DeFries & Hewitt, 2006; Miyake, Friedman, Emerson, Witzki, Howerter & Wager, 2000). Recent work has additionally identified several other dissociable executive functions, including a separable component of selective attention, distinct from Updating, Inhibition and Shifting (Fournier-Vicente, Larigauderie & Gaonac'h, 2008). The executive function of Shifting in this sense is defined by the commonalities in the tasks used to measure it—mostly a series of task switching experiments using a variety of different tasks (e.g., Friedman et al., 2006; Miyake et al., 2000). The question of what particular processes this separable executive function represents, however, is less clear. As discussed by Miyake et al. (2000), the executive function of Shifting may primarily reflect processes involved in resolving proactive interference from prior task sets, in addition or alternatively to simple engagement/disengagement of task set representations. What is clear is that typical individuals (including both VGPs and NVGPs) appear to have an executive control ability of Shifting, partially correlated with but distinguishable and separable from other executive abilities such as updating working memory, effortfully suppressing incorrect prepotent responses, and the deliberate control of selective attention.

Framed in this way, we have observed this Shifting ability and seen it modulated by a range of factors in all of our participants in both experiments in the present study. We have also observed a selective VGP benefit in an intersection of conditions most susceptible to the benefits of controlled selective attention in both experiments. In conditions requiring executive Shifting processes to resist substantial proactive interference, we observed no selective VGP benefit in task switching costs, despite a concurrent VGP benefit for other factors; only with conditions of lower proactive interference and concurrent opportunity for endogenously driven preparation for performance did we observe a VGP benefit in task switching. We suggest that these data represent a dissociation of selective attention and executive Shifting processes, both of which are involved with performance of typical task switching paradigms. While VGPs may demonstrate reduced task switching costs relative to NVGPs in some situations, we suggest that this is representative of a superior ability to control the allocation of selective attention, and not a more general benefit in cognitive control abilities underlying task switching performance.

References

Andrews, G. & Murphy, K. (2006). Does video-game playing improve executive function? In M. A. Vanchevsky (Ed.) *Frontiers in Cognitive Sciences* (pp. 145-161). New York. Nova Science Publishers Inc.

Arbuthnott, K. D. (2005). The influence of cue type on backward inhibition. *Journal of Experimental Psychology: Learning, Memory and Cognition, 31*, 1030-1042.

Arbuthnott, K. & Frank, J. (2000) Executive control in set switching: Residual switch cost and task-set inhibition. *Canadian Journal of Experimental Psychology, 54*, 33-41.

Arbuthnott, K. D. & Woodward, T. S. (2002). The influence of cue-task association and location on switch cost and alternating-switch cost. *Canadian Journal of Experimental Psychology, 56*, 18-29.

Blumberg, F. C. (1998). Developmental differences at play: Children's selective attention and performance in video games. *Journal of Applied Developmental Psychology, 19*, 615-624.

Boot, W. R., Kramer, A. F., Simons, D. J., Fabiani, M., & Gratton, G. (2008). The effects of video game playing on attention, memory, and executive control. *Acta Psychologica, 129,* 387-398.

Castel, A. D., Pratt, J., & Drummond, E. (2005). The effects of action video game experience on the time course of inhibition of return and the efficiency of visual search. *Acta Psychologica, 119,* 217-230.

Fabiani, M., Buckley, J., Gratton, G, Coles, M. H., Donchin, E., & Logie, R. (1989). The training of complex task performance. *Acta Psychologica, 71*, 259-299.

Feng, J., Spence, I., & Pratt, J. (2007). Playing an action video game reduces gender differences in spatial cognition. *Psychological Science, 18*, 850-855.

Fournier-Vicente, S., Larigauderie, P., & Gaonac'h, D. (2008). More dissociations and interactions within central executive functioning: A comprehensive latent-variable analysis. *Acta Psychologica*, *129,* 32-48.

Friedman, N. P., Miyake, A., Corley, R. P., Young, S. E., DeFries, J. C., & Hewitt, J. K. (2006). Not all executive functions are related to intelligence. *Psychological Science*, *17,* 172–179.

Gopher, D., Weil, M., & Bareket, T. (1994). Transfer of skill from a computer game trainer to flight. *Human Factors*, *36,* 387-405.

Green, C. S. & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature, 423,* 534-537.

Green, C. S. & Bavelier, D. (2006a). Effect of action video games on the spatial distribution of visuospatial attention. *Journal of Experimental Psychology: Human Perception and Performance*, *32,* 1465-1478.

Green, C. S. & Bavelier, D. (2006b). Enumeration versus multiple object tracking: The case of action video game players. *Cognition, 101*, 217-245.

Green, C. S. & Bavelier, D. (2007). Action-video-game experience alters the spatial resolution of vision. *Psychological Science, 18*, 88-94.

Greenfield, P. M., deWinstanley, P., Kilpatrick, H., & Kaye, D. (1994). Action video games and informal education: Effects on strategies for dividing visual attention. *Journal of Applied Developmental Psychology, 15,* 105-123.

Mayr, U. & Keele, S. W. (2000). Changing internal constraints on action: The role of backward inhibition. *Journal of Experimental Psychology: General, 129*, 4-26.

Mayr, U., & Kliegl, R. (2000). Task-set switching and long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*, 1124-1140.

Meiran, N., Chorev, Z., & Sapir, A. (2000). Component processes in task switching. *Cognitive Psychology, 41*, 2211-2253.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41,* 49-100.

Rogers, R. & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124,* 207-231.

Trick, L. M., Jaspers-Fayer, F., & Sethi, N. (2005). Multiple-object tracking in children: The "Catch the Spies" task. *Cognitive Development, 20,* 373–387.

Wylie, G., & Allport, A. (2000). Task switching and the measurement of "switch costs." *Psychological Research, 63*, 2212-2233.

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Chapter 4

Karle, J. W., Watter, S., Kiss, I., & Shedden, J. M. (submitted; Acta Psychologica). ERP Evidence For Selective Spatial Working Memory Benefits In Expert Video Game Players.

CHAPTER SUMMARY:

The experiments detailed in this chapter were designed to expand on the work presented in Chapters 2 and 3 of this dissertation. To review, in Chapter 2, VGPs were shown to have superior performance when engaged in a visual search task, replicating previous findings in the literature. Although capable of responding more rapidly than NVGPs, this benefit was not demonstrated to be sensitive to elements of contextual control. In Chapter 3, we employed several task switching paradigms to investigate aspects of higher cognitive control. It was anticipated that some combination of these methodologies would successfully localize the benefits demonstrated by VGPs in visuospatial processing. VGPs showed reduced task switching costs compared to their NVGP contemporaries when tasks were comprised of minimally overlapping components and sufficient time was available to make use of informative cues. However, elevating proactive interference through increasing task overlap negated any such task switching benefits for VGPs. Our findings suggest that VGPs have no generalized benefit in task switching-related control. We proposed two hypotheses to explain these data.

Our findings could be explicated through making reference to a model that places better or more efficient control by VGPs over higher level processing mechanisms that manage the deployment of selective attention. An alternate account would argue that VGPs are more capable of lower level perceptual and attentional processing. Our data could not differentiate between these two perspectives.

Having identified two competing hypotheses explaining the VGP visuospatial superiority effects established in the literature and replicated in our work here, we set out to distinguish between them. While recording event-related potentials (ERP), we compared performance of VGPs and NVGPs on a task designed to assess cognitive control in both verbal and spatial working memory (WM). Despite parity of behavioural performance, differential patterns of electrophysiological activity were observed between VGPs and NVGPs. Both groups demonstrated load-sensitive WM effects in response to the presentation of to-be-remembered stimuli. Comparable ERP effects for VGPs and NVGPs were observed both in easy and hard verbal WM tasks, and during a relatively easy spatial WM condition. Patterns diverged considerably when spatial WM required constant manipulation and updating. In the hard spatial WM condition, ERP indices of cognitive control demonstrated relatively less cortical involvement by VGPs over NVGPs. These ERP data can be interpreted as demonstrating differential and effortful strategic engagement in the more difficult spatial WM task by NVGPs compared to VGPs. This suggests that VGPs may benefit from a superior ability in representing visuospatial information rather than more efficient or better control of the mechanisms that direct the deployment of selective attention.

Running Head: VIDEO GAME EXECUTIVE CONTROL

ERP Evidence For Selective Spatial Working Memory Benefits In Expert Video Game Players

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Abstract

Expert video game players (VGPs) demonstrate superior performance on a wide variety of tasks involving visuospatial perception and attention compared to their non-video game playing contemporaries (NVGPs). One proposed source of this performance benefit is that VGPs may have superior abilities in cognitive control compared to NVGPs. To examine this hypothesis, we compared VGP and NVGP performance using event-related potentials (ERPs) in a running memory paradigm, designed to assess central executive-related control processes in both verbal and spatial working memory (WM). Participants were instructed to remember either verbal (digit identity) or spatial information (digit location) for the first or last three items in a variable length sequence of spatially distributed digit stimuli. Consistent patterns of load-sensitive WM effects were observed in response to the presentation of to-be-remembered stimuli. VGP and NVGP groups showed comparable patterns of ERP effects for verbal WM tasks, and for a relatively easier spatial WM task, but differed substantially when spatial WM required constant updating. ERP data demonstrated differential and effortful strategic engagement in this more difficult spatial WM task for NVGPs compared to VGPs, suggesting that the VGPs may benefit from a superior ability in representing visuospatial information.

Keywords: executive control; working memory; video games; event-related potentials; ERPs

PsyclNFO classification:

2300 Human Experimental Psychology

2340 Cognitive Processes

2346 Attention

1. Introduction

Video game play, like the watching of television, has become widespread as a form of leisure. It is estimated that 7 out of 10 North American homes have some type of entertainment platform capable of video game play (Entertainment Software Association, 2009). Considering both the number of individuals who play video games and the many hours spent engaged in this activity on a weekly basis, it seems likely that such intense practice has consequences not only for a variety of cognitive systems but for a multiplicity of populations. Indeed, studies that compare video game players (VGPs) with non-video game player (NVGP) controls show differences in performance between the two groups and suggest that VGPs have markedly reduced choice reaction times (Orosy-Fildes & Allan, 1989), superior eye-hand coordination demonstrated during several versions of a rotor pursuit task (Griffith, Voloschin, Gibb, & Bailey, 1983), enhanced spatial reasoning (Greenfield, Brannon, & Lohr, 1994; McClurg & Chaillé, 1987; Subrahmanyam & Greenfield, 1994), and increased success at dividing attention (Greenfield, deWinstanley, Kilpatrick, & Kaye, 1994). There is some evidence to suggest that playing action video games can reduce or eliminate the gap in performance on spatial reasoning tasks demonstrated between the genders (Feng, Spence, & Pratt, 2007; Spence, Yu, Feng, & Marshman, 2009).

More recently, Green and Bavelier (2003) have used a variety of well established attentional paradigms, including a modified Eriksen flanker task (i.e. flanker compatibility task), the useful field of view (UFOV), an enumeration procedure, and the attentional blink (AB) to demonstrate that VGPs show superior performance on tasks that tap spatial and temporal visual attention, and may have a larger general attentional capacity, compared to NVGPs. Green and Bavelier (2003) employed a training paradigm to better address concerns in causally relating video game expertise with improved attentional performance—for example, that VGPs may be a selected population with preexisting superior attentional abilities, which may preferentially lead them to play video games in the first place. Alternatively, better visual-manual coordination in VGPs may free up processing resources to speed other aspects of task performance. After as little as 10 hours of practice playing a visual attention-demanding video game, participants showed a significant increase in UFOV, AB, and enumeration performance compared to pre-test measures. In contrast, a control group who had practiced on a challenging visuo-motor game without similar visual attentional demands showed no such improvement on these laboratory tasks. Green and Bavelier (2006a, 2006b, 2007) extended these and similar results in further studies.

Although a range of results suggest that video game play may improve performance on tasks that tap processing of the visual environment, it remains uncertain as to how this improvement is achieved. Castel, Pratt, and Drummond (2005) provided evidence that while VGPs responded more rapidly than NVGPs, they showed the same basic pattern of lower-level cuing and visual search effects, suggesting that the advantage of video game play experience in their tasks was likely due to a benefit in higher-level processes—for example, better control and allocation of selective attention, and faster instantiation of stimulus-response mappings. While their more recent work (2006a, 2006b, 2007) has focused on earlier perceptual processes, Green and Bavelier (2003) suggested that a potential source of the superior visual selective attention abilities of VGPs may be the mechanisms and processes involved in working memory (WM), especially those of the central executive (CE). Several recent studies have demonstrated a benefit in performance by VGPs over NVGPs in task switching, interpreted as support for a benefit in cognitive control (Andrews & Murphy, 2006; Boot, Kramer, Simons, Fabiani & Gratton, 2008).

The goal of the present study was to further investigate potential differences in cognitive control processes between VGPs and NVGPs. Instead of examining task switching, we chose to examine executive control processes in a WM paradigm, using event-related potential (ERP) methods. Working memory is typically conceptualized as a series of independent but capacity limited storage systems (e.g., the visuospatial scratchpad and phonological loop), the activities of which are mediated and directed by a supervisory central executive system (Baddeley, 2000; Baddeley and Hitch, 1974). While the general neurological substrates of this WM system have been well studied (e.g., for reviews see D'Esposito, Aguirre, Zarahn, Ballard, Shin & Lease, 1998; Kane & Engle, 2002), there is less agreement and a substantial degree of ongoing research in identifying and separating CE-related processes and their related neurological correlates from subordinate storage processes in WM (e.g., Corbetta & Schulman, 2002; Gruber and Von Cramon, 2003; Narayan, Prabhakaran, Bunge, Christoff, Fine, & Gabrielli, 2005; Raye, Johnson, Mitchell, Greene, & Johnson, 2007).

