COGNITIVE CONTROL IN VIDEO GAME PLAYERS

INVESTIGATING COGNITIVE CONTROL BENEFITS IN EXPERT VIDEO GAME PLAYERS

By JULIE CONDER, B.A. (HONOURS FIRST CLASS), M. A.

A Thesis Submitted to the School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy

McMaster University DOCTOR OF PHILOSOPHY (2015) Hamilton, Ontario
(Psychology, Neuroscience, & Behaviour)

TITLE: Investigating Cognitive Control Benefits in Expert Video Game Players
AUTHOR: Julie Conder, B. A. (Honours First Class) (Simon Fraser University), M. A. (University of South Carolina)
SUPERVISORS: Dr. Karin R. Humphreys and Dr. Scott Watter
NUMBER OF PAGES: x, 159

Lay Abstract

Many people enjoy playing video games, and it is important to understand whether playing these games is associated with differences in the way we think, or our ability to complete tasks. Previous studies have claimed that playing video games is associated with increased control over our ability to selectively respond to our environment. This dissertation uses a series of experiments to compare the cognitive control ability of video game players (VGPs), and people who do not play video games (nVGPs). We tested their ability to switch between different tasks, to hold items in memory, and to withhold responses. Results of these experiments suggest that although VGPs may generally respond faster and process spatial information better than nVGPs, there are no differences in cognitive control between VGPs and nVGPs.

Abstract

As the popularity of video games increases, a growing literature has begun to examine the association of video game play with cognitive processes. An advantage in cognitive control ability for video game players (VGPs) compared to nongamers (nVGPs) has been suggested by a number of recent studies. Miyake et al. (2000) identify three separable components of cognitive control: ability to shift mental set, updating and monitoring of working memory, and ability to inhibit automatic responses. In three sets of experiments, we investigated claims of a benefit in cognitive control for VGPs compared to nVGPs. Chapter 2 used two task switching paradigms to examine the ability to shift mental set, finding no difference in cognitive control between VGPs and nVGPs when baseline differences in response speed were accounted for. In Chapter 3, a series of n-back experiments to investigate working memory demonstrated that VGPs display an advantage in spatial processing, but not in cognitive control. Chapter 4 assessed group differences using three measures of inhibitory control: flanker, Stroop, and go no-go tasks. The results of these experiments suggest that VGPs may rely more on automaticity-based response strategies than do nVGPs, but no group differences in cognitive control were evident. Overall, the results of this dissertation dispute a growing literature that assumes a cognitive control benefit for VGPs compared to nVGPs. Although VGPs reliably show faster performance on a range of tasks used to assess cognitive control (e.g., task switching paradigms), when examined with careful methods, these observed differences in performance are not attributable to differences in cognitive control ability.

Acknowledgements

Across the span of my doctoral research, I have received support and encouragement from a great number of individuals. Dr. Scott Watter and Dr. Karin Humphreys have been mentors and friends to me throughout this time, and their guidance has provided me with a thoughtful and rewarding journey. I would also like to thank my committee member Dr. Judith Shedden for her valuable insight and support.

This work would not have been possible without the tireless efforts of Esther Manoian, who spent countless hours proofreading my work and listening to my thoughts, and who coordinated data collection. I am also grateful to Stefania Cerisano and Ally Scione, who helped with data collection, and to all the members of the Cognitive Science Lab at McMaster, past and present, who have provided encouragement and have helped make my lab a home during the past several years.

I would like to thank the Natural Sciences and Engineering Council of Canada for generously providing funding to complete portions of this research.

Finally, I deeply thank my husband Stephen Brown and my daughter Madeleine Brown (who joined us during my doctoral research) for their love, understanding, and sacrifice during completion of this work.

Table of Contents

Figures

Declaration of Academic Achievement

This dissertation consists of three studies designed to investigate the association of cognitive control in video game players and non-video game players. Chapter 1 is a general introduction that identifies previous literature and key issues that will be explored throughout the experiments. I am the author of this dissertation and will be the first author of possible peer-reviewed papers related to this work that may be submitted in the future.

Chapter 2 is a set of two task switching experiments that were developed in collaboration with my Ph.D. advisor Dr. Scott Watter. Chapter 3 is a series of working memory n-back tasks designed to examine the role of cognitive control in working memory in both video game players and non-video game players. A portion of these experiments was included in the Honours Thesis of undergraduate student Stefania Cerisano. I supervised Stefania in data collection, analyses, and writing, and helped her create a poster to be presented at her Honours Thesis poster session and at a conference (CSBBCS). Chapter 4 is a set of experiments designed to examine inhibitory control performance in video game players and non-video game players. Chapter 5 is a general discussion of all experimental results and implications of this work.

All of the above experiments have been developed and analyzed in collaboration with my thesis supervisor. All written work in this thesis has been authored by me, including revisions based on input from my thesis supervisors and my Ph.D. committee.

Chapter 1

GENERAL INTRODUCTION

For the past several decades, video game play has been on the rise. A large majority of children and adolescents play video games with some degree of regularity throughout their development. In the United States, 91% of children between age 2 and 17 play video games (NPD Group, 2011). These rates are even higher for teenagers, with up to 94% of female and 99% of male teens engaging in video game play (Lenhart et al., 2008). As the popularity of gaming has increased, the location of play has shifted from external arcade locations to within the home. In 2013, the average American household had at least one home gaming console, and many have more than one (Entertainment Software Association, 2013). This shift will continue to make video game play more convenient and accessible, likely resulting in increased play, especially for younger children. Much attention has been given to the possible negative effects of video game play by the press and popular media, particularly in the direction of possible negative social consequences, such as violence and aggression. While these concerns are certainly valid, a more recent trend is the growing research literature pointing toward evidence of cognitive benefits as a potential outcome of video game play. Granic, Lobel and Engels (2014) point out that in order to fully understand the effects of video game play, a balanced perspective is necessary. If there are cognitive benefits that may result from video game play, it is important to understand their full scope and nature, both for understanding the complete range of effects of video game play, and for practical and therapeutic application of benefits.

A cognitive advantage for video game players

In recent years, research has begun to suggest that differences in performance on cognitive tasks may exist between people who spend large amounts of time playing action or first-person shooter video games (video game players, VGPs) and those do not (non-video game players, nVGPs), and these results have led some researchers to conclude that VGPs may possess an advantage in cognitive control (Granic, Lobel, & Engels, 2014; Bavelier, Green, Pouget, & Schrater, 2012; Powers, Brooks, Aldrich, Palladino, & Alfieri, 2013; Spence & Feng, 2010). Although some studies have shown VGPs to outperform nVGPs in a number of cognitive tasks, others have found no differences between the groups, leading to inconsistency in the literature about whether a true cognitive advantage might exist for VGPs. Consequently, research examining the differences in performance on perceptual and cognitive tasks between VGPs and nVGPs has amassed in recent years. This research has led to experimental comparisons between gaming groups on a wide variety of cognitive and perceptual tasks, and the identification of a number of issues that should be addressed when studying cognitive differences that are associated with video game play.