To better study this separation of CE and storage processes in WM, Kiss, Watter, Heisz & Shedden (2007) developed a variant of the running memory procedure (Morris and Jones, 1990; Kiss, Pisio, Francois, & Schopflocher, 1998; Kiss, Pazderka-Robinson, & Floden, 2001), a design in turn based on the n-back WM task (Dobbs and Rule, 1989). This design allowed them to selectively observe and characterize ERP correlates of CE-related encoding and updating activity in verbal. WM. Kiss et al. (2007) presented participants with variable-length sequences of single digits, and asked them to either remember the first 2 or 3 items in the sequence (the *maintenance* task), to remember the last 2 or 3 items in the sequence (the *updating* task), or to simply monitor for and assess a probe item (a non-WM *control* task). Participants responded only when a probe stimulus was presented at the end of a digit sequence, as to whether the to-be-remembered items matched those digits presented in the probe display. In the maintenance task, participants could ignore stimuli subsequent to the required 2- or 3-item memory set; in the updating task, participants had to continually update their WM representations for the most recently presented 2 or 3 items, as subsequent items were presented in a sequence of unpredictable length. Kiss et al. (2007) demonstrated an item-by-item WM load sensitivity across stimuli within these sequences. When participants were asked to remember the first 2 items, substantial central parietal P300-related and prolonged slow wave activity was observed to increase over serial positions 1 and 2, with no activity for subsequent items; this activity extended to serial position 3 when remembering the first 3 items. When asked to remember the last 2 or 3 items in a sequence, this kind of parietal activity was observed for all presented stimuli in a sequence. Kiss et al. (2007) interpreted this distinctive pattern of sequential ERP effects as reflecting neural activity of executive control processes involved with the effortful encoding and consolidation of coherent representations in WM.

Recent work from our laboratory has extended the Kiss et al. (2007) running memory paradigm to directly compare ERP correlates of CE-related control processes in verbal versus spatial WM (Watter, Heisz, Karle, Shedden & Kiss, 2010). This study presented variable-length sequences of single digit stimuli at one of eight regular positions around a central fixation point, with instructions to remember either the identity (verbal WM) or position (spatial WM) of the first or last 3 presented digits. Watter et al. (2010) replicated the verbal WM findings of the 3-item memory tasks from Kiss et al. (2007), showing the same characteristic patterns of serial position-sensitive effects for the first 3 items in the maintenance task, and all items in the updating task, over central parietal sites. Similar effects were observed for spatial WM, with one notable exception—while the spatial maintenance task showed the same increasing parietal P300-like and slow wave activity over sequence items 1 to 3 as the verbal maintenance and updating conditions, the spatial updating task showed a very different pattern.

Parietal ERP activity in the spatial updating task was maximal for serial position 1, reduced to a minimal P300-like effect with negligible slow wave at position 3, with some subsequent increase over serial positions 4 and 5.

Watter et al. (2010) suggested that these differential findings in the spatial updating task reflected the effortful up-front preparation of a more detailed spatial WM representation, into which the second and third stimulus items could be easily integrated. In contrast, participants appeared to use a less immediately effortful approach of dealing with individual stimuli in turn in the spatial maintenance task, where participants knew they would have time to consolidate their WM set after the third stimulus, reflected by exaggerated and extended slow wave activity in prefrontal and parietal areas. Watter et al. (2010) suggested that these effects reflected the result of differential strategy use by participants, in response to particularly difficult task conditions.

Our present study employed the same adapted procedure as used by Watter et al. (2010) to investigate potential differences in CE-related executive control processes between VGPs and NVGPs. We primarily assessed our data with respect to whether our VGP and NVGP participant groups replicated the characteristic patterns of item-by-item WM load sensitivity in parietal ERPs observed in Kiss et al. (2007) and Watter et al. (2010), and to what extent behavioural or ERP findings suggested differences in CE-related executive control processes between VGPs and NVGPs. To anticipate our findings, NVGPs closely replicated previous findings, with evidence of differential early engagement of WM processes in the difficult spatial updating task. In contrast, VGPs did not show this differential early effort for spatial WM updating, despite equivalent overt performance, suggesting differences in ability in spatial representation and the subsequent requirements for CE-related processes to control spatial WM representation and performance.

2. Method

2.1 Participants

Forty-four English-speaking undergraduate students (all male, 21 NVGPs; mean age for both groups 20 years) enrolled in an Introduction to Psychology or Cognition course at McMaster University participated in this experiment in exchange for course credit. All participants reported normal or corrected to normal vision and gave their written informed consent prior to beginning the experimental session. Upon conclusion of the experimental procedure, all participants completed a questionnaire which assessed VGP status through directed questions such as whether or not the participant played video games; if so, how often; for how long per day, per week, etc. The data collected from this questionnaire were employed as a means to divide the participants into the two populations of interest, VGPs and NVGPs. Initial recruitment of participants asked for two distinct types of participant: VGPs, with 4 hours or more of game play per week, with at least 1 hour per session over the past 6 months; and

NVGPs, described as having not played video games over the course of the past 6 months, preferably having never played video games.

2.2 Apparatus and Stimuli

The experiment was conducted on a 19-inch colour CRT monitor, with a resolution of 1024 x 768 pixels at a frame rate of 75Hz, connected to an IBM-compatible computer running the Windows XP operating system. Presentation® software (version 9.90, Neurobehavioural Systems, www.neurobs.com) was used to present stimuli and record manual responses from a standard QWERTY computer keyboard. Throughout the experiment, participants were seated in a dimly lit room approximately 90 cm from the monitor. A chinrest was used to keep viewing distance constant and reduce aberrant muscle activity that would interfere with the recording of ERPs.

A series of eight continually visible light gray squares, each subtending 1.6° visual angle per side and separated by a small 0.1° gap (all together, the "study grid"), were presented around a 0.6° x 0.6° central fixation cross, on a black background (see Figure 4.1). The space enclosed by the inner borders of the study grid subtended 3.3° square. On each trial, a variable-length sequence of white single digits was presented in Helvetica font, followed by a probe stimulus. Digits subtended approximately 1.3° of visual angle vertically. Probe displays consisted of three digits or two digits and a letter (one of A, B, D, F, H, K, M, N, P, R, T, V, or X) presented centrally (obscuring the central fixation point) for verbal WM tasks, or of two or three light grey shaded squares presented within some of the study grid positions. Stimuli were presented for 200 msec, with a randomly varied inter-stimulus interval of 1200 msec to 1500 msec.

Figure 4.1 about here

2.3 Procedure

The experiment was comprised of two independent sessions, each lasting approximately 25 minutes. A verbal WM session asked participants to remember the identities of spatially presented digit stimuli, and a spatial WM session asked participants to remember the locations of similarly spatially presented digit stimuli. Session order was counterbalanced across participants. Each session incorporated six separate blocks for each of three different task types: control, maintenance, and updating. Each block contained 5 trials, with a single trial involving the presentation of a series of individual digit stimuli followed by a probe stimulus. An additional 15-trial practice block was given prior to the beginning each session, which included 5 trials of each task type. Blocks were presented in mixed and counterbalanced order, with no two consecutive blocks involving the same task type. Participants received on-screen instructions regarding which task to perform prior to the beginning of each block, informing them to “Remember the FIRST 3 [numbers/positions]”, “Remember the LAST 3 [numbers/positions]”, and “Look for a SET OF 3 [numbers/positions]” for maintenance, updating and control tasks, respectively. Responses to probe displays were made by pressing “1” or “2” on the numeric keypad to indicate presence of a target or non-target, counterbalanced across participants.

On any particular trial, single digits were presented one at a time within the squares of the study grid surrounding the fixation cross, demonstrated in the top panel of Figure 4.1. Stimulus identity and location were both determined randomly, with the constraint that neither identity nor location could repeat over a set of three consecutive stimuli. Between 3 and 8 stimuli were shown in each trial, with runs of 3, 4, and 5 digits each having a 25% likelihood, and runs of 6, 7, and 8 each having an 8.33% likelihood, randomly determined. Probe items were presented at the end of each sequence and either matched (target) or did not match (non-target) the to-be-remembered information, randomly determined and constrained to have two targets and three non-targets, or vice versa, within a single 5-trial block.

For the *maintenance* task, participants were instructed to remember the first three items presented in a sequence of stimuli—for verbal WM, to remember the identities of the first 3 presented digits, and for spatial WM, to remember the locations of the first 3 presented digits. When the probe stimulus appeared, participants were required to respond as to whether the presented digits (for verbal WM) or grid positions (for spatial WM) were the same as the first three items presented in the current stimulus sequence. The bottom panel of Figure 4.1 shows examples of the probe displays. Non-target probes were constructed by altering one digit or position of corresponding target probes +/- one integer value or spatial position around the display, randomly determined. The *updating* task was quite similar to the maintenance task, with participants instead instructed to remember the identity or position of the most recently presented three items. For our *control* task, participants were instructed to monitor the sequence of single digits for a probe, and indicate whether the probe was any set of three digits in the verbal WM session (compared to two digits and a letter), or any three positions in the spatial WM session (compared to two positions). Instructions for all tasks equally emphasized speed and accuracy of performance.

2.4 Electrophysiology

The ActiveTwo Biosemi electrode system (BioSemi, Amsterdam, the Netherlands) was used to record continuous electroencephalographic (EEG) activity from 128 Ag/AgCl scalp electrodes. An additional six electrodes were used: four to record horizontal and vertical eye movements, located just lateral to the outer canthi and just below each eye; and two additional electrodes – common mode sense (CMS) active electrode and driven right leg (DRL) passive electrode – which substitute for the ground electrodes used by traditional systems (see documentation available from the BioSemi company for more information, http://www.biosemi.com/faq/cms&drl.htm). The BioSemi system has no conventional reference electrode, with monopolar signals from each active electrode stored digitally, and rereferencing done via software after initial data acquisition. In the present study, the continuous EEG signal was acquired with an open pass-band from DC to 150 Hz and digitized at 512 Hz. The signal was bandpass filtered off-line at 0.1 to 30 Hz and rereferenced to a common average reference.

Event-related potential averaging and analysis were performed with EEProbe software (ANT, www.ant-software.nl). EEG and EOG artifacts were removed using a +/-35 μV deviation over 200 msec intervals on all electrodes. Signal artifacts due to eye blinks were manually identified and then corrected by a subtraction of VEOG propagation factors via a regression algorithm on EOG components, again with EEProbe software. ERP epochs for analysis were defined by a total 1000 msec recorded EEG epoch, with a 100 msec pre-stimulus baseline and 900 msec interval following stimulus onset. Only ERP data from trials with correct responses to probe identity or location were included for analysis. Stimulus-locked ERP waveforms for each participant were averaged separately for each electrode for each serial position, task type (control, maintenance, updating), and WM modality (verbal, spatial).

2.5 Data Analysis

Mean reaction times for correct trials and mean error proportions were analyzed by separate repeated measured Analysis of Variance, with within-subjects factors of task type (control, maintenance, updating), WM modality (verbal, spatial), and probe type (target, non-target), with a between-subjects factor of video game experience (VGP, NVGP). These behavioural analyses focused on overt responses to probe displays.

In contrast, our ERP analyses concentrated on stimulus-locked activity related to the processing of potential to-be-remembered stimulus items, prior to any comparison or response to the probe display. An overt response reflects the output of a large number of individual cognitive processes, making it difficult to attribute variations in RT and accuracy to variations in a specific cognitive process (Luck, 2005). This makes stimulus-locked ERPs ideally suited to address issues of maintenance and updating in WM. We assessed ERP data only from the first five presented items in sequence, as the number of available trials per condition diminished with increasing serial position. Following methods and primary findings from Kiss et al. (2007) and Watter et al. (2010), our ERP analyses focused on a central parietal region of interest. Initial visual inspection of grand mean waveform data demonstrated substantial central parietal effects for both VGP and NVGP groups, with the location of maximal amplitude effects observed slightly more posteriorly for VGPs than NVGPs. Considering our a priori focus on replicating specific previously observed patterns of effects under varying WM conditions, we used a slightly more posterior set of electrodes for our VGP analysis region of interest compared to that for NVGPs. Our central parietal area of interest involved a set of four contiguous electrodes: two adjacent midline electrodes approximately 2 cm apart, plus one electrode to the right and left of this pair, approximately 2 cm from the midline. For VGPs, the more anterior of the two midline electrodes was Pz; for NVGPs, the more posterior of these two midline electrodes was approximately 2 cm anterior to Pz.

Again following visual inspection of grand mean waveforms and prior methods of Kiss et al. (2007) and Watter et al. (2010), we identified two epochs for analysis: a 300 msec to 500 msec epoch capturing a distinct P300-like component, and a 700 msec to 900 msec epoch capturing late slow wave activity, separated from earlier P300-like effects. Mean amplitude data for trials with correct responses to probe stimuli were included for analysis, excluding 11.5 % and 12.1 % of all trials for VGP and NVGP participants, respectively. Separate repeated measures Analysis of Variance (ANOVA) with Huynh-Feldt correction were conducted for data from each epoch, with within-subjects factors of WM modality (verbal, spatial), task type (control, maintenance, updating), and serial position (1, 2, 3, 4, 5), with a between-subjects factor of video game expertise (VGP, NVGP).

3. Results

3.1 Overt Behaviour

Mean reaction time and error rate data are presented in Figure 4.2. VGP and NVGP groups did not differ in their overt performance across modality or difficulty of working memory tasks, with no main effects or interactions observed for video game group in either error rate or RT data, all Fs < 1. Across gaming groups, mean error rates increased across control (6.2 %), maintenance (10.9 %), and updating tasks (17.4 %), $F(2, 84) = 49.179$, $p < 0.001$, with the interaction of task type and WM modality supporting the observation of less errorful performance in spatial versus verbal tasks in maintenance and updating conditions compared to control tasks, $F(2, 84) = 5.628$, $p < 0.01$.

Figure 4.2 about here

Participants' mean reaction times were consistent with their error rates, with no evidence of a speed-accuracy trade-off in performance. Reaction times increased across control (648 msec), maintenance (741 msec) and updating tasks (824 msec), $F(2, 84) = 97.366$, $p < 0.001$. Participants were similarly faster for spatial versus verbal WM tasks in maintenance and updating conditions compared to control tasks, supported by both the main effect of WM modality, $F(1, 42) = 7.377$, $p < 0.05$, and the interaction of WM modality and task type, $F(2, 84) = 15.628$, $p < 0.001$. Responses were also faster overall to targets (704 msec) than non-targets (776 msec), $F(1, 42) = 133.112$, $p < 0.001$. Target type interacted with task type, $F(2, 84) = 68.774$, $p < .001$, with maintenance task performance faster and close to control performance on target trials, but substantially slower on non-target trials. Target type also interacted with WM modality, $F(1, 42) = 5.723$, $p = .021$, with selectively faster responding to targets but not lures in spatial versus verbal conditions.

3.2 Event-Related Potentials

The grand mean ERP waveforms presented in Figure 4.3 represent the mean activity across the four adjacent electrode sites comprising our central parietal region of interest for VGP and NVGP data. We assessed mean amplitudes over this parietal region of interest in two analysis epochs to characterize effects of a P300-like component (300 msec to 500 msec) and a late slow wave component (700 msec to 900 msec) observed on initial inspection of grand mean waveforms, and to allow more direct comparison to prior studies. Patterns of effects in both analysis epochs were extremely similar, replicating the findings of Kiss et al. (2007) and Watter et al. (2010). For brevity, we present only the late slow wave analyses here; patterns of effects in the earlier epoch can be considered to be essentially the same.

Figure 4.3 about here

Amplitudes were generally larger in verbal versus spatial conditions, $F(1, 42) = 7.732$, $p < 0.01$, and in maintenance and updating compared to control conditions, $F(2, 84) = 6.069$, $\varepsilon = 0.996$, $p < 0.01$. Visual inspection of grand mean waveform data suggested the presence of previously observed item-by-item WM load-sensitive serial position effects. Considerable slow wave activity was observed leading up to item position 3 in the maintenance task for both spatial and verbal modalities, with a similar pattern extending across all serial positions in the verbal updating task, and mixed effects within spatial updating tasks. These observations were supported by a main effect of serial position, $F(4, 168) = 6.333$, $\varepsilon = 0.766$, $p < 0.001$, modified by a significant 3-way interaction of WM modality, task type and serial position, $F(8, 336) = 2.096$, $\varepsilon = .913$, $p < 0.05$, and a marginal interaction of serial position and task type, $F(4, 168) = 2.200$, $\varepsilon = .950$, $p = 0.075$. This general pattern of ERP activity was reflected in both verbal and spatial conditions by VGPs and NVGPs, though the pattern was relatively more pronounced with larger overall amplitudes for VGPs, $F(1, 42) = 4.859$, $p < 0.05$. To better examine these apparent effects, and to more sensitively investigate our a priori hypotheses regarding differences in CE-related processes between gaming groups, we performed four additional repeated-measures ANOVAs with factors of WM modality (verbal, spatial) and serial position (1 to 5), to separately assess the patterns of item-by-item WM load-sensitivity on ERP performance by VGPs and NVGPs in maintenance and updating tasks.

Recent work by Watter et al. (2010) in turn replicating the verbal WM serial position ERP effects of Kiss et al. (2007), demonstrated that the pattern of parietal slow wave activity over serial positions was the same in the maintenance condition for both verbal and spatial working memory but diverged in the updating condition. In our present study, NVGPs generally replicated these findings. In the maintenance condition, run position 3 was maximally active in both verbal and spatial WM tasks, with relatively smaller amplitudes in spatial versus verbal conditions leading to an interaction of serial position and WM modality, $F(4, 80) = 2.700$, $\varepsilon = .917$, $p < .05$, modifying marginal main effects of WM modality, $F(1, 20) = 2.527$, $p = 0.128$, or serial position, $F(4, 80) = 1.901$, $\varepsilon = 0.909$, $p = 0.126$. However, this similarity of serial position activity across WM modality was not repeated when performing the updating task. Slow wave amplitudes observed for NVGPs were nearest baseline in the verbal updating task at serial position 1 and generally increased in amplitude with subsequent serial positions. In contrast, the spatial updating task showed a very different pattern, with maximal and sustained amplitudes at serial position 1, with subsequent serial positions less active and less differentiated from each other. This observation was supported by the interaction of WM modality and serial position, $F(4, 80) = 2.939$, $\varepsilon = 0.902$, $p < 0.05$, modifying a main effect of WM modality, $F(1, 20) = 5.812$, $p < .05$, with no main effect of run position, $F < 0.5$. These effects directly replicate both the verbal WM findings of Kiss et al. (2007), and the recent verbal versus spatial WM findings of Watter et al. (2010), showing differential patterns of CE-related ERP responses to verbal versus spatial performance under difficult WM updating conditions.

VGPs demonstrated similar parietal slow wave activation patterns across WM modality for the maintenance task, akin to NVGPs. Serial position 3 showed maximal activation over other run positions, again with relatively smaller amplitudes in spatial versus verbal conditions, leading to an interaction of WM modality and serial position, $F(4, 88) = 2.890$, $\varepsilon = 0.974$, $p < .05$, modifying a main effect of serial position, $F(4, 88) = 3.736$, $\varepsilon = 0.884$, $p < .05$, with no main effect of WM modality, $F < 1$. In the updating condition, in particular contrast to NVGP performance, VGPs showed no differential pattern of ERP activity across serial positions. Verbal and spatial updating for VGPs appeared similar to patterns of effects generally observed for verbal updating conditions throughout this and prior related studies (Kiss et al, 2007; Watter et al., 2010), with relatively low amplitudes at initial serial positions becoming progressively larger with increasing serial position. This finding was supported by a main effect of serial position, $F(4, 88) = 5.640$, $\varepsilon = 0.893$, $p < 0.01$, with no main effect of WM modality and no interaction, Fs < 1.3.

4. Discussion

The present study compared the performance of VGPs and NVGPs on a running memory paradigm in an effort to explore potential differences in working memory, particularly executive control processes. Participants were asked to remember either identity (verbal) or location (spatial) information about presented digits from the same visual displays, under predictable and constant WM conditions (remembering the first 3 items in a series, the *maintenance* task) or under unpredictable and increasingly difficult WM conditions (remembering the last 3 items in a series, the *updating* task). Our analyses focused on patterns of central parietal ERP slow wave effects over sequential stimulus presentations, previously suggested by Kiss et al. (2007) to represent CE-related control processes in WM encoding and consolidation, distinct from ERP activity reflecting the maintenance of WM information itself.

For verbal WM tasks, ERP data for both VGP and NVGP groups closely replicated the pattern of effects previously observed by Kiss et al. (2007) with centrally presented digit stimuli in an equivalent paradigm, and by Watter et al. (2010) using the present design. Participants showed maximal parietal amplitude effects at serial position 3 with little subsequent activity in the verbal maintenance task (remember the first 3 digits). These data are consistent with additional work performed following the presentation of the third stimulus, reflecting possible recoding and consolidation of a now-complete 3-item WM set, with no need to remember subsequent stimuli in this task. The verbal updating task (remember the last 3 digits) showed similar activity at earlier serial positions, but with sustained parietal amplitude effects for stimuli beyond position 3, reflecting the continued need to encode new stimuli and update the contents of WM with each subsequent stimulus presentation. While VGPs demonstrated larger amplitude effects than NVGPs, the pattern of effects over serial position appeared consistent between these groups, suggesting a similar item-by-item approach in encoding and manipulating items in verbal WM.

For the spatial maintenance task (remember the first 3 positions), patterns of ERP data for both VGPs and NVGPs appeared similar to data from the verbal maintenance task, again replicating recent data from the same paradigm in Watter et al. (2010), and related maintenance task data in Kiss et al. (2007). Although somewhat less distinct than in our verbal condition, amplitudes were maximal at serial position 3, reflecting the final stimulus item requiring encoding and consolidation in WM for the maintenance task. These ERP data suggested that all participants appeared to approach the encoding of verbal and spatial information in a strategically similar way in our maintenance tasks, incorporating new stimulus information into their current WM representations in a progressive and increasingly effortful manner as each new stimulus item was presented.

However, in the spatial updating task, VGPs and NVGPs were observed to display quite different patterns of WM-related parietal amplitude effects over serial positions. ERP data from NVGPs showed a change from other updating or maintenance task amplitude patterns, with maximal amplitude effects observed in response to the first stimulus in a sequence. This notably different pattern of ERP effects again replicated the findings in Watter et al. (2010), who also described this maximal first item slow wave amplitude effect with spatial updating performance. In comparison to ERP data in the spatial maintenance task, NVGPs appeared to be doing a substantial amount of WM-related work in response to the first stimulus item in the spatial updating task—well in excess of that required for successful encoding and representation of the first stimulus item in the spatial maintenance task. We suggest that this pattern of data represents the effortful establishment of a more complex and complete spatial WM representation at serial position 1, into which subsequent spatial information could be more easily integrated. While NVGP participants appeared to employ this up-front preparation strategy only in the spatial updating task, it seems likely that they could also have done so for spatial maintenance, but chose not to. We suggest that participants likely adjust their performance strategies to optimize the tradeoff between required levels of performance and the subjective costs of cognitive difficulty or effort. In the spatial maintenance task, participants learn that they can perform adequately by performing additional WM consolidation after the third item is presented; in the updating task, this approach is incompatible with having to keep encoding and updating WM with subsequent stimuli. Here, NVGP participants appear to be forced into more effortful up-front preparation in order to successfully perform this task.

While NVGPs showed this differential pattern of WM-related parietal effects in spatial updating, suggesting a different strategic approach to this task, the pattern of spatial updating data for VGPs appeared consistent with performance in all other WM tasks. VGPs showed the same pattern of parietal ERP responses to spatial information in the difficult spatial updating task as they did in the simpler spatial maintenance task, and in both verbal tasks, with increasing parietal amplitudes in response to stimuli at serial positions 1 through 3, with continued sustained effects at positions 4 and 5. VGPs showed no evidence of more effortful WM-related ERP activity at the beginning of a stimulus sequence, instead showing the now-characteristic pattern of increasingly demanding processing over serial positions.

Despite this lack of additional up-front preparation in the difficult spatial updating task, VGPs showed equivalent overt behavioural performance when responding to probe items as NVGPs, whose ERP data did suggest such additional up-front preparation. This suggests that VGPs require a lesser degree or extent of overt cognitive control to mediate spatial WM performance compared to

NVGPs, potentially due to a superior ability to represent visuospatial information. Such an explanation would be consistent with a growing set of behavioural findings showing a performance benefit for VGPs over NVGPs on tasks involving a range of visuospatial processing requirements (e.g., Dorval and Pepin, 1986; Feng, Spence, & Pratt, 2007; Green and Bavelier, 2003; 2006b, 2007; Subrahmanyam and Greenfield, 1994). Given a much more demanding spatial WM task than used here, one might expect to observe better overt WM performance in VGPs as NVGPs more quickly reach a performance ceiling, or to observe ERP evidence of VGPs adopting a more effortful strategic approach to spatial WM performance.

The differential pattern in strategic performance and apparent cognitive control demands for spatial WM updating between our participant groups would seem to reflect the fact that VGPs are relative experts at some aspects of visuospatial processing. Whether this benefit is primarily a result of considerable experience playing attentionally demanding action video games, or may more substantially reflect a selection bias for those with such superior abilities to be drawn to playing such games is still an open question. While studies such as Green and Bavelier (2003) have shown significant training effects on certain visuospatial tasks with particular attentionally demanding games, other studies have shown little effect of similar degrees of action video game training on a wide range of visual perceptual and attentional abilities (Boot et al, 2008), lending support to at least a moderate contribution of self-selection to this observed VGP benefit. Substantial further investigation will be required to delineate the degree to which these factors may contribute to observed differences between VGPs and NVGPs.

In either case, there is increasingly strong evidence in the literature for superior visuospatial abilities in VGPs versus NVGPs. We suggest that this benefit is due at least in part to a superior ability to represent visuospatial information in WM. This quantitative difference in spatial representational ability appears to place fewer demands on cognitive control processes in maintaining a given level of WM performance, allowing VGPs to engage in less effortful strategic approaches to WM performance. This situation would appear to reflect a true qualitative difference between VGP and NVGP performance in strategic spatial WM performance, as an emergent result of underlying quantitative differences in visuospatial representational ability.