The earliest noted benefit of video game play was visual attention. Green and Bavelier (2003) were the first to compare VGPs and nVGPs on a visual attention task, and found that VGPs demonstrated enhanced performance compared to nVGPs. Since then, cognitive differences between VGPs and nVGPs have been noted in a number of tasks. Studies in visual attention have also found an advantage for VGPs (Castel, Pratt, & Drummond, 2005; Green & Bavelier, 2006a, 2006b, 2007). Some research has shown that VGPs perform better than nVGPs on visual search tasks (Chisholm, Hickey, Theeuwes, & Kingstone, 2010; Hubert-Wallander, Green, Sugarman, & Bavelier, 2011). VGPs also perform better in spatial attention tasks (Feng, Spence, & Pratt, 2007), mental rotation (Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Feng et al., 2007), speeded response (Bialystok, 2006; Castel et al., 2005), and change detection (Clark, Fleck, & Mitroff, 2011). VGPs are more able to effectively process temporal information compared to nVGPs (Donohue, Woldorff, & Mitroff, 2010; West, Stevens, Pun, & Pratt, 2008) and show an advantage in multisensory processing as well (Donohue et al., 2010). Several studies have examined VGP and nVGP performance in cognitive control using task switching measures and have found advantages for VGPs in these tasks (Andrews & Murphy, 2006; Cain, Landau, & Shimamura, 2012; Colzato, van Leeuwen, van den Wildenberg, & Hommel, 2010; Green, Sugarman, Medford, Klobusicky, & Bavelier, 2012; Strobach, Frensch, & Schubert, 2012). VPGs also outperform nVPGs in tracking objects at high speeds and visual short term memory (Boot et al., 2008), and memory ability (Colzato, van den Wildenberg, Zmigrod, & Hommell, 2013; McDermott, Bavelier, & Green, 2014). Contrast sensitivity function, a measure of visual evaluation, appears to be improved as a result of video game play (Li, Polat, Makous, & Bavelier, 2009). West, Al-Aidroos, and Pratt (2013) demonstrates that oculomotor performance differs between VPGs and nVPGs, with VGPs showing enhanced oculomotor ability. The studies mentioned here have, for the most part, employed quasi-experimental designs, comparing data from self-identified VGPs and nVGPs, but true experimental training studies in which novices are pre-tested, asked to play video games for a set amount of time, and then post-tested, and compared with non-playing controls, have also suggested that engaging in video game play can result in enhanced cognition (Glass, Maddox & Love, 2013; Green & Bavelier, 2006a; Powers et al., 2013).

Components of cognitive control

Cognitive control is the ability to interact with the environment in a goal-directed manner, through constant assessment and re-adjustment of performance based on incoming information. Cognitive control ability is often considered synonymous with executive functions. Researchers have long theorized about the theoretical structure and functionality of cognitive control. Baddeley (1986) and Norman and Shallice (1986) identified cognitive processes within discrete domains, highlighting the necessity of a domain-general executive overseer to these functions; Baddeley's model describes a "central executive" while Norman and Shallice describe a "Supervisory Attentional System" to control these functions. These proposed supervisory components represent the need to define executive functions, and emphasize the qualitative difference between functions requiring cognitive control, problem solving, and decision-making, versus domain-specific cognitive function. Botvinick, Braver, Barch, Carter, and Cohen (2001) describe cognitive control as a process of conflict monitoring that is achieved through interactions of the anterior cingulate and lateral frontal cortex. In this account, a series of events are activated by a conflict in information processing. Once a conflict is detected by the anterior cingulate, centres for cognitive control in the frontal cortices are activated to respond to the conflict by a shift in strategy. The increase in cognitive control effort expended by frontal regions results in a reduction in conflict (Botnivick et al., 2007). In an influential study on individual differences, Miyake and colleagues (2000) observed that the term "executive functions" often escapes clear definition, and observed the relation of individual differences to performance in a number of executive tasks to identify and quantify three main components of executive function: 1) shifting of mental set, 2) monitoring and updating of working memory, and 3) inhibiting of automatic responses.

Task switching as a measure of cognitive control

The first component of Miyake et al.'s (2000) division of cognitive control is shifting of mental set. The ability to shift mental set is best measured by cognitive paradigms requiring participants to perform two or more types of task, while switching between tasks (Jersild, 1927). This task relies heavily on a participant's ability to actively maintain several sets of task set rules, while constantly assessing task demands to determine which task set is appropriate on any given trial.

Task switching paradigms, often considered measures of cognitive flexibility, or, more generally, executive function, require a participant to switch among two or more tasks rapidly while making speeded decisions within the framework of each task. In a basic task switching paradigm, participants are asked to perform one task on each trial.

The following trial may consist of the same task again ("repeat trials") or a different task ("switch trials"). Reaction times (RTs) and accuracy are compared between repeat and switch trials. Typically, switch trials result in greater RTs and error rates in comparison to repeat trials. This well documented phenomenon is known as the "switch cost" (for reviews, see Allport & Wylie, 1999; Kiesel et al., 2010; Monsell, 2003; Vandierendonck, Liefooghe, & Verbruggen, 2010).

Several experimental designs enable the measurement of switch cost. Early designs compared fixed task block performance with mixed task block performance. Rogers and Monsell (1995) created an alternating-runs design to avoid confounding the effects of increased arousal and load on working memory with effects of task switching. The majority of task switching studies have used simple decision tasks such as object naming, word reading, categorization of letters or digits, or visual location of a stimulus. Some research has recognized that switch costs on different trial types can be influenced by the preceding trials. Arbuthnott and Frank (2000) formulated a task-switching design enabling analysis of four kinds of switch trial types: repeat trials, one-switch trials, two-switch trials, and alternating trials. According to this design, trials are ranked in terms of difficulty as reflected by switch cost. Repeat trials (AA, where task A is the same on the first trial and on the second trial) result in the lowest switch cost. One-switch trials are trials in which one task is followed by a different task (AB, where task A is followed by a different task B). One-switch trials generally result in greater switch costs than repeat trials, but lower switch costs than two-switch or alternating trials. Two-switch trials are trials in which one task is followed by a different task, and both are followed by a new third task (ABC, where each letter represents a new task). Finally, the trial type resulting in the greatest switch cost is the alternating trial. On alternating trials, participants must complete one task followed by a different task, and then return the original task (ABA, where A is the original task). Using this paradigm, the type of trial (switch type) is a variable that can be manipulated as a measure of cognitive difficulty; alternating and two-switch trials can be thought of as more cognitively difficult, while repeat trials may be considered as baseline performance.