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Chapter 5: General Discussion

5.1 Summary of Results

The relevant literature of the past thirty year period clearly indicates that expertise with—or occasionally even short exposure to—video games has an impact on a variety of socio-emotional and cognitive functions. VGPs demonstrate differential and often superior performances over their non-game playing contemporaries on a wide variety of tasks (Achtman, Green, & Bavelier, 2009; Donohue, Woldorff, & Mitroff, 2010; Green and Bavelier, 2003; Karle, Watter, & Shedden, 2010). In some instances, training studies explicate these effects as causally linked to expertise with certain game genres (Green and Bavelier, 2003, 2006a, 2006b, 2007; Feng, Spence, & Pratt, 2007). For example, findings suggest that improvements on tasks of visuospatial attention are in part due to action-video game play (Green and Bavelier, 2003). The direction of this thesis has not been driven by issues of social-value (i.e. exposure to video games and resultant addiction or aggressive behaviour) nor by a simple desire to describe the super-operative components of expertise with video games (i.e. serially defining differences between VGPs and NVGPs on various tasks). Rather, knowing that expert VGPs demonstrate superior performance on a series of tasks involving visuospatial perception and attention compared to their non-video game playing contemporaries, the current series of experiments sought to localize these benefits in the processing stream. It has been proposed (Andrews & Murphy, 2006; Castel et al., 2005; Green and Bavelier, 2003) that success at tasks of visuospatial attention by VGPs may be selectively due to different or more efficiently engaged cognitive control mechanisms. Alternately, benefits in tasks of visuospatial attention may be more basic, relying on fundamental changes to the visual system that allow lower level mechanisms to be available during attentionally demanding situations (Green and Bavelier, 2003, 2007). This thesis sought to dissociate these two hypotheses.

In Chapter 2 of this manuscript, we demonstrated that visuospatial superiority effects of VGPs relative to NVGPs were uninfluenced by contextual demands, suggesting that such performance benefits are the result of a durable form of learning at some fundamental level of the perceptual and attentional systems. In brief, we first established that VGPs outperformed NVGPs on a task of visuospatial attention (i.e. visual search), conceptually replicating Castel and colleagues (2005). Subsequently, we compared performance on the visual search task amongst VGPs after playing a dynamic puzzle game or action video game. Genre of video game played had no effect on visual search efficiency, suggesting contextual dependence is of minimal or no importance to the overall success VGPs demonstrate on measures of attention. This finding places a certain degree of doubt on the argument that the visuospatial attentional effects demonstrated by so many other laboratories (e.g. Green and Bavelier, 2003; Greenfield, deWinstanley, Kilpatrick, & Kaye, 1994; Feng et al., 2007) are the result of the engagement of some set of executive control processes, such as those found in the central executive (CE; Andrews and Murphy, 2006; Green and Bavelier, 2003; Castel et al., 2005).

In an effort to more directly address the role executive control processes might play in the benefits displayed by VGPs on tasks of visuospatial attention, in Chapter 3 we examined performance on two task switching paradigms across video game players and non-players. Task switching has been viewed as an integral component of higher cognitive control (Monsell, 2003), making it ideal for our purposes. Importantly, previous work (Andrews and Murphy, 2006; Boot et al., 2008) suggests that VGPs are more capable at switching between tasks. Andrews and Murphy (2006) argue that video game players have more efficient executive control mechanisms as confirmed by improved task switching performance. We demonstrated that VGPs perform more effectively under certain conditions, such as on trials that allow both the extra time and information needed to actively prepare. However, a dramatic increase in response overlap between tasks leads to VGPs responding more quickly on average than NVGPs but demonstrating no benefits in task switching. With respect to likely component processes involved in task switching performance—counter to Andrews and Murphy (2006)—we argue that VGPs demonstrate benefits in effortful selective attention-dependent preparation for upcoming task performance, and not those processes involved with resolving proactive interference arising from consecutive performance of diverse but overlapping tasks.

Using the construct of working memory (WM) as defined by Baddeley and Hitch (1974; Baddeley, 2000), in Chapter 4 of this manuscript we examined both the behavioural and electrophysiological performance of VGPs and NVPGs on a task that taps verbal and spatial working memory and related central executive processes. Using a running memory procedure designed by Watter and colleagues (2010), no behavioural differences were detected between VGPs and NVGPs. Previous work (Watter et al., 2010) has demonstrated clear electrophysiological similarities between conditions where material must be maintained or updated in memory. There was one exception to this pattern of activity, in that subjects seemed to engage in a significant amount of upfront preparatory activity on conditions where spatial stimuli were to be maintained and then updated. NVGPs from our experiment replicated these data exactly. Importantly, in the spatial updating condition, VGPs did not engage in generating an early spatial representation for later use in a trial, rather approaching each stimulus as it was presented in the same manner used in every other task, whether maintaining or updating verbal or spatial information. We argue that this finding corresponds to a superior ability in VGPs to represent visuospatial information in WM.

5.2 Cognitive Control and Video Game Play

Within the literature, it has been argued that VGPs may outperform NVGPs on tasks that tap visuospatial attention due to either differences in higher cognitive control or to more basic development of the perceptual and attentional systems (cf. Andrews and Murphy, 2006; Castel, Pratt, & Drummond, 2005; Green and Bavelier, 2003). In the experiments presented in this thesis, we find little evidence that VGPs have improved and more efficient mechanisms and processes involved in higher cognitive control.

Our first study replicated earlier findings that VGPs are generally faster than NVGPs when performing visual search but provided no evidence for contextual control of that ability. Of more interest are our two following studies. As described in Chapter 3 of this thesis, we performed two experiments, establishing that when both the time and information were available and task-set overlap was low, VGPs demonstrated improved performance over NVGPs and a reduction in task-switching costs (Karle et al., 2010). Interestingly, as proactive interference increased, this benefit disappeared, though VGPs continued to respond more rapidly overall. As such, there was no apparent benefit of expertise with video games on generalizable task switching performance.

The data collected here suggested to us that video game players have a specific advantage in the control of the deployment of selective attention, rather than more global benefits to higher cognitive control (though we modify this statement based on data discussed in Chapter 4—see below). We argued that improvements to control of selective attention could lead to benefits in advance reconfiguration processes of task set representations (Mayr & Kliegl, 2000; Meiran, Chorev, & Sapir, 2000; Rogers & Monsell, 1995) rather than reducing the impact of proactive interference between task set representations (Wylie & Allport, 2000) on task switching costs. Framed in this manner, while VGPs may demonstrate reduced task switching costs relative to NVGPs in some situations, this is likely due to a superior capacity to control the allocation of selective attention and not a more general benefit in the elements of cognitive control that underlie task switching.

Two other studies have assessed the impact of action video game play on task switching ability (Andrews and Murphy, 2006; Boot et al.; 2008). Both studies demonstrated that VGPs showed smaller switching costs than NVGPs in task switching paradigms, arguing that video game play increases task switching efficiency (Andrews and Murphy, 2006; Boot et al.; 2008). Our data fit well with these findings but our conclusions regarding the underlying cognitive effects differed. Both studies used task switching paradigms that involved little interference. Indeed, in the case of Andrews and Murphy (2006), VGPs only demonstrated a benefit to task switching when the task was relatively easy (with congruent and bivalent stimuli or neutral and non-interfering stimuli). This benefit disappeared when the task involved more overlap (i.e. incongruent and bivalent stimuli). Boot el al. (2008) also made use of a bivalent design (e.g. Rogers and Monsell, 1995). However, their task involved less overlap of task set rules than our Experiment 2, involving only parity or magnitude judgments on single digit stimuli cued by background screen colour. The designs of both of these studies involved in principle far less proactive interference than in our Experiment 2. As such, we suggested that VGPs do not enjoy a general benefit in higher cognitive control, but rather have selectively better control over the deployment of selective attention (but see also Andrews and Murphy, 2006 and Clark, Lanphear and Riddick,1987, for an alternate conclusion). This conclusion is modified by findings in Chapter 4.

In our experiment conducted in Chapter 4, we compared the performance of VGPs and NVGPs on a running memory paradigm in order to assess potential differences in cognitive control, this time framed as Working Memory (WM). This task was ideally suited for our purposes as it had previously been demonstrated to allow for the electrophysiological dissociation of central executive (CE) related processes involved in WM encoding and updating, and those involved in the maintenance of information in WM (Kiss et al, 2007; Watter et al., 2010). As a brief reminder, participants were tasked to remember the first (maintenance) or last three (updating) items in a steam of digits, recalling either stimulus identity (verbal condition) or location (spatial condition). In this experiment, behavioural performance between NVGPs and VGPs was equivalent. Both groups demonstrated very similar patterns of electrophysiological activity, diverging only in the most difficult instance, the spatial updating condition. Again replicating Watter et al. (2010), in this condition NVGPs seemed to engage in a distinctly different and effortful kind of initial preparatory behaviour, showing the most activity on the first item presented. In contrast, VGPs showed no ERP evidence of this more effortful WM-related behaviour, instead demonstrating the typical pattern of increasingly demanding processing over serial position seen in every other condition and across groups.

The lack of any behavioural differences, when combined with these ERP findings, suggests that VGPs require a lesser degree of overt cognitive control to mediate demanding spatial WM performance compared to NVGPs. We argue that this reflects a superior capacity to represent visuospatial information in VGPs, and not a superior capacity for cognitive control. This is supported by the following key points from Chapter 4. Firstly, our WM task demonstrated increased ERP amplitudes with greater demands on WM executive control. As load increased, amplitude increased accordingly. These effects are common across VGPs and NVGPs, and replicate two previous studies (Kiss et al., 2007; Watter et al., 2010) showing that these ERP components index WM CE related processes and are larger as more demands are placed on the system. Importantly, we see less use of these processes by VGPs in the highly demanding spatial updating condition, with ERP amplitudes mimicking easy spatial and verbal conditions. Correspondingly, we observe that NVGPs deploy an even more effortful strategy to achieve parity of behavioural performance in the spatial updating condition. As such, to achieve equivalent performance, we would argue that VGPs require *less* control because their underlying representational systems are relatively better developed than NVGPs. If video game players were to demonstrate greater control, we would expect to see that demonstrated in the ERP data, with increased amplitudes in the demanding spatial updating condition.

It would appear that VGPs benefit from a superior ability to represent visuospatial information over their NVGP contemporaries. Such an argument fits well with the extensive and growing body of evidence demonstrating superior visuospatial processing by VGPs over NVGPs (Chisholm, et al., 2010; Feng et al., 2007; Green and Bavelier, 2003, 2006a, 2006b, 2007; West, Stevens, Pun, & Pratt, 2008). This conclusion also accounts for our findings in Chapters 2 and 3. In Chapter 2, we demonstrated only general speeded processing by VGPs over NVGPs in a task of visual search but found no effect of contextual control. Our findings in Chapter 3 go on to support the above conclusion, in that VGPs generally responded more rapidly than NVGPs but when proactive interference increased, task switching benefits became non-significant. Indeed, we modify our conclusions from Chapter 3 that VGPs have a benefit in the control of the deployment of selective attention. Rather, there appears to be little evidence that VGPs have superior control over higher cognitive mechanisms and processes, but rather seem more capable of representing visuospatial information which accounts for many of the benefits in attentional and perceptual processing seen in the extant literature.

5.2.1 Caveats

It should be noted that the results presented in this thesis are entirely based on correlational methodology. We cannot definitively say that playing video games leads to a change in the manner in which visual information is represented. It would be necessary to run a training study in the vein of Bavelier and colleagues (Green and Bavelier 2003, 2006a, 2006b, 2007; Li, Polat, Makous, & Bavelier, 2009; Li, Polat, Scalzo, & Bavelier, 2010), in which NVGPs engage in video game play over some number of hours. In these studies, various video games are employed to control for motivation and arousal and for Hawthorne-like effects. Performance is compared across groups to assess the capacity of a particular genre to change cognitive and motor function. The failure to include a training component in a study leaves some ambiguity in the interpretation of acquired data. It could be that video games influence performance on the empirical task used in the study. Alternately, video games may require a particular set of skills that allow for successful performance. Those with these skills experience considerable positive feedback because they are capable of meeting the challenges of the video game. Those who lack these skills experience little reinforcement and eventually cease playing. In effect, the two populations—VGPs and NVGPs— become selected by preexisting skill rather than the inherent ability of the games to influence or train cognitive and motor abilities. This latter possibility could in part explain findings in the extant literature. It has yet to be established what proportion of video game based effects are due to training and what may be due to pre-existing abilities and skill-sets.

Of course, the lack of a training component does not invalidate our results. Firstly, video games have been broadly shown to causally influence performance (Green and Bavelier 2003, 2006a, 2006b, 2007; Feng, Spence, & Pratt; 2007; Li, Polat, Makous, & Bavelier, 2009; Li, Polat, Scalzo, & Bavelier, 2010). This fact provides us with some confidence that our effects are driven by engaging in the activity of video game play rather than entirely due to differences between self-selected populations. Secondly, while in some instances it is important to demonstrate causality, it is not always necessary to obtain meaningful data. Simply knowing that VGPs demonstrate differential patterns of behaviour can be important in a variety of settings. For example, Blumberg and colleagues (2008) demonstrated that children who play video games engage in differential problem-solving strategies. Having such information can lead to important applications in educational settings in terms of lesson plans, teaching, and support policies. Future research can establish the directionality of our findings.

It should also be pointed out that we are interpreting changes in electrophysiological activity as indicative of more or less effortful processing. Some might argue that larger amplitudes of ERP correlates do not necessarily equate to increased processing. We are fairly confident with our interpretation because our task is designed specifically to test effortfulness of processing. The load sensitivity demonstrated throughout our experiment correlates with behavioural activity, with increased amplitudes co-occurring with more demanding CE-related WM processing conditions, in turn reflected by slower reaction times and increased error rates. This pattern of activity replicates earlier work (Kiss et al., 2007; Watter et al., 2010) and so provides us with some confidence that ERP amplitude in our task correlates with difficulty or effortfulness of processing.