A more traditional task switching paradigm is the alternating runs design created by Rogers and Monsell (1995), in which a quadrant of empty squares is presented on a visual display. Stimuli may be a combination of numbers and letters, such that each task requires a response to either the number or the letter appearing. Stimuli appear in the boxes in a predictable clockwise manner, with stimulus location serving as cue informing the participant which stimulus should be responded to on that trial. In this manner, stimuli are presented in an order of AABBAABB, requiring the participant to switch tasks once every two trials.

VGP benefit in task switching

Some research has focused specifically on differences between VGPs and nVGPs in task switching ability. The ability to allocate (and then reallocate) attentional resources efficiently and quickly is paramount to playing such games successfully, and a number of studies have attempted to measure this ability in a cognitive laboratory setting using task switching paradigms.

A number of studies have found evidence of a VGP advantage in task switching performance. Andrews and Murphy (2006) demonstrated that VPGs outperformed nVGPs using a predictable alternating runs task switching paradigm in which VGPs and nVGPs alternated between digit and letter classification tasks. Results showed that this VGP advantage was pronounced when the response-to-stimulus interval (RSI) was brief (150 ms). Boot and colleagues (2008) found a small switch cost benefit for VGPs compared to nVGPs, but were unable to replicate this effect using a training paradigm. Colzato and colleagues (2010) used players of first person shooter style video games and a task switching paradigm to demonstrate reduced switch cost for VGPs. Because cue-to-stimulus intervals (CSIs) were long in this study (900-1100 ms), the authors conclude that the VGP advantage was probably not attributable to a preparatory component of task switching. Instead, they speculate that the advantage may be due to more efficient control of episodic memory, and an increased ability to selectively activate and update task sets. Cain, Landau, and Shimamura (2012) point out that the VGP advantage observed in Colzato et al. (2010) may have been due to a speed-accuracy tradeoff, given that VGPs produced twice the number of errors as nVGPs on trials requiring a switch. Cain et al. (2012) sought to elucidate these results using long RSIs, no cues, and an unpredictable task sequence in their task switching paradigm. VGPs and nVGPs switched between a familiar task and a novel task. VGPs demonstrated lower switch cost and less asymmetry in switch cost than nVGPs. Switch cost asymmetry is a phenomenon wherein switch costs are not equivalent for a pair of tasks with different difficulty levels. When participants switch from an “easy” task to a “difficult” task, switch cost is lower than switching from a difficult to an easy task. Here, Cain et al. (2012) interpret smaller switch cost asymmetry as evidence of more facile switching ability on the part of VGPs. No differences were observed between VGPs and nVGPs in the ability to ignore distractors; Cain et al. (2012) conclude that video game experience results in benefits to executive function but not the ability to filter visual information.

Other research has attempted to expand the literature on task switching ability in VGPs. Green and colleagues (2012) have observed that the reduction in switch cost for VGPs can be generalized to vocal responses in addition to manual responses, eliminating the possibility that switch cost advantage for VGPs is merely a result of overlearned manual responses. In the same study, Green et al. (2012) showed that VGPs maintained a switch cost advantage when the task was more cognitive than perceptual, and when the task required motor response remapping. In order to establish a causal relationship between video game play and reduction in switch cost, Green and colleagues (2012) also conducted a training study in which nVGPs were given 50 hours of video game training on either an action video game (experimental group) or a strategy video game (control group). The group trained on an action video game showed a greater reduction in switch cost than controls, indicating a causal relationship between action video game play and decreased switch cost. Strobach and colleagues (2012) found that VGPs performed better than nVGPs both task switching and simultaneous dual-task situations, but no advantage was seen in single task situations. This group was also able to demonstrate a causal role for video game play using a training study. Training nVGPs for 15 hours on either an action video game or a puzzle game, they found that training on the action game caused a decrease in RTs in the dual task paradigm, and reduced switch cost in the task switching paradigm (Strobach et al., 2012).

Working memory and cognitive control

The second component of cognitive control according to Miyake et al.'s (2000) analysis is the ability to monitor and update working memory. Most models of working memory accept working memory as the ability to temporarily store information. The traditional view of working memory organization put forth by Baddeley and Hitch in 1974 suggests three components involved in working memory processes: the central executive, which acts as an attentional control system, and its slave systems, the visuopatial sketchpad and the phonological loop, which can each manipulate and process information within the visual and auditory domains.

This account of a domain-free attentional control centre is consistent with other accounts of memory function, including Norman and Shallice's (1986) Supervisory Attentional System, a higher-level executive attention mechanism controlling lower-level responses to incoming information via an action-selection process. Engle and colleagues (Engle, Cantor, & Carullo, 1992; Kane, Bleckley, Conway, & Engle, 2001; Turner & Engle, 1989) also explain working memory function as a domain-free, task-independent ability in which specific domains rely on a higher-level, controlled-attention component. Kane et al. (2001) argue that working memory capacity reflects a general ability to maintain information, such as currently relevant task goals, in an active state. Kane and Engle (2002) relate a hierarchical system of working memory including short-term memory, representational components and a general executive attention component to prefrontal cortical function. This account explains the executive attention component of working memory as the ability to maintain pieces of relevant information (goals, task sets, action plans, stimuli, and other information) in an active state. In this state, working memory may be disrupted by interference. Kane and Engle (2002) maintain that working memory is most taxed in the presence of interfering information, because when no interference is present, it is easy to correctly retrieve relevant information from long-term memory stores. In active task environments where interfering information must be inhibited in order to successfully complete a task, executive attention must correctly identify and process incoming information. These authors further suggest that individual differences in working memory capacity may be explained by differences in high level, domain-general attentional capability, and in the ability to maintain attentional focus when faced with mental or environmental distractor information. All of these accounts express working memory as a portion of a larger cognitive control ability, which is necessary for successful completion working memory tasks, and, importantly, applies across all domains.

VGP benefit in working memory tasks

Some research has specifically investigated the relation of video game play to performance on memory tasks. Sungur and Boduroglu (2012) compared VGP and nVGP performance on several memory tasks, including asking participants to freely recall colours of briefly presented stimuli, and found that VGPs were able to recall stimuli, track more objects in space, and maintain the identity of tracked objects more accurately than nVGPs. These authors also used a Useful Field of View (UFOV) tasks to determine that VGPs had greater attentional breadth and increased resolution of spatial representation compared to nVGPs, and conclude that VGPs may possess a greater amount of memory resources compared to nVGPs. Blacker and Curby (2013) used visuospatial tasks to assess whether VGPs and nVGPs differed in visual short term memory ability using a change detection paradigm, and found that VGPs performed better than nVGPs in working memory tasks using both simple and complex stimuli. Boot et al. (2008) also found a VGP advantage in change detection.

Blacker, Curby, Klobusicky, and Chein (2014) conducted a training study to determine whether video game play results in visual working memory benefits. This training study found that participants who played an action video game showed increases in visual working memory capacity compared to participants who played a control game, but that the benefit did not persist to more complex working memory tasks.

Colzato, van den Wildenberg, Zmigrod, and Hommel (2013) used an n-back task to assess the VGP benefit in working memory. Varying memory load to manipulate task difficulty, these authors found that VGPs demonstrated faster and more accurate responses than nVGPs, concluding that VGPs have increased working memory capacity and enhanced ability to update information in working memory. In contrast to these findings, Boot and colleagues (2008) were unable to find differences in working memory ability between VGPs and nVGPs in their 21-day training study. It should be noted that these studies examined working memory ability in different domains; Colzato et al.

employed a digit task, whereas Boot and colleagues (2008) used a spatial memory task. McDermott, Bavelier, and Green (2014) examined putative differential working memory ability in VGPs and nVGPs using a complex n-back paradigm and a change detection task, finding no benefit for VGPs in the n-back task, but noting that VGPs were faster and more accurate than nVGPs in detecting changes in a visual display. McDermott et al. (2014) conclude that VGPs possess an advantage in visuospatial memory that can be attributed to increased processing speed.

Cognitive control and the ability to inhibit behaviour

Miyake et al. (2000) described the third component of cognitive control as the ability to inhibit automatic responses. A number of studies have investigated this ability in VGPs and nVGPs to determine whether differences across groups might exist. Several cognitive tasks have been well established in measuring participants' ability to withhold automatic responses caused by distractor stimuli, overlearned responses, and automaticity-inducing conditions.

Green and Bavelier (2003) examined attentional differences between VGPs and nVGPs. Among other tasks, these authors compared VGP and nVGP performance in a flanker task. They manipulated levels of task difficulty by increasing the number of distractors present in each trial. VGPs performed better than nVGPs in all four difficulty levels. Taken together with the results of other tasks, the authors concluded that these results were indicative of a cognitive benefit for VGPs.

Other research has found supporting evidence for increased inhibitory control in VGPs. Colzato, van den Wildenberg, Zmigrod, and Hommel (2013) used a stop-signal paradigm to assess possible differences between VGPs and nVGPs. Stop-signal tasks, similar to go no-go tasks, measure inhibitory control by having participants respond to a stimulus on each trial. On a minority of trials, participants are given a signal indicating that they must inhibit their in-progress response. Colzato et al. (2013) found that VGPs were able to respond faster to “go” trials than nVGPs, while performing on par with nVGPs in false alarm rate. These results coincide with those of Dye, Green, and Bavelier (2009), who used a meta-analysis to show that VGPs performed faster than nVGPs on a number of tasks without sacrificing accuracy. A recent training study found that playing a custom racing video game requiring multitasking (not an action or first person shooter game) is associated with long-term increases in multitasking ability in older adults, which the authors attribute to enduring changes in cognitive control ability (Anguera et al., 2013). These results imply that cognitive control ability may be altered by video game play experiences.

Not all studies investigating a VGP benefit in inhibitory control have found supporting results. Irons, Remington, and McLean (2011) found no difference in performance between VGPs and nVGPs using both spatial and Eriksen (1974) style flanker tasks. Boot and colleagues (2008), using a training study, were unable to find differences between VPGs and nVPGs in working memory, visual short term memory, and spatial memory.

Bailey, West, and Anderson (2010) investigated putative differences in inhibitory control ability between VGPs and nVGPs using a Stroop task in combination with event-related potentials (ERPs). Distinguishing between proactive (future-stimulus oriented) and reactive (current-stimulus oriented) (Braver, Gray, & Burgess, 2007) cognitive control, Bailey and colleagues found separate ERP components to be associated with engagement in each. Bailey et al. (2010) found that in long, but not short, RSI conditions of the Stroop task, VGPs showed less susceptibility to interference from the preceding trial, and that this effect was linked to attenuations in medial frontal negativity in VGPs. The authors concluded that VGPs had similar recruitment of cognitive control processes compared to nVGPs, but were unable to maintain cognitive control when the delay between stimuli was extended. No differences between VGPs and nVGPs in reactive control were observed. These results suggest that VGPs may be more likely than nVGPs to adopt a task completion strategy that allows faster responding based on global task rules, at the expense of ability to adjust effectively to interference on a trial-by-trial basis.

Inconsistency in the VGP literature

Although much research has suggested a cognitive benefit for VGPs, other studies have failed to replicate these findings or have found no difference between VGPs and nVGPs. Murphy and Spencer (2009) were not able to replicate Green and Bavelier's (2003) VGP advantage using attentional blink and useful field of view tasks, and suggest that sample size may be a contributing factor to lack of replicability; Green and Bavelier (2003) used a sample size of only eight participants per group. Powers and colleagues'

(2013) meta-analysis suggests that many of the studies finding a VGP advantage in cognitive tasks had small effect sizes (Unsworth et al., 2015). In a comprehensive training study, Boot and colleagues (2008) were unable to find differences between participants who played 20+ hours of video games and control participants on twelve cognitive measures, including attentional blink, useful field of view, enumeration, working memory, visual short term memory, and spatial memory. Other work has shown that while VPGs do show an advantage in visual attention tasks, this advantage does not transfer to visual search tasks (Castel et al., 2005; Irons,et al., 2011). Irons et al. (2011) found no differences between VPGs and nVPGs in visual attention using a flanker task. This group manipulated eccentricities of peripheral targets in order to determine whether VPGs showed an advantage in peripheral target detection; no differences were noted.

Baniqued et al. (2013), in an investigation of the validity of using video games as cognitive training devices, described the relationship between task and game performance. They found that high performance on skill assessments for skills closely resembling game demands predicted game performance. For example, performance on games requiring high levels of working memory and reasoning skills was predicted by an individual's scores on tasks of working memory and fluid intelligence. These results suggest that VGP effects acquired within training studies may not transfer to tasks outside the training environment. To test this hypothesis, Baniqued and colleagues (2014) used a training study to assess skill transfer, finding that transfer to untrained tasks was limited, and that the largest gains in skill were in the areas of attention and visuospatial attention.

There are a number of inherent methodological issues involved in studying differences between VGPs and nVGPs. A majority of non-training studies compare extreme gaming groups to those with limited or no video game experience. Pre-existing cognitive and perceptual differences may exist between these groups (Boot, Blakely, & Simons, 2011; Kristjánsson, 2013; Unsworth et al., 2015). A recent meta-analysis by Powers et al. (2013) has found that effect sizes of differences between VGPs and nVGPs in studies using quasi-experimental designs are often small, and that studies using true experimental designs (e.g., training studies) result in even smaller effect sizes, suggesting that observed differences between groups may be inflated. Recruiting procedures usually call for participants with "video game expertise," fostering in participants an awareness that their gaming ability is being studied (Boot et al., 2011). This could result in demand characteristics, with VPGs being more motivated than nVPGs to perform well. Although these issues are factors that should be considered when assessing group differences, elucidating the cause of group differences is not the purpose of the current paper. Rather, this dissertation aims to distinguish putative differences in cognitive control from benefits in other domains, regardless of their origin.