Lastly, an analysis of Figure 4.2 shows that VGPs demonstrate generally worse performance in the verbal task when compared to NVGPs. This was not statistically significant but rather a trend in the data. It is possible that with more subjects this trend would become significant. If this were true, such an effect could not be explained with reference to a criterion shift, where accuracy was sacrificed by VGPs in favour of speed. It is possible that action VGPs are slightly worse than NVGPs at tasks that tap verbal attention. The video games VGPs demonstrate expertise with seem to place significant demands on visuospatial processing rather than verbal processing and language skills. While we have shown that the visuospatial attentional superiority effects in VGPs do not seem to be the result of high level cognitive control, it remains unclear as to what lower level components are differentially improved. It remains to be established whether VGPs have stronger visual representations of stimuli or better and more efficient control over the basic processes and mechanisms of visuospatial attention. Though we tentatively ascribed to the view that VGPs have better spatial representations of visually presented information, we are unable to dissociate between these two interpretations with our current data.

5.3 The Question of Application

Video games offer a series of diverse and important opportunities for researchers and other professionals. An examination of the literature supplies three primary themes. These include:

i. The empirical evaluation of the influence that experience with video games has on behavior and physiology.
ii. Their use as vehicles through which experimental manipulations are instantiated.
iii. The application of theoretical knowledge to a broad variety of practical issues and mandates.

Each theme develops a unique facet regarding the value of video games, demonstrating that counter to popular belief, research into the effects of video game experience and the application of this theoretical knowledge is neither frivolous nor fruitless. A description of each theme follows.

First, the data and literature reviewed in this dissertation have amply demonstrated the significant value of empirical research on the impact of video games on a variety of cognitive and motor functions, as well as general learning strategies and socio-emotional behaviours. Research into the effects of off-the-shelf (OTS) video games extends as far back as the late 1970s, with the first studies comparing video game play and behavior (e.g. Scheibe and Erwin, 1979) being conducted in this period. Such research has continued, with periods of elevated publication occurring in the mid-1980s, the mid-1990s and the new millennium. An examination of this literature reveals that topics of study are broadly distributed and shallowly developed; this pattern suggests that there is much to be gained through continued analysis of the effect video game play has on behavior and physiological functioning.

A second, and perhaps less obvious, theme is the concept that video games themselves have the capacity to be useful tools for pursuing empirical research. Video games can serve as the platforms through which data is collected and performance evaluated (for a review, see Washburn, 2003). Common empirical laboratory tasks are by necessity highly impoverished environments, designed to produce maximal control over nuisance and target variables. Such control comes at the cost of ecological validity; a frequently voiced concern is that the results gathered from laboratory contexts provide limited information towards the explanation and prediction of behavior in real-world situations. These antithetical views can be illustrated with reference to research performed on higher cognitive reasoning and problem-solving. Gilovich (1991) has postulated that humans are very poor at reasoning, being quickly misdirected by irrelevant information. Counter to this perspective, it has been suggested (Gigerenzer and Goldstein, 1996) that humans are well equipped to address daily situations. The use of carefully learned and developed schemata and scripts serve to free up processing resources that would otherwise be allocated to simple analysis and reasoning tasks, thus endowing individuals with the additional capacity to deal with unexpected stimuli and situations. However, when participants are placed in seemingly arbitrary and unfamiliar laboratory situations, it can be quickly demonstrated how easily human reasoning skills can fail. And yet, such contrived contexts are rarely faced by individuals on a daily basis, arguing against the generalizability of such results. While it would seem ideal to perform studies directly in day-to-day contexts in answer to these issues, such approaches have their own weakness. Most notably, extra-laboratory experiments are significantly less controlled, making it difficult to articulate what processes and mechanisms are responsible for any observed behavioural change.

Video games may provide an important middle ground. On the one hand, modern video games provide rich, high fidelity environments, satisfying the desire for more life-like settings from which to gather behavioural data. On the other, accurate assessment of stimulus onset and response provision is achievable through the manipulation of game software, providing a measure of control not usually obtainable in applied settings. Video games are also easily data-mined, capable of supplying information on experimental variables in a variety of formats. Indeed, Blumberg and colleagues (2008) argue that their results demonstrate the viability of using off-the-shelf video games as a method of examining problem-solving skills within the frame-work of an ecologically valid task. Importantly, OTS video games and the platforms with the graphical power necessary to run them are generally inexpensive, providing researchers with ready access to such equipment. Furthermore, OTS video games provide a common research platform across laboratories, easing the comparability of data between varying projects and disciplines (Washburn, 2003). This author and colleagues have commenced work on a video game designed to test visual search in realistic and dynamic situations. This process has supported the positive statements mentioned above but has also highlighted a series of difficulties that will be faced by researchers choosing to employ video games as empirical tools. Most notable is the fact that the majority of psychological empiricists have limited or no knowledge of the often proprietary source code associated with a particular video game to sufficiently modify it to suit their empirical purposes. One natural solution to this difficulty is multidisciplinary research programs, integrating psychology and computing and software programming teams. However, Washburn (2003) points out that this is a significant investment by comparison to standard pencil and paper or computer-based empirical tasks. Further, the ecological validity of video games can come at some cost of control over such factors as motivation, psychomotor issues, and vigilance, making it difficult to make clear comments about the basic processes underlying behaviour (Washburn, 2003). Like any research tool, it is clear that video games have their strengths and weaknesses making it necessary as always to assess the efficacy of a tool for a particular task or problem.

Current research would suggest that there are both costs and benefits associated with playing video games. The majority of research into the cognitive consequences suggests that mainly benefits are to be had and that these positive effects are not, for the most part, contingent on gender (although in some instances, such as spatial processing, women may benefit more than men from training on action video games; Feng et al, 2007). These facts combined with the apparent ability to train such benefits for NVGPs present the third theme: the application of theoretical findings to issues faced by a variety of populations.

Video games may be broadly valuable as applied instruments, being useful for assessment and prediction of skill performance, aiding in normal cognitive development, remediating cognitive and physiological age-related decline, as training regimen to improve cognitive and motor skills beyond standard capabilities, in refining educational curricula, as corrective platforms for developmental disabilities, and for general health and well-being programs. Such activities are predicated by an expanding body of evidence, several of which are described below.

Jones, Kennedy, Bittner, and their colleagues (Jones, Kennedy, & Bittner, 1981; Kennedy, Bittner, & Jones, 1981; Kennedy, Bittner, Harbeson, & Jones, 1982; Lintern & Kennedy, 1984) completed a series of studies interested in establishing the validity of using video games as platforms from which to assess and predict subsequent performance. The initial focus was to develop a test battery that would examine performance in unusual environments over prolonged periods and be capable of rapid stabilization (elimination of practice effects). An action video game was not only demonstrated to have the same qualities as a traditional test of compensatory tracking (Kennedy, Bittner, & Jones, 1981) but also to be superior to 9 out of 10 tests in terms of obtaining stability (Jones Kennedy, & Bittner, 1981). It was later demonstrated that the same game correlated well with glide-slope tracking, making it a potentially useful covariate for research into aircraft carrier landing training (Lintern & Kennedy, 1984). Importantly, Jones and colleagues (1981) point out that not only is the equipment necessary for the use of video games inexpensive, easily replaced, and portable but that the tasks themselves are engaging, thereby improving participant involvement and performance. In terms of increasing experimental power, ameliorating practical issues of testing outside a laboratory, as well as encouraging patient/trainee compliance to treatment/training regimen, these are highly desirable assets.

Age-related decline in motor and cognitive functioning has been broadly demonstrated. When compared to younger persons, individuals in late adulthood exhibit poorer performance in recent memory, abstract and complex conceptualization, and mental flexibility (Lezak, 1983) and response selection (Salthouse and Somberg, 1982). The decline model of aging has received additional support from findings such as reduced speed of performance, including but not limited to decreased functioning in tasks of simple discrete movements (Hodgkins, 1962), sequential choice reaction time (Griew, 1964), and simple repetitive movements (Singleton, 1955). Compounding these negative age-related changes is the fact the over the next two decades in North America 77 million people will turn 60 years of age, of which a significant number will live well into their 80s (George, 2007). Resultantly, a larger proportion of our population than ever before will be faced with the challenges that come from the effects of neurological and physiological aging, making medical, social, and behavioral intervention programs increasingly pertinent.

As a form of tertiary prevention—programs aimed at mitigating the effects of an already established disease or loss of function—video games may prove surprisingly effective. From an information processing perspective, Clark, Lanphear and Riddick (1987) sought to evaluate the capacity of video games to moderate decrements in performance of late adults (57 – 83 years) on a task designed to assess response selection. Using a spatial stimulus-response compatibility task, it was demonstrated that late adults who practiced on a video game for at least 2 hours a week for 7 weeks significantly reduced response latencies between pre- and post-test when compared against a non-video game playing control group. Clark and colleagues (1987) argue their findings can be explained by differential strategy employment. The game playing experimental group may have employed the strategy of installing the bivalent response choices into a short-term memory buffer, thereby improving speed of response selection. It is important to note that the control group in the Clark et al. (1987) study was not engaged in an appropriate control task to mitigate Hawthorne-like effects for motivation and arousal, leaving the findings open to some interpretation.

Dustman and colleagues (Dustman, Emmerson, Steinhaus, Shearer, and Dustman, 1992) tested late adults on a broad set of tests of neuropsychological performance, including reaction time, visual sensitivity, various components of cognition, and affect. Participants were assigned to one of three groups, video game practice, movie viewing, or a control. The only significant group effect involved video game practice, with this group outperform the other two from pre-test to post-test on reaction time (see also Goldstein, Cajko, Oosterbroek, Michielsen, Van Houten, & Salverda, 1997 for similar reaction time results in late adults playing video games).

This finding is similar to Clark and colleagues (Clark et al., 1987) but is perhaps most interesting when considered in light of two other studies. After a 4-month program of aerobic fitness, previously sedentary late adults demonstrated improvements in physical endurance, critical flicker fusion threshold, and simple reaction time (Dustman et al., 1984). These results were interpreted in terms of an improvement to central nervous function through facilitation of system-wide oxygenation. This effect is of some novelty as aerobic activity and mental function are often ignored. More traditionally, common knowledge ascribes to the view that board games, crossword puzzles, and other games that are mentally challenging can be engaged to instantiate neuropsychological benefits. It is of some surprise that work by Hambrick, Salthouse, and Meinz (1999) has found no evidence that age-related effects in fluid and crystallized cognition can be moderated through experience with crossword puzzles. Considering these findings and those of Clark and colleagues (1987) and Dustman and colleagues (1984, 1992), it would appear that experience with video games is neither unique nor ideal for remediation of some or all aspects of age-related decline. However, they may be more effective than some traditional methods of intervention and particularly useful to particular populations, especially those aged individuals suffering from disabilities that prevent aerobic activity, enforcing a sedentary life-style. Two things can be said for certain. First, strong evidence suggests video games can be selectively useful tools in tertiary prevention of cognitive and motor decline brought about by aging. Second, further research is needed to both identify those populations of late adults that will benefit most (or at all) from video game interventions and longitudinal programs should be set in motion to determine the efficacy of video games as instruments of primary prevention.

Video game may be have a relatively more effective capacity to develop various elements of cognitive and motor function when compared against other methods of development. As was already mentioned in this thesis, Trick and colleagues (2005) showed that those who play action video games have demonstrably improved capabilities when simultaneously tracking positions of target-items embedded in fields of distractors. A marginal effect was found for those who engage in action oriented sports (e.g. hockey, football). Not only does this finding suggests that even developing populations can benefit from experience with action video games but that video games make be uniquely endowed to develop cognition beyond other methods. Alternately, it is possibly an issue of transfer of appropriate processing, as the training and testing scenarios for VGPs were nearly identical, whereas these differed considerably for the sports training environments. However, a study recently completed on 11,000 British citizens found that while practicing such brain-training programs as Lumosity™ and Brain Age® does lead to improvements in cognitive processing, these benefits do not transfer out of the training environments (Owen, Hampshire, Grahn, Stenton, Dajani, et al., 2010). This combined with the finding by Trick and colleagues (2005) suggests that video games may be uniquely positioned to improve cognitive function across various age groups. It is not being argued that to develop cognition abilities it is a necessary and sufficient condition that one play video games. Rather, video games may be an optimal method of training specific cognitive abilities, especially those related to visuospatial attentional processing.

5.4 Conclusions

In Chapter 2, we demonstrated that VGPs did not show contextual control of performance during a visual search task. We followed this by demonstrating that in task switching paradigms, VGPs did not show a general task switching benefit, but only a specific benefit in reducing task switch costs when selective attention could provide informative cuing information under low interference conditions. Finally, in a WM paradigm, VGPs showed distinctively smaller degrees of CE-related ERP activity in demanding visuospatial WM conditions relative to NVGPs, while maintaining equivalent behavioural performance. These findings, when taken together suggest that the observed performance benefits for VGPs in visuospatial tasks is likely not due to improved cognitive control ability, but is most probably the result of a superior representational ability for visuospatial information.

Video games have the possibility to be used in a wide variety of contexts, as things to be studied, as empirical tools, and as applied interventions. Multiple populations may be able to benefit from experience with video games, including aging populations, military personnel, developing populations, corporations and even normative populations looking to improve various cognitive and motor skills beyond the average. There is clearly a wide variety of benefits gained from, or correlated with, experience with video games. Taken in a context of cautious regard for the possible socioemotional and physiological costs, it seems time to lay to rest the polemic that has raged for 3 decades over whether or not game play is a ‘mindless’ activity.