Does the VGP advantage extend to cognitive control?

A number of studies have described a benefit for VGPs in tasks requiring visual or visuospatial ability. The results within the domain of cognitive control seem less clear. Taken together, the research findings described above provide some evidence toward a VGP advantage in cognitive control, but null results have also been reported. The evidence from task switching, a task requiring the greatest degree of endogenous cognitive control, is particularly divisive. While some studies have reported clear VGP advantages in task switching, VGP performance may depend on the cognitive demand elicited by the task.

Task switching is an established measure of cognitive control (Allport & Wylie, 1999; Miyake et al., 2000; Monsell, 2003). However, although cognitive control is needed to engage in task switching, other skill domains are necessarily involved in task completion. Stimuli must be perceived, using visual, attentional, and visuospatial processing, and responses are made using motor skills. Performance on such a complex task must be deconstructed in order to correctly understand which aspect, out of several involved, might result in a difference between groups.

Karle, Watter, and Shedden (2010) manipulated levels of cognitive demand within two task switching paradigms to show that VGPs demonstrate differing switch cost benefits depending on the degree of cognitive demand required by the task. VGPs outperformed nVGPs when tasks in a cued task switching paradigm were distinct and little cognitive demand was required to succeed in the task. However, when the task took on an increased amount of stimuli and response overlap, thereby increasing the cognitive control demand necessary, VGPs performed on par with nVGPs. Karle et al. (2010) conclude that VGPs do enjoy an advantage in controlling selective attention, but this benefit does not extend to a domain-general benefit in cognitive control.

A majority of the task switching studies observing a VGP benefit in cognitive control have not controlled for the influence of benefits stemming from advantages unrelated to cognitive control, such as speeded responses and visuospatial processing. Benefits such as these will necessarily affect response times in control-related tasks, such as task switching, and it is possible that researchers investigating these effects may interpret differences in performance as an advantage in cognitive control. Green et al. (2012) observed a VGP benefit across three task-switching paradigms and a training study. Although this group attempted to separate effects of cognitive control from simple motor and auditory responses, they noted that the generally speeded responses of VGPs in comparison to nVGPs resulted in inflated effects, and when the baseline speed difference between groups was taken into consideration, the difference in switch cost between VGPs and nVGPs was only marginal. Across task switching studies, only Green et al. (2012) and Karle et al. (2010) have attempted to control for baseline differences between VGPs and nVGPs that may be unrelated to cognitive control. These results call into question the validity of the previous findings. A recent meta-analysis by Powers et al. (2013) demonstrates that effect sizes for quasi-experimental studies examining differences between VGPs and nVGPs result in particularly low effect sizes for studies investigating executive function, in comparison with moderate to large effect sizes for other domains, such as visual and spatial processing.

In light of possible misinterpretations, whether VGPs possess an advantage in cognitive control remains unclear. The purpose of this dissertation is to carefully and deliberately manipulate measures of cognitive control to compare cognitive control ability in VGPs and nVGPs, while clearly dissociating cognitive control from other task elements. By manipulating the degree of cognitive demand within levels of each cognitive control task, the following experiments will observe differences between groups while controlling for the effects of possible VGP advantages in other domains. In the following three data chapters, this dissertation will investigate differences between VGPs and nVGPs using well-established tasks that harness the three components of cognitive control as put forth by Miyake et al. (2000): task switching, working memory, and inhibitory control.

Distinguishing cognitive control ability from performance in other domains

The following dissertation will carefully examine whether differences exist between VGPs and nVGPs in cognitive control using three sets of experiments reflecting the components of cognitive control as described by Miyake et al. (2000). In Chapter 2, a set of experiments will use two task switching paradigms to investigate group differences in cognitive control: a comprehensive task switching design to examine task switching performance across four types of switch trials (Arbuthnott & Frank, 2000), and a traditional quadrant-style task switching design with locational cues (Rogers & Monsell, 1995). Within each design, degree of cognitive demand will be manipulated across levels to distinguish general performance benefits (e.g., speeded response, visuospatial ability) from benefits related directly to cognitive control via the ability to switch mental set. Chapter 3 will investigate possible group differences in the second component of cognitive control, the ability to update and monitor working memory, using a series of n-back tasks. In these tasks, levels of cognitive demand will be varied via manipulation of memory load and the incorporation of misleading lure stimuli. Chapter 4 will address the third component of cognitive control, the ability to inhibit automatic responses. In this chapter, a set of three experiments using well-established measures of inhibitory control (flanker, Stroop, and go no-go tasks) will examine whether VGPs and nVGPs exhibit differences in the ability to withhold automatic responses. In each of these tasks, level of cognitive demand will be manipulated by varying the proportion of congruent trials within blocks. Using these three approaches, this dissertation will carefully establish that although VGPs may possess an advantage in some domains, there is no convincing evidence for a VGP benefit in cognitive control.

Chapter 2

INTRODUCTION

This chapter uses two task switching paradigms to assess differences between VGPs and nVGPs in cognitive control. Task switching performance is a well-established index of cognitive flexibility, and has been identified by Miyake et al. (2000) as the first component of cognitive control. Experiment 1 uses a comprehensive task switching paradigm (Arbuthnott & Frank, 2000). This paradigm allows analysis of four possible switch types (repeat, 1-switch, 2-switch, and alternate switching), providing a complete portrait of switching performance in participants. Experiment 2 uses a traditional quadrant locational cue paradigm (Rogers & Monsell, 1995).

Cueing

Task switching particularly lends itself to comparing groups that may differ in cognitive ability, because the cognitive difficulty of each task can be manipulated along several dimensions. One such manipulation is varying the amount of time between a cue and the target stimulus, or the cue-to-target interval (CTI). Researchers who have varied this factor in task switching have employed a cueing paradigm. Some task switching designs have incorporated informative, explicit cues instructing participants about which task type they are about to complete. These cues appear before the target stimulus, and they allow researchers to make interpretations about the time course of cognitive processes involved in switching from one task to another. Varying the CTI allows observation of precisely how switch costs are altered by smaller or larger amounts of time to prepare a response between cue presentation and task stimulus presentation.