References

Andrews, G. & Murphy, K. (2006). Does video-game playing improve executive function? In M. A. Vanchevsky (Ed.) *Frontiers in Cognitive Sciences* (pp. 145-161). New York. Nova Science Publishers Inc.

Anderson, C. A., & Bushman, B. J. (2001). Effects of violent video games on aggressive behavior, aggressive cognition, aggressive affect, physiological arousal, and prosocial behavior: A meta-analytic review of the scientific literature. *Psychological Science, 12*, 353-359.

Arbothnott, K. D. (2005). The influence of cue type on backward inhibition. *Journal of Experimental Psychology: Learning, Memory and Cognition, 31*, 1030-1042.

Arbuthnott, K. & Frank, J. (2000) Executive control in set switching: Residual switch cost and task-set inhibition. *Canadian Journal of Experimental Psychology, 54*, 33-41.

Arbuthnott, K. D. & Woodward, T. S. (2002). The influence of cue-task association and location on switch cost and alternating-switch cost. *Canadian Journal of Experimental Psychology*, *56*, 18-29.

Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4*, 417-423.

Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. A. Bower (Ed), *The Psychology of Learning and Motivation: Advances in Research and Theory* (vol. 8). New York: Academic Press.

Bartholow, B. D., Bushman, B. J., & Sestir, M. A. (2006). Chronic violent video game exposure and desensitisation to violence: Behavioral and event-related brain potential data. *Journal of Experimental Social Psychology, 42*, 532-539.

Blumberg, F. C. (1998). Developmental differences at play: Children's selective attention and performance in video games. *Journal of Applied Developmental Psychology, 19*, 615-624.

Blumberg, F. C. (2000). The effects of children's goals for learning on video game performance. J*ournal of Applied Developmental Psychology, 21*, 641-653.

Blumberg, F. C., Rosenthal, S. F., & Randall, J. D. (2008). Impasse-driven learning in the context of video games. *Computers in Human Behavior, 24*, 1530-1541.

Blumberg, F. C. & Sokol, L. M. (2004). Boys' and girls' use of cognitive strategy when learning to play video games. *The Journal of General Psychology, 131*, 151-158.

Boot, W. R., Kramer, A. F., Simons, D. J., Fabiani, M., & Gratton, G. (2008). The effects of video game playing on attention, memory, and executive control. *Acta Psychologica, 129,*387-398.

Bradburn, N. M., Rips, L. J., & Shevell, S. K. (1987). Answering autobiographical questions: The impact of memory and inference on surveys. *Science, 236*, 157-161.

Brady, T. F., & Chun, M. M. (2007). Spatial constraints on learning in visual search: Modeling contextual cuing. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 798-815.

Buchman, D. D., & Funk. J. B. (1996). Video and computer games in the '90s: Children's time commitment and game preference. *Children Today, 24*, 12-16.

Capaldi, D. M. (1996). The reliability of retrospective report for timing first sexual intercourse for adolescent males. Journal of Adolescent Research, 11, 375-387.

Castel, A. D., Pratt, J., & Drummond, E. (2005). The effects of action video game experience on the time course of inhibition of return and the efficiency of visual search. *Acta Psychologica, 119,* 217-230.

Chisholm, J. D., Hickey, C., Theeuwes, J., & Kingstone, A. (2010). Reduced attentional capture in action video game players. *Attention, Perception, & Psychophysics, 72*, 667-671.

Chun, M. M., & Jiang, Y. (1998). Contextual-cueing: Implicit learning and memory of visual context guides spatial attention. *Cognitive Psychology, 36*, 28-71.

Clark, J. E., Lanphear, A. K. & Riddick, C. C. (1987). The effects of videogame playing on the response selection processing of elderly adults. *Journal of Gerontology, 42,* 82-85.

Corbetta, M., & Shulman, G.L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience, 3,* 201-215.

D'Esposito, M., Aguirre, G. K., Zarahn, E., Ballard, D., Shin, R. K., & Lease, J. (1998). Functional MRI studies of spatial and nonspatial working memory. *Cognitive Brain Research, 7,* 1-13.

Di Lollo, V., Arnett, J. L., & Kruk, R. V. (1982). Age-related changes in rate of visual information processing. *Journal of Experimental Psychology: Human Perception and Performance, 8*, 225-237.

Dill, K. E., & Dill, J. C. (1998). Video game violence: A review of the empirical literature. *Aggression and Violent Behavior, 3*, 407-428.

Dobbs, A. R., & Rule, B. G. (1989). Adult age differences in working memory. *Psychology and Aging, 4*, 500-503.

Donald, M. C., Bransford, J. D., & Franks, J. J. (1977). Levels of processing versus transfer appropriate processing. *Journal of Verbal Learning & Verbal Behavior, 16,* 519-533.

Dorval, M., & Pepin, M. (1986). Effect of playing a video game on a measure of spatial visualization. *Perceptual & Motor Skills, 62*, 159-162.

Drew, B., & Waters, J. (1986). Video games: Utilization of a novel strategy to improve perceptual motor skills and cognition functioning in the non-institutionalized elderly. *The journal of cognitive rehabilitation, 4*, 26-31.

Durkin, K., & Barber, B. (2002). Not so doomed: Computer game play and positive adolescent development. *Developmental Psychology, 23*, 373-392.

Dustman, R. E., Emmerson, R. Y., Steinhaus, L. A., Shearer, D. E., & Dustman, T. J. (1992). The effects of videogame playing on neuropsychological performance of elderly individuals. *Journal of Gerontology, 47*, 168-171.

Dustman, R. E., Ruhling, R. O., Russell, E. M., Shearer, D. E., Bonekat, H. W., Shigeoka, J. W., Wood, J. S., & Bradford, D. C. (1984). Aerobic exercise training and improved neuropsychological function of older individuals. Neurobiology of Aging, 5, 35-42.

Egli, E. A., & Meyers, L. S. (1984). The role of video-game playing in adolescent life: Is there a reason to be concerned? *Bulletin of the Psychonomic Society, 22,* 309–312.

Entertainment Software Association (2009). *2009 Essential Facts About the Computer and Video Game Industry.* Retrieved from http://www.theesa.com/

Fabiani, M., Buckley, J., Gratton, G, Coles, M. H., Donchin, E., & Logie, R. (1989). The training of complex task performance. *Acta Psychologica, 71,* 259-299.

Feng, J., Spence, I., & Pratt, J. (2007). Playing an action video game reduces gender differences in spatial cognition. *Psychological Science, 18,* 850-855.

Ferguson, C. J. (2007). The good, the bad, and the ugly: A meta-analytic review of positive and negative effects of violent video games. Psychiatric Quarterly, 78, 309-316.

Ferguson, C. J., Cruz, A. M., & Rueda, S. M. (2008). Gender, video game playing habits, and visual memory tasks. *Sex Roles*, *58*, 279-286.

Fournier-Vicente, S., Larigauderie, P., & Gaonac'h, D. (2008). More dissociations and interactions within central executive functioning: A comprehensive latent-variable analysis. *Acta Psychologica*, *129*, 32-48.

Friedman, N. P., Miyake, A., Corley, R. P., Young, S. E., DeFries, J. C., & Hewitt, J. K. (2006). Not all executive functions are related to intelligence. *Psychological Science, 17*, 172–179.

George, L. (2007, April). The secret to not losing your marbles. *MacLean's, 120*, 36-39.

Gilovich, T. (1991). *How we know what isn't so: The fallibility of human reason in everyday life*. New York: The Free Press.

Gigerenzer, G., & Goldstein, D. G. (1996). Reasoning the fast and frugal way: Models of bounded rationality. *Psychological Review*, *103*, 650-669.

Godden. D. R., & Baddeley, A. D. (1975). Context-dependent memory in two natural environments: On land and underwater. *British Journal of Psychology, 66*, 325-331.

Goldstein, J. H., Cajko, L., Oosterbroek, M., Michielsen, M., Van Houten, O., & Salverda, F. (1997). Video games and the elderly. *Social Behavior and Personality, 25*, 345-352.

Gopher, D., Weil, M., & Bareket, T. (1994). Transfer of skill from a computer game trainer to flight. *Human Factors, 36,* 387-405.

Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature, 423*, 534-537.

Green, C. S., & Bavelier, D. (2006a). Enumeration versus multiple object tracking: The case of action video game players. *Cognition, 101*, 217-245.

Green, C. S., & Bavelier, D. (2006b). Effect of action video games on the spatial distribution of visuospatial attention. *Journal of Experimental Psychology: Human Perception and Performance, 32,* 1465-1478.

Green, C.S. & Bavelier, D. (2006c). "The Cognitive Neuroscience of Video Games" in *Digital Media: Transformations in Human Communication*. Messaris, P. & Humphreys, L. (eds). New York, Peter Lang.

Green, C. S., & Bavelier, D. (2007). Action-video-game experience alters the spatial resolution of vision. *Psychological Science, 18,* 88-94.

Greenfield, P. M., Brannon, C., & Lohr, D. (1994). Two-dimensional representation of movement through three-dimensional space. *Journal of Applied Developmental Psychology, 15,* 87-103.

Greenfield, P. M., deWinstanley, P., Kilpatrick, H., & Kaye, D. (1994). Action video games and informal education: Effects on strategies for dividing visual attention. Journal of Applied Developmental Psychology, 15, 105-123.

Griew, S. (1964). Age, information transmission and the positional response in the performance of a choice task. *Ergonomics, 7*, 267-277.

Griffiths, M. (1999). Violent video games and aggression: A review of the literature. *Aggression and Violent Behaviour, 4*, 203-212.

Griffith, J. L., Voloschin, P., Gibb, G. D., & Bailey, J. R. (1983). Differences in eye-hand motor coordination of video-game users and non-users. Perceptual & Motor Skills, 57, 155-158.

Gruber, O., & Von Cramon, D. (2003). The functional neuroanatomy of human working memory revisited: Evidence from 3-T fMRI studies using classical domain-specific interference tasks. *NeuroImage, 19*, 797-809.

Hambrick, D. Z., Salthouse, T. A., & Meinz, E. J. (1999). Predictors of crossword puzzle proficiency and moderators of age-cognition relations. *Journal of Experimental Psychology: General, 128*, 131-164.

Hertzog, C. K., Williams, M. V., & Walsh, D. A. (1976). The effect of practice on age differences in central perceptual processing. *Journal of Gerontology, 31*, 428-433.

Hodgkins, J. (1962). Influence of age on the speed of reaction and movement in females. *Journal of Gerontology, 21*, 210-277.

Jansz, J., & Tanis, M. (2007). Appeal of playing online first person shooter games. *CyberPsychology & Behavior, 10*, 133-136.

Jones, M. B., Kennedy, R. S., & Bittner, A. C. (1981). A video game for performance testing. *American Journal of Psychology, 94*, 143-152.

Kalyuga, S., Chandler, P., & Sweller, J. (2001). Learner experience and efficiency of instructional guidance. *Educational Psychology, 21,* 5-23.

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. Psychonomic Bulletin & Review, 9, 637-671.

Karle, J. W., Watter, S., Kiss, I., & Shedden, J. M. (submitted; Acta Psychological). ERP Evidence For Selective Spatial Working Memory Benefits In Expert Video Game Players.

Karle, J. W., Watter, S., & Shedden, J. M. (2010). Task Switching in Video Game Players: Benefits of Selective Attention But Not Resistance to Proactive Interference. *Acta Psychologica, 134,* 70-78.

Kennedy, R. S., Bittner, A. C., Harbeson, M. M., & Jones, M. B. (1982). Television computer games: A “new look” in performance testing. *Aviation, Space, & Environmental Medicine, 53,* 49-53.

Kennedy, R. S., Bittner, A. C., & Jones, M. B. (1981). Video-game and conventional tracking. *Perceptual & Motor Skills, 53,* 310.

Kiss, I., Pisio, C., Francois, A., & Schopflocher, D. (1998). Central executive function in working memory: An event-related potential study. Cognitive *Brain Research, 6,* 235-247.

Kiss, I., Pazderka-Robinson, H., & Floden, D. (2001). Event-related brain potentials and central executive function. Journal of Psychophysiology, 15, 1-13.

Kiss, I., Watter, S., Heisz, J. J., & Shedden, J. M. (2007). Control processes in verbal working memory: An event-related potential study. Brain Research, 1172, 67-81.

Kline, D. W., & Szafran, J. (1975). Age differences in backward monoptic visual noise masking. *Journal of Gerontology, 30*, 307-311.

Koepp, M. J., Gunn, R. N., Lawrence, A. D., Cunningham, V. J., Dagher, A., et al. (1998). Evidence for striatal dopamine release during a video game. *Nature*, *393*, 266-268.

Kunar, M. A., Flusberg, S., Horowitz, T. S., & Wolfe, J. M. (2007). Does contextual cuing guide the deployment of attention? *Journal of Experimental Psychology: Human Perception and Performance, 33*, 816-828.

Lezak, M. D. (1983). *Neuropsychological assessment* (2nd ed.). New York: Oxford University Press.

Li, R., Polat, U., Scalzo, F., & Bavelier, D. (2010). Reducing backward masking through action game training. *Journal of Vision, 10*, 1-13.

Lintern, G. & Kennedy, R. S. (1984). Video game as a covariate for carrier landing research. *Perceptual and Motor Skills, 58*, 167-172

Lucas, K., & Sherry, J. L. (2004). Sex differences in video game play: A communication-based explanation. *Communication Research, 31*, 499-523.