Another factor that can be varied to increase cognitive difficulty of the task is response-to-stimulus interval, or RSI. Varying RSI manipulates the amount of time on each trial between the particpant's response and when the next stimulus appears. According to theories of task switching, (e.g., Allport et al., 1994; Jersild, 1927; Rogers & Monsell, 1995) in order for a participant to complete a task, a set of rules associated with the stimulus in question must be activated. These rules can be thought of as a set of cognitive representations of task-relevant stimuli and corresponding processes associated with them, including stimulus-response (S-R) mappings (Kiesel et al., 2010). However, these rules must also be deactivated before the next stimulus can be processed, leading to its own activation of distinct rules for a new task set. The amount of time it takes to deactivate a task set and activate a new one is called *advance reconfiguration* (Rogers & Monsell, 1995). Advance reconfiguration can also be thought of as the amount of time a participant has to prepare for an upcoming task. Rogers and Monsell (1995) found that on switch trials, switch cost is decreased as participants are given more time to prepare via increased RSI. Mieran (1996) supported these results using a cueing paradigm and varying the amount of time between cue and stimulus, or the cue-to-stimulus interval (CSI), with longer CSIs resulting in decreased switch costs.

Task set overlap

Another factor that can be varied in order to manipulate cognitive difficulty level of a task is valency of the stimulus. When a stimulus is univalent, the stimulus and response do not overlap with any other task being completed; use of univalent stimuli result in low task overlap conditions. However, if a stimulus is bivalent, it may serve as a target for more than one type of task. Use of bivalent stimuli result in high task overlap conditions. For example, a study may use the same digit stimuli for two distinct tasks: parity determination and magnitude. Participants are informed about which task to perform by using explicit cues, as described above. For example, in a parity task, participants are required to indicate whether the digit is odd or even. For the magnitude task, using the same two response keys, they are required to indicate whether the digit is larger or smaller than a given reference number. Through a combination of bivalent stimuli and informative cues, researchers are able to employ identical stimuli for both (or more) tasks. Bivalent stimuli with the same response keys (response mappings) are more cognitively challenging than univalent stimuli, because one stimulus can activate more than one task set, and these activations may overlap, causing interference. As more tasks are added using the same stimulus, task overlap increases and greater interference is created, and the task becomes increasingly more cognitively challenging.

The combination of bivalent stimuli and predictive cues allows researchers to manipulate many aspects of task switching, including the length of intervals between cue and target, and response and the following trial's target stimulus (response-to-stimulus interval; RSI). The study of participant response to CTI and RSI manipulations are of interest in understanding the components involved in task switching, and in interpretation of what causes the switch cost. These manipulations are also useful for discovering performance differences across different populations, such as VGPs compared with nVGPs.

The variety in cognitive difficulty levels across studies and the lack of comparison across levels of difficulty may account for some of the inconsistency in the VGP literature, and careful manipulation of these factors may help determine whether VGPs show a true cognitive advantage compared with nVGPs. Many of the studies finding a VGP advantage may be finding this advantage in tasks that are more perceptual than cognitive in nature. Karle and colleagues (2010) found that VGPs demonstrated an advantage on a cognitive task that was relatively easy, but when the difficulty of the task was increased by increasing interference through response mapping overlap, VGPs performed on par with nVGPs. They increased task difficulty by manipulating stimulus overlap and the time that participants had to prepare a response during the cue-to-target interval.

In this study, we conducted two experiments to determine how cognitive difficulty of the task might influence VGP advantage in task switching. Experiment 1 varies stimulus overlap and response preparation time in a task-switching paradigm using explicit verbal cues. Experiment 2 uses a more traditional Rogers and Monsell (1995) style task switching paradigm to determine whether the same results can obtained without the use of explicit verbal cueing.

Based on the previous literature, we can expect to see some differences in performance between VGPs and nVGPs. In these experiments, we have manipulated level of cognitive difficulty. By distinguishing cognitive difficulty from other dimensions of the tasks, we can examine results for differences attributable only to this domain. If VGPs do show a cognitive advantage in the following experiments, we would expect to see faster RTs and lower switch costs on all trials. Further, we would expect to see that VGPs perform especially well compared with nVGPs in conditions that have been manipulated to maximize cognitive difficulty. These conditions are switch trials in comparison to repeat trials, high stimulus overlap compared to low stimulus overlap, and short CTI compared with long CTI. If we find that VGPs do show an advantage in these cognitively difficult conditions, we can conclude that VGPs do possess a cognitive advantage compared with nVGPs. If we find no differences between groups, then we can assume that no such cognitive advantage for VGPs exists. Another possibility is that VGPs do possess an advantage over nVGPs, but that this advantage is a result of an ability to respond faster across all types of trials, not only the more cognitively challenging conditions. If this is the case, we can expect to see faster absolute response times for VGPs compared with nVGPs on all trial types. When differences are expressed as a proportion of repeat RTs to account for baseline differences between VGPs and nVGPs (e.g., switch trials as a proportion of repeat trials), we should see no difference between groups.

EXPERIMENT 1

METHODS

Experiment 1 was designed to investigate how varying switch type, CTI, and stimulus overlap might affect the task switching performance of VGPs compared with nVGPs. Karle et al. (2010) showed that under low stimulus overlap conditions, VGPs demonstrated an advantage over nVGPs, but when stimulus overlap was increased, this advantage disappeared. This task switching paradigm incorporates two levels of stimulus overlap (low, high) and two levels of response preparation time (cue-to-target interval; short, long).

Participants

For this experiment, we wanted to avoid a bias in recruiting such that expert video game players might perform better because they knew they were being recruited for their gaming ability and deduced what the experiment might be about (see Boot, Simons, Stothart, & Stutts, 2013). Participants were recruited through an advertisement stating that during the course of a psychology experiment they would play a fun game and challenge themselves. No information about video games was presented in the advertisement.

We also wanted to avoid some of the problems that have arisen in the classification of VGPs in the literature as raised by Latham, Patston, and Tippett (2013), which may be contributing to some of the contradictory and inconclusive results among video game studies (see also, Boot et al., 2008; Murphy & Spencer, 2009;, Powers et al., 2013; Unsworth et al., 2015). Latham and colleagues point out that the number of hours played per week within the last six months to one year may be a misleading number, not necessarily representative of whether or not a participant should be considered a VGP or not. For example, we found that a large subset of VGPs were very disciplined in controlling their play during the school semester, but would play 20+ hours per week during vacations. Another subset had recently stopped playing video games for a variety of reasons, but during the past 1-3 years had periods in which they played upwards of 60 hours per week, for several weeks or months at a time. If cognitive or physiological changes are truly occurring in people who spend large amounts of time playing video games, surely these participants, who spent incredibly large amounts of time playing in the relatively recent past, should be considered VGPs, even if they are currently playing zero hours per week.

In order to most accurately classify participants into VGP and nVGP groups, we asked all participants to complete a questionnaire about their video game play habits, including questions about hours played per week *currently*, hours played per week at their *peak* play period, what game genres they played, what specific games they played, what gaming platforms they most often used for play, whether they played socially or independently, and how they would rate their own gaming ability. Using information from the questionnaire, we divided them into groups of gamer (VGP) and nongamer (nVGP). We classified *current* hours per week and *peak* hours per week into *high* (> 4 hours per week) and *low* (< 2 hours per week). If a participant was classified as *high* for both current and peak periods, they were classified as a gamer. If a participant was classified as *low* current but *high* peak, we examined their other questionnaire data and determined their classification based on their estimation of their own skill level and the magnitude of their *peak* number of hours per week. In addition, all participants who were classified as VGPs reported playing first person shooter (FPS) games (most often in addition to a number of other game genres). Participants who reported playing action games, but not first person shooter games, were excluded from the analyses.