Luck, S. J. (2005). *An introduction to the event-related potential technique.* Cambridge, MA: MIT Press.

Mathiak, K., & Weber, R. (2006). Toward brain correlates of natural behavior: fMRI during violent video games. *Human Brain Mapping, 27*, 948 –956.

Mayr, U. & Keele, S. W. (2000). Changing internal constraints on action: The role of backward inhibition. *Journal of Experimental Psychology: General, 129*, 4-26.

Mayr, U., & Kliegl, R. (2000). Task-set switching and long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*, 1124-1140.

McCarney, R., Warner, J., Illife, S., van Haselen, R., Griffin, M., & Fisher, P. (2007). The Hawthorne effect: A randomized, controlled trial. *BMC Medical Research Methodology, 7*, 1-8.

McClure, R. F., & Mears, F. G. (1984). Video game players: Personality characteristics and demographic variables. *Psychological Reports, 55,* 271-276.

McClurg, P. A., & Chaillé, C. (1987). Computer games: Environments for developing spatial cognition. *Journal of Educational Computing Research, 3,* 95-111.

Meiran, N., Chorev, Z., & Sapir, A. (2000). Component processes in task switching. *Cognitive Psychology, 41*, 2211-2253.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*, 49-100.

Morris, N., & Jones, D. M. (1990). Memory updating in working memory: The role of the central executive. *British Journal of Psychology, 81*, 111-121.

Narayan, N., Prabhakaran, V., Bunge, S., Christoff, K., Fine, E., & Gabrielli, J. (2005). The role of the prefrontal cortex in the maintenance of verbal working memory: An event-related fMRI analysis. *Neuropsychology, 19*, 223-232.

Okagaki, L., & Frensch, P. A. (1994). Effects of video game playing on measures of spatial performance: Gender effects in late adolescence. *Journal of Applied Developmental Psychology, 15,* 33-58.

Orosy-Fildes, C. & Allan, R. W. (1989). Psychology of computer use: XII. Video game play: Human reaction time to visual stimuli. *Perceptual and Motor Skills*, *69*, 243-247.

Orvis, K. A., Horn, D. B., & Belanich, J. (2006). Video game-based training success: The impact of trainee characteristics – Year 2 (*Technical Report, No. 1188*). Arlington, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Orvis, K. A., Orvis, K. L., Belanich, J., & Mullin, L. N. (2005). The Influence of Trainee Gaming Experience and Computer Self-Efficacy on Learner Outcomes of Video game-Based Learning Environments (*Technical Report*, *No. 1164*). Arlington, VA: U.S. Army Research Institute for the Behavioural and Social Sciences.

Orvis, K. A., Orvis, K. L., Belanich, J., & Mullin, L. N. (2007). The influence of trainee gaming experience on affective and motivational learner outcomes of video game-based training environments. In H. F. O'Neil & R. S. Perez (Eds.), *Computer games and team and individual learning* (pp. 125-144) Oxford, UK: Elsevier Ltd.

Owen, A. M., Hampshire, A, Grahn, J. A., Stenton, R., Dajani, S. Burns, A., et al. (2010). Putting brain training to the test. *Nature, 465*, 775-77.

Paik, H. (2001). The history of children's use of electronic media. In D. G. Singeer & J. L. Singer (Eds.), *Handbook of Children and the Media* (pp. 7-27). Thousand Oaks, California: Sage Publications, Inc.

Pillay, H. (2002). An investigation of cognitive processes engaged in by recreational computer game players: Implications for skills of the future. *Journal of Research on Computing in Education, 34*, 336-350,

Przybylski, A. K., Rigby, C. S., & Ryan, R. M. (2010). A motivational model of video game engagement. *Review of General Psychology, 14*, 154-166.

Quaiser-Pohl, C., Geiser, C. & Lehmann, W. (2006). The relationship between computer-game preference, gender, and mental-rotation ability. *Personality and Individual Differences, 40*, 609-619.

Rausei, V., Makovski, T., & Jiang, Y. V. (2007). Attention dependency in implicit learning of repeated search context. *The Quarterly Journal of Experimental Psychology, 60*, 1321-1328.

Raye, C. L., Johnson, M. K., Mitchell, K. J., Greene, E. J., & Johnson, M.R. (2007). Refreshing: A minimal executive function. *Cortex, 43,* 135-145.

Riddick, C. C., Drogin, E. B., & Spector, S. G. (1987). The impact of videogame play on the emotional states of senior center participants. *The Gerontologist, 27*, 425-427.

Rogers, R., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124,* 207-231.

Salthouse, T. A., & Somberg, B. L. (1982). Isolating the age deficit in speeded performance. *Journal of Gerontology, 37*, 59-63.

Scheibe, K. E., & Erwin, M. (1979). The computer as alter. *Journal of Social Psychology, 108,* 103-109.

Schueren, B. (1986). Video games: An exploration of their potential as recreational activity programs in nursing homes. *Activities, Adaptation, & Aging. Special Issue: Computer Technology and the Aged: Implications and Applications for Activity Programs, 8*, 49-58.

Shaddy, D. J., & Colombo, J. (2004). Developmental changes in infant attention to dynamic and static stimuli. *Infancy, 5*, 355-365.

Sims, V. K., & Mayer, R. E. (2002). Domain specificity of spatial expertise: The case of video game players. *Applied Cognitive Psychology, 16*, 97-115.

Singleton, W. T. (1955). Age and performance timing on simple skills. In *Old Age in the Modern World: Rep. 3rd Congress of the International Association of Gerontology* (pp.221-231). London, England: Livingstone.

Spence, I., Yu, J. J., Feng, J., & Marshman, J. (2009). Women match men when learning a spatial skill. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35,* 1097-1103.

Subrahmanyam, K., & Greenfield, P. M. (1994). Effect of video game practice on spatial skills in girls and boys. *Journal of Applied Developmental Psychology, 15*, 13-32.

Subrahmanyam. K., Kraut, R., Greenfield, P., & Gross, E. (2001). New forms of electronic media. In D. G. Singer & J. L. Singer (Eds.), *Handbook of Children and the Media* (pp. 73-99). Thousand Oaks, California: Sage Publications, Inc.

Trick, L. M., Jaspers-Fayer, F., & Sethi, N. (2005). Multiple-object tracking in children: The "Catch the Spies" task. *Cognitive Development, 20*, 373–387.

Watter, S., Heisz, J. J., Karle, J. W., Shedden, J. M., & Kiss, I. (2010). Modality-specific control processes in verbal versus spatial working memory. *Brain Research, 1347*, 90-103

Walsh, D. A. (1976). Age differences in central perceptual processing: A dichoptic backward masking investigation. *Journal of Gerontology*, *31*, 178-185.

Welch, A. J., & Watt, J. H. Jr. (1982). Visual complexity and young children's learning from television. *Human Communication Research, 8,* 133-145

West, G. L., Stevens, S. A., Pun, C., & Pratt, J. (2008). Visuospatial experience modulates attentional capture: Evidence from action video game players. *Journal of Vision*, *8*, 1-9.

Wiegman, O., & van Schie, E. G. M. (1998). Video game playing and its relations with aggressive and prosocial behavior. *British Journal of Social Psychology, 37*, 367-378.

Wylie, G., & Allport, A. (2000). Task switching and the measurement of "switch costs." *Psychological Research, 63,* 2212-2233.

Appendix A

Game Play History

Surname:______________________________________

Given Name:___________________________________

Middle Initial(s):_____________________

For Experimenter Use Only:
Experiment: ____________
Subject #: ____________

Age:________

Gender:_______

Handedness:________

1. Approximately, how many hours a week do you play video games? If zero, have you played video games in the past 6 months?

2. How many years have you played video games?

3. During your peak-play period (period of play with the most hours per week), how many hours a week did you play video games?

4. How long (in months or years) did your peak-play period last and roughly when was it (provide a date: month/year)?

5. Do you play video games socially (i.e. with others)?

Yes ____ No ____

A. If yes, in what types of venues do you play video games with others (e.g. over the internet, arcades, LAN parties, multiple players on same platform, etc.)?

B. Please indicate if you play cooperatively, competitively, and/or team competitively?

C. Do you play with close friends, online-only friends or anonymously?

6. Which of the following game genres do you play (you may select more than one)?	5. Please number the genres to indicate which games you play most often, with 1 standing for most frequently played. You can use the

	same value more than once to denote game types played with equal frequency.
First Person Shooters ________	First Person Shooters ________
Action Adventures ________	Action Adventures ________
Turn-Based Strategy ________	Turn-Based Strategy ________
Massively Multiplayer ________	Massively Multiplayer ________
Racing ________	Racing ________
Adventure Games ________	Adventure Games ________
Real-Time Strategy ________	Real-Time Strategy ________
Tactical Shooters ________	Tactical Shooters ________
Sports ________	Sports ________
Role-Playing ________	Role-Playing ________
Other Strategy ________	Other Strategy ________
Dance/Music ________	Dance/Music ________
Online ________	Online ________
Other ________	Other ________

If you selected “Other”, please describe the game(s):

7. Which game platforms do you use?	7. Which game platforms do you use most frequently? With 1 standing for most frequently played, you can use the same value more than once to denote platform types used with equal frequency?

PC	________	PC	________
Xbox	________	Xbox	________
Xbox360	________	Xbox360	________
Game Cube	________	Game Cube	________
PSP	________	PSP	________
PS	________	PS	________
PS2	________	PS2	________
PS3	________	PS3	________
Nintendo Wii	________	Nintendo Wii	________
Dual Saga	________	Dual Saga	________
GBA	________	GBA	________
N-Gage	________	N-Gage	________
Mobile (i.e. cell phones)	________	Mobile (i.e. cell phones)	________

8. Please list here other systems you have played games on (e.g. Commodore 64, Commodore Vic 20, Atari, Nintendo, Super NES, Sega, Sega Dreamcast, etc.):

9. On average, how accomplished of a video game player are you (using a seven-point scale as described below):

1	2	3	4	5	6	7
Novice			Average			Expert

10. List some of the specific games you most often play and for each indicate using a seven-point scale how accomplished a player you are (with 1 being novice, 4 being average, and 7 being expert, using the 7 point scale as shown above):

11. Would you be interested in participating in future video game oriented studies?

Yes ____ No ____

If you selected “Yes”, please provide permanent contact address information:

Address: ____

City: ____

Province: ____

Postal Code: ____

Telephone: (_____)____

Email: ____

12. Are there any other comments you’d like to make to illuminate your gaming history?

Figure Captions

Figure 1.1. A history in brief describing the development of the video game medium, chronologically detailing the progressive advancement of video game oriented technology from the impractical and unmarketable to the current juggernauts that dominate the industry and have so successfully penetrated the consumer market.

Figure 3.1. Mean reaction time data for Experiment 1. Within a single panel, data are divided by task switching status (repeat or switch trial), and cue informativeness (cued or uncued), stimulus perceptual difficulty (Stim; easy or hard), and response mapping difficulty (easy or hard). These data are grouped by cue-to-target interval (CTI; short = 100 msec, long = 1000 msec), and video gaming participant group (VGP = video game players, NVGP = non-video game players). Error bars represent standard error of the mean. In addition to a main effect of faster responses for gamers, a number of interactions between overall task effects and gaming expertise group were observed.

Figure 3.2. Mean reaction time data for Experiment 2. Within a single panel, data are divided by task type (odd/even, prime/multiple or less/more) and task switching type (repeat, 1-switch, 2-switch and alternate). These data are grouped by cue-to-target interval (CTI; short = 100 msec, long = 1000 msec), and video gaming participant group (VGP = video game players, NVGP = non-video game players). Error bars represent standard error of the mean. Despite an overall main

effect of faster responses for gamers, no interactions between overall task effects and gaming expertise group were observed.

Figure 4.1. Example stimulus sequence and probe trials for control, maintenance and updating tasks in verbal and spatial WM conditions. Random sequences of 3 to 8 single digit stimuli were randomly presented at one of eight screen positions around a central fixation point. Participants had to remember either digit identities (verbal WM) or digit locations (spatial WM). Participants responded only to a final probe display presented at the of a variable-length stimulus sequence.

Figure 4.2. Mean reaction times for correct trials (left axis) and error rates (right axis) for probe trial responses. Data are separated by task type (maintenance, updating, control), WM modality (verbal, spatial), and video game expertise group (VGP, NVGP). Data are presented collapsed over probe type (target, non-target) for clarity. Error bars represent standard errors. Video game expertise groups did not differ on any reaction time or error rate measures.

Figure 4.3. Grand average stimulus-locked ERP waveforms from our central parietal region of interest, divided by task type (control, maintenance, updating), WM modality (verbal, spatial), and serial position (1 to 5), for VGP and NVGP participant groups.

Table 2.1. Mean response times (RT) and percent error for NVGPs and VGPs in the Presence, Difficulty, and Display Size conditions. Comparison of performance in the pre-test condition only. Standard Errors (SE) are shown.

Table 2.2. Mean response times (RT) and percent error for VGPs in the Presence, Difficulty, and Display Size conditions. Values are collapsed across counter condition and Game factor. Standard errors (SE) are shown.

Figure 1.1

YEAR	EVENT	YEAR	EVENT
1947	First videogame invented: Cathode-Ray tube amusement device. 8 Vacuum tubes with targets on a CRT. Missiles fired at targets.	1985	Nintendo Entertainment System revives faltering video game industry, beginning the current golden age of game production and development
1958	First video game available to public. Tennis for two on oscilloscope.	1990s	PC game boom. Increased power of both computer processors and graphics cards generate increasingly high fidelity game environments. Massive public interest in microcomputer based games.
1960s	Mainframe games. Microcomputers not yet available. Simple games like Tic Tac Toe. Unavailable to public. Found primarily with universities, major industry and government organizations.	1995	Modern CD-ROM based consoles reach consumer market. Dramatic increase in game sales as console games do not suffer compatibility issues faced by PC contemporaries.
1970s	First arcades, consoles, and microcomputers. Pong developed by Atari. Hugely successful.	2000s	Current modern console boom, prompted by high fidelity graphics and easy multiplayer access via broadband
1980s	Console boom. Videogames move into many consumers homes.	2006	Wireless control and intuitive play style of Nintendo Wii brings video games to a wide variety of demographics. 7 out of 10 North American homes have some form of entertainment device designed for video game play.
1983 -84	Console market crashes due to a proliferation of poorly designed and developed games.	2010+	Development of consoles that are fully interactive, responding to gross and fine motor movements of the body as the interface (no input control required).

Figure 2.1

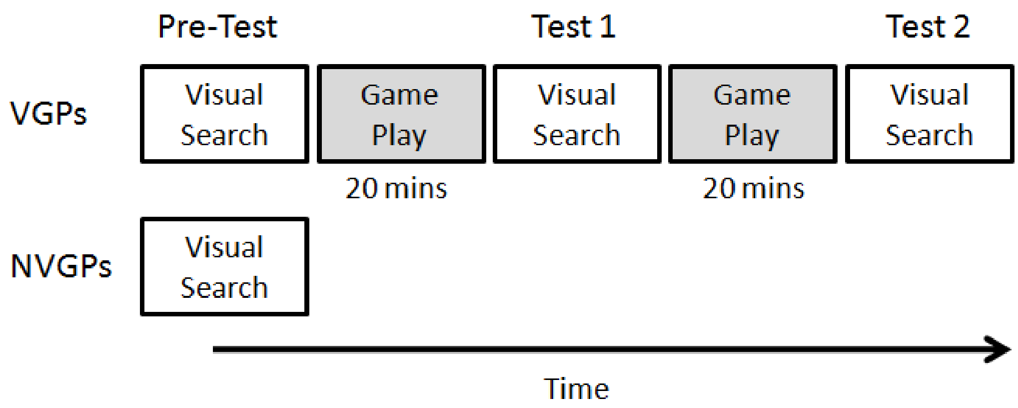
Pre-Test
Test 1
Test 2
VGPs
Visual Search
Game Play
20 mins
Visual Search
Game Play
20 mins
Visual Search
NVGPs
Visual Search
Time

Figure 3.1

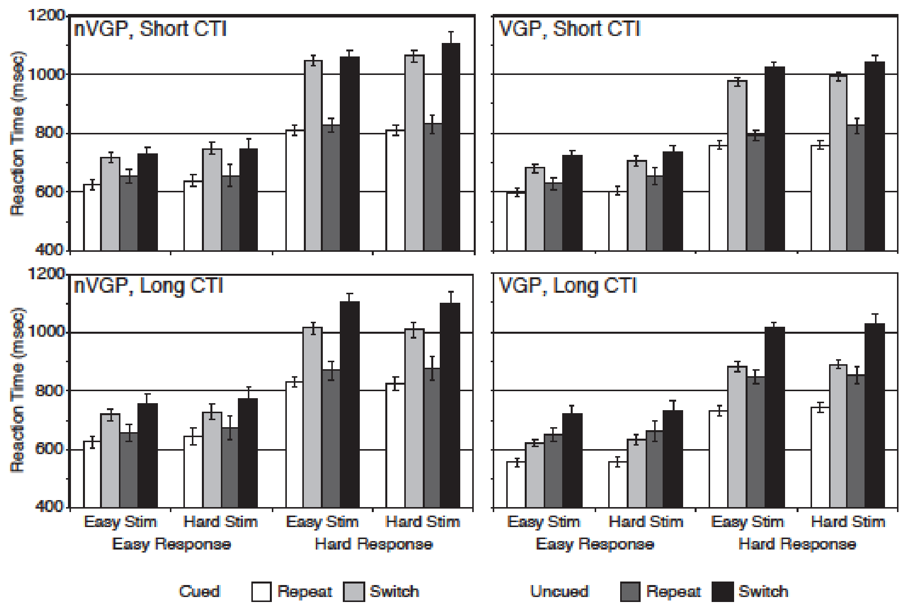
nVGP, Short CTI
VGP, Short CTI
nVGP, Long CTI
VGP, Long CTI
Reaction Time (msec)
1200
1000
800
600
400
Easy Stim
Hard Stim
Easy Response
Hard Response
Cued
Repeat
Switch
Uncued
Repeat
Switch

Figure 3.2

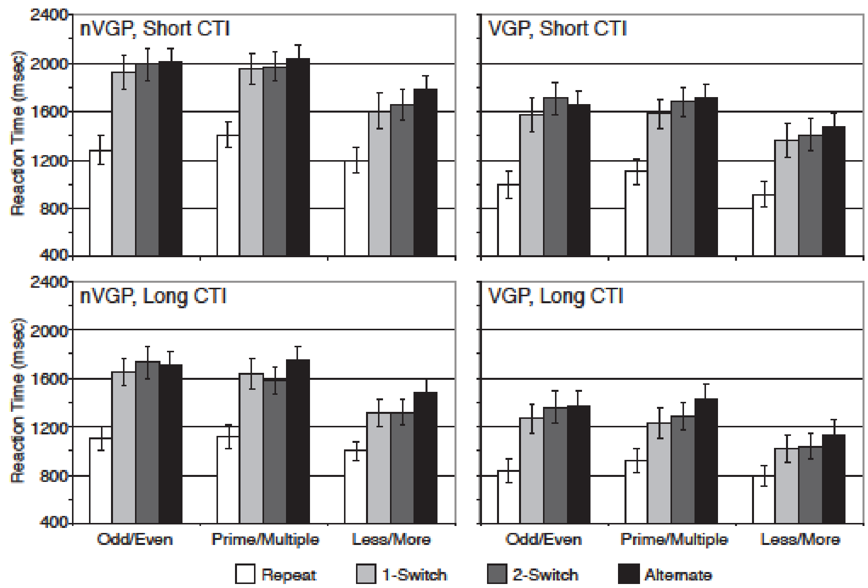
nVGP, Short CTI
VGP, Short CTI
nVGP, Long CTI
VGP, Long CTI
Reaction Time (msec)
2400
2000
1600
1200
800
400
Odd/Even
Prime/Multiple
Less/More
Repeat
1-Switch
2-Switch
Alternate

Figure 4.1

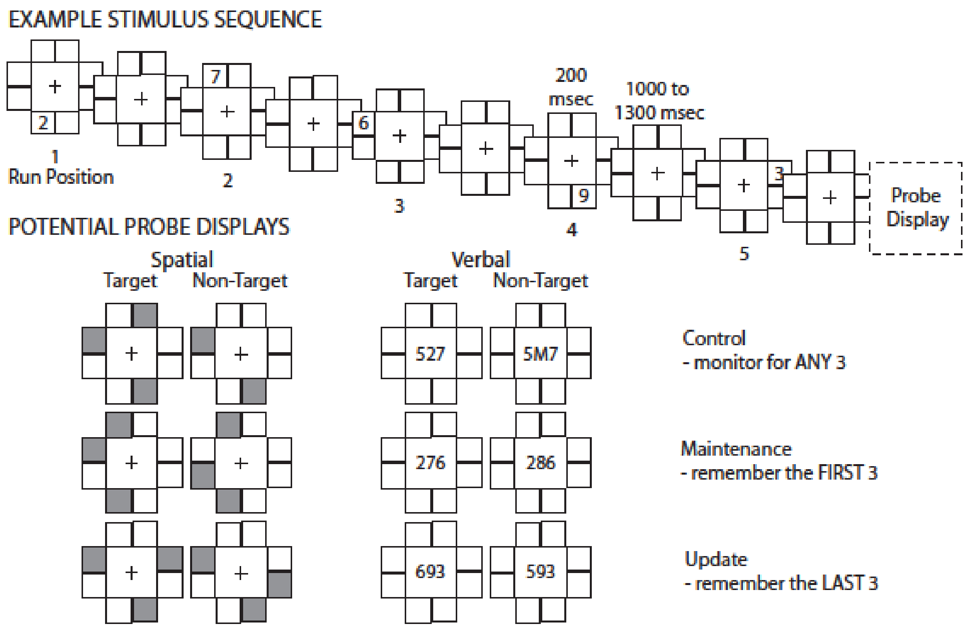
EXAMPLE STIMULUS SEQUENCE
2
7
6
9
3
200 msec
1000 to 1300 msec
1
Run Position
2
3
4
5
Probe Display
POTENTIAL PROBE DISPLAYS
Spatial
Target
Non-Target
Verbal
Target
Non-Target
527
5M7
276
286
693
593
Control
- monitor for ANY 3
Maintenance
- remember the FIRST 3
Update
- remember the LAST 3

Figure 4.2

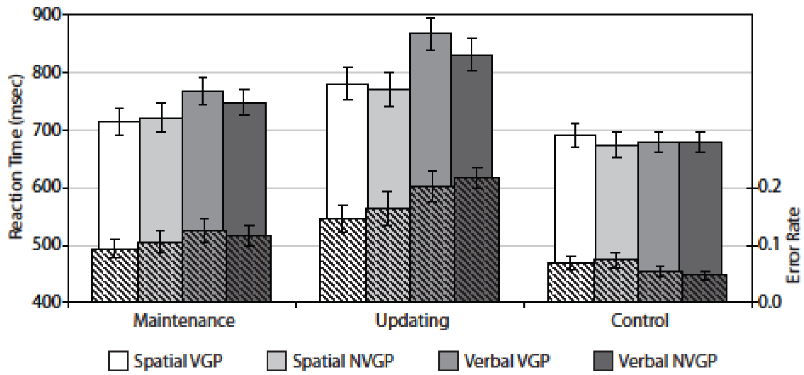
900
800
700
600
500
400
Reaction Time (msec)
0.2
0.1
0.0
Error Rate
Maintenance
Updating
Control
Spatial VGP
Spatial NVGP
Verbal VGP
Verbal NVGP

Figure 4.3

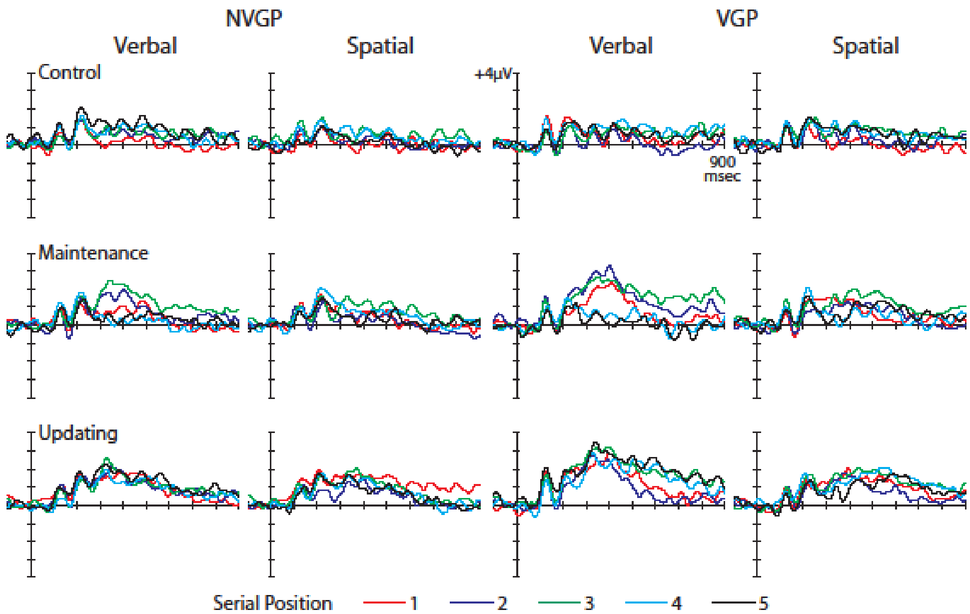
NVGP
VGP
Verbal
Spatial
Verbal
Spatial
Control
+4μV
900 msec
Maintenance
Updating
Serial Position
1
2
3
4
5

Table 2.1

		Presence		Difficulty		Display Size			
		Present	Absent	Hard	Easy	4	10	18	26
NVGP	RT	1092	1543	1703	932	865	1187	1469	1747
	SE	47	93	91	48	38	72	78	91
VGP	RT	951	1376	1541	787	749	1024	1331	1551
	SE	35	68	73	30	28	44	61	73
NVGP	Error	6.0	1.0	5.4	1.6	2.8	1.9	3.9	5.4
	SE	1.3	0.5	1.1	0.6	1.0	0.6	0.9	1.1
VGP	Error	5.3	0.8	4.7	1.4	1.6	2.2	3.6	4.8
	SE	1.3	0.4	1.2	0.5	0.6	0.7	1.0	1.0

RT = Response Time (in msec) **Error =** Percent Incorrect **SE** = Standard Error

Table 2.2

	Presence		**Difficulty**		**Display Size**			
	Present	Absent	Hard	Easy	4	10	18	26
RT	916	1295	1473	739	713	979	1255	1475
SE	46	91	98	39	34	61	82	97
Error	5.6	1.0	5.1	1.5	2.2	2.3	3.7	5.0
SE	1.9	0.7	1.7	0.8	1.0	1.0	1.4	1.7

RT = Response Time (in msec) **Error =** Percent Incorrect **SE** = Standard Error