We recruited 30 male and 13 female participants from the McMaster undergraduate psychology participation pool using this advertisement. Female participants were recruited in the hopes that female gamers could be analyzed, but because all female participants were nongamers, we excluded females from further analysis in order to avoid sex as a confounding variable in the groups. It should be noted that the female participants recruited did play a moderate amount of video games, but they were most often mobile-based and non-action games, such as "Candy Crush." Upon completion of the experiment, all participants completed the questionnaire about their video game play habits.

Virtually every participant recruited played some amount of video games per week. A large majority of participants played a small-to-moderate amount of hours per week. In order to distinguish VGPs from nVGPs we categorized nVGPs as players who spent less than 2 hours per week playing video games. This criterion resulted in 28 nVGPs and 1 VGP. In order to recruit additional "true" VGPs who spent more time gaming, we recruited participants once more, this time using advertisements for participants who considered themselves to be "expert" video game players or who considered themselves to be nongamers. We recruited 12 additional male VGP participants, resulting in group of VGPs (N = 13, mean age = 18.6) and nVGPs (N=28, mean age = 19.1). According to the criteria mentioned above, three participants who signed up as nongamers were switched to the VGP group because although they were not playing many hours currently, they had very high peak hours of play per week.

Stimuli and apparatus

Stimuli were the letters “M”, “G”, “A”, “R”, “U”, “E”, the numbers “1”, “2”, “3”, “4”, “6”, “7”, “8”, “9”, and the symbols “<”, “&”, “+”, “?”, “=”, and “!” in Arial font, coloured grey and presented on a black background. All stimuli were sized to subtend a visual angle of approximately 1° and presented individually in the centre of a computer monitor display. One of five informative verbal cues (“vowel/consonant”, “math/text”, “odd/even”, “prime/multiple”, “less/more”) was presented directly above the current stimulus on every trial, indicating which task the participant should complete on the current stimulus. On each trial, the task cue was presented for either 100 ms or 1000 ms and then accompanied by the verbal task cue presented approximately 1.5° visual angle. Both the stimulus and task cue remained on screen until a response was made. The next trial would then begin after a constant inter-trial interval of 100 ms. Incorrect responses elicited an immediate auditory feedback signal of 100 ms and 100 Hz square wave. All stimuli were presented via a 19-inch computer monitor and a Pentium 4 computer using Presentation (v.12. 0, http: www.neurobs.com) experimental software and a Windows XP operating system.

Procedure

Experiment 1 asked participants to make speeded responses to one of 6 single-digit characters in low and high stimulus overlap conditions. Within these conditions, we varied the time participants had to prepare between the cue and target (cue-to-target interval; CTI). CTI was either short (100 ms), giving participants limited time to prepare their response, or long (1000 ms), giving participants ample time to prepare their response. CTI length alternated by block.

On each trial of the low overlap condition, participants were given an informative verbal task cue indicating which of three tasks they would complete on that trial: a *letter* task (is this letter a vowel or a consonant?), a *symbol* task (is this a text symbol (e.g., "&"), a math symbol (e.g., "+"), or a *number* task (is this number odd or even?). After the cue and the CTI (100 or 1000 ms, depending on the blocked condition), a stimulus corresponding to the cue appeared in the center of the visual display. Participants used assigned keys to indicate their response; six individual keys were assigned for vowel, consonant, text symbol, math symbol, odd, and even. Three of the response keys were accessed with the left hand and three were accessed with the right hand, with one half of each response set corresponding to each hand. For example, the response "odd" was a left hand response, and "even" was a right hand response. Nine blocks of stimuli were presented, with 60 trials per block. Task type presentation was pseudorandom (see below) with an equal number of trials for each type; one third of trials (20 trials per block) were the letter task, one third were the number task, and one third were the symbol task. Prior to the experiment, each participant completed one block of practice trials in order to ensure they understood the task. In this low overlap condition, participants are completing three separate tasks, each with its own distinct set of stimuli, resulting in low stimulus overlap among the tasks.

In the high overlap condition, participants were asked once more to complete one of three separate tasks on each trial. In this condition, participants once again used six response keys in order to respond to the tasks. However, in this condition, the stimuli for all the tasks were *number* stimuli. Here, participants answered *a parity* task (“is this number odd or even?”), *a magnitude* task (“is this number less than 5 or more than 5?”) or a *prime* task (“is this number a prime or a multiple?”). Thus, although participants are completing three different tasks, there is high overlap across stimuli, because stimuli for all three tasks are numeric. Stimulus overlap condition varied every other block, such that low and high overlap would be combined with short and long CTI conditions for all possible iterations within each participant.

RESULTS

One participant was excluded for poor performance in the task (unusually slow reaction times (> 4000 ms on a more than 50% of trials). For the remaining participants, trials with responses that were unusually fast (less than 250 ms) or unusually slow (greater than 3000 ms) were excluded from analyses.

Reaction Time

Correct RT and accuracy data were analysed with repeated measures ANOVA with within-subjects factors of task set overlap (low, high), switch type (repeat, 1-switch, 2-switch, alternating), and CTI (short, long), and a between-subjects variable of gaming expertise (VGP, nVGP).

Figure 1 shows mean RT and accuracy data for Experiment 1 separated by switch type, CTI and task set overlap and gamer group. Typical task switching effects were observed. Switch trials of all types were slower than repeat trials, $F(3, 117) = 152.08$, $p < 0.001$, $\eta_p^2 = 0.80$; trials with short cue-to-target intervals were slower than trials with long CTIs, $F(1, 39) = 167.21$, $p < 0.001$, $\eta_p^2 = 0.81$; high task set overlap trials were slower than low task set overlap trials $F(1, 39) = 231.27$, $p < 0.001$, $\eta_p^2 = 0.86$. A number of interactions revealed combined effects of task difficulty. Task switching costs were larger at long versus short CTIs, $F(3, 117) = 12.21$, $p < 0.001$, $\eta_p^2 = 0.24$, and also in high task set overlap versus low task set overlap conditions, $F(3, 117) = 25.86$, $p < 0.001$, $\eta_p^2 = 0.40$. The three-way interaction of switch type, CTI, and task set overlap was also significant, $F(3, 117) = 5.30$, $p = 0.002$, $\eta_p^2 = 0.12$, with the effect of increased switch cost at short CTI magnified in high task set overlap conditions. Finally, the interaction of CTI and task set overlap was also significant, $F(1, 39) = 56.18$, $p < 0.001$, $\eta_p^2 = 0.59$, reflecting the effect of increased RT at short CTI trials amplified at high task set overlap conditions.

Within these characteristic task switching effects, we observed a number of group differences. There was an overall main effect of group, $F(1, 39) = 6.64$, $p = 0.014$, $\eta_p^2 = 0.15$, with VGPs performing faster overall compared to nVGPs. Switch costs were observed to be smaller for VGPs than in nVGPs, $F(3, 117) = 3.06$, $p = 0.031$, $\eta_p^2 = 0.07$. VGPs showed marginally smaller switch costs compared to nVGPs in high task set overlap conditions, $F(3, 117) = 2.36$, $p = 0.075$, $\eta_p^2 = 0.06$, and also on short CTI trials, $F(3, 117) = 2.17$, $p = 0.094$, $\eta_p^2 = 0.05$. Faster performance for VGPs was generally larger in high task set overlap conditions, $F(1, 39) = 5.73$, $p = 0.022$, $\eta_p^2 = 0.13$. Interactions of group and CTI, group and CTI with task set overlap, and the four-way interaction were not significant, $Fs < 0.2$.

To better evaluate the effect of gaming group on switch costs, we re-analysed data separately for low and high task set overlap conditions. For low task overlap data, strong typical task switching effects of switch type and CTI were observed, mirroring the effects described in the main analysis above. VGPs were faster overall compared with nVGPs, with a main effect of group, $F(1, 39) = 4.20$, $p = 0.047$, $\eta_p^2 = 0.10$. However, this gaming group difference did not interact with any other variables, $Fs < 1.1$, with no switch cost differences between VGPs and nVGPs.

For high task overlap data, strong typical task switching effects of switch type and CTI were once more observed, mirroring the main analysis and the univalent data above. VGPs were again faster overall compared with nVGPs, with a main effect of group, $F(1, 39) = 8.27$, $p = 0.007$, $\eta_p^2 = 0.18$. VGPs showed marginally reduced switch costs compared with nVGPs, $F(3, 117) = 4.06$, $p = 0.090$, $\eta_p^2 = 0.09$. CTI did not interact with the group variable alone or in combination with switch type, $Fs < 0.1$.

Figure 1 shows mean RT proportion-adjusted data. Given the main effect of decreased VGP RTs compared with nVGPs in the main analysis and within the subsequent low and high task overlap conditions, we wanted to address the possibility of baseline differences in RT between VGPs and nVGPs. If VGPs respond more quickly to all trial types (repeat, 1-switch, 2-switch, and alternating) compared with nVGPs, the relative effects of all RTs may be interpreted as decreased in switch cost rather than simply as a faster baseline RT. As such, taking the absolute RT difference may be less useful than adjusting proportional RT relative to the baseline trial type (repeat trials), providing a more accurate portrait of switch cost while controlling for baseline differences. To do this, we normalized the repeat trial RT for each participant (set to 1.0) and recalculated the mean switch cost for each trial as a proportion relative to repeat trials. In this proportion-adjusted analysis, we continued to observe typical task switching effects of switch type, $F(1, 39) = 13.36$, $p < 0.001$, $\eta_p^2 = 0.26$. Participants performed better in low compared with high task set overlap conditions, $F(1, 39) = 25.69$, $p < 0.001$, $\eta_p^2 = 0.40$, and this effect was more pronounced on low compared with high CTI trials, $F(1, 39) = 5.63$, $p = 0.023$, $\eta_p^2 = 0.13$. A marginal interaction of switch type, CTI and group reflected reduced switch costs for VGPs compared with nVGPs in short CTI and more difficult trial type conditions, $F(1, 39) = 2.92$, $p = 0.060$, $\eta_p^2 = 0.07$. However, we observed that controlling for baseline differences in RT in this manner resulted in no overall difference between VGPs and nVGPs, $F(1, 39) = 1.57$, $p = 0.215$.

To further examine where differences might exist between VGPs and nVGPs, we also analysed the proportion-adjusted data separately for low and high task set overlap conditions. For the low task set overlap data, typical task switching effects of switch type and CTI were once more observed. There was no overall group difference between VGPs and nVGPs, $F(1, 39) = 0.244$, $p = 0.624$ and no interactions of group with either CTI or switchtype, $Fs < 1.8$. The high task set overlap data also showed typical task switching effects of switch type and CTI. However, unlike the main proportion-adjusted analysis above, we observed no group interaction with CTI and switch type, $F(1, 39) = 1.26$, $p = 0.268$.

We analyzed the proportion-adjusted data for only high task set overlap conditions for short and long CTI separately. In high task set overlap and short CTI conditions, there was a typical main effect of switch type but no interaction with group, $F < 0.8$, and no overall effect of group, $F < 0.9$. In high task set overlap and long CTI conditions, we observed a typical main effect of switch type. We also observed an overall group difference, with VGPs showing a reduced switch cost compared with nVGPs in high task set overlap and long CTI conditions, $F(1, 39) = 4.911$, $p = 0.033$, $\eta_p^2 = 0.11$. Group did not interact with switch type on long CTI and high task set overlap trials, $F < 1$.

Accuracy

Figure 1 shows mean accuracy data for Experiment 1. We analysed accuracy data within the main dataset to determine whether differences in accuracy existed between VGPs and nVGPs. As expected, we found typical task switching effects in accuracy. All participants made fewer errors in low compared with high task set overlap, $F(1, 39) = 9.63$, $p = 0.004$, $\eta_p^2 = 0.20$, and in repeat trials compared with switch trials, $F(1, 39) = 12.18$, $p < 0.001$, $\eta_p^2 = 0.24$. There were no differences in accuracy between short and long CTI, $F < 2$. There was no overall difference in accuracy between VGPs and nVGPs, $F (1, 39) = 0.003$.

To further determine differences in accuracy, we separately analysed low and and high task set overlap conditions. In low task set overlap conditions, we observed strong typical task switching effect of switch type, mirroring the main effect of the main accuracy analysis above. However, there was no overall difference in accuracy between short and long CTIs, $F < 1$. We observed a marginal interaction of gamer group, CTI, and switch type, reflecting lower accuracy for VGPs compared with nVGPs on repeat trial types at short CTIs, $F(3, 117) = 2.62$, $p = 0.054$, $\eta_p^2 = 0.06$. This interaction seems to be driven by very high accuracy performance by nVGPs in the short CTI repeat condition. This may suggest some degree of speed-accuracy tradeoff for VGPs in this particular trial type, but this effect is not observed across the rest of the data. We observed no overall difference in accuracy between VGPs and nVGPs in this low task set overlap condition, $F(1, 39) = 0.113$.

In high task set overlap conditions, we again observed a strong main effect of switch type, but no overall difference in accuracy between short and long CTI, $F < 0.5$. We observed no overall group difference between VGPs and nVGPs in accuracy in this high task set overlap condition, $F < 0.03$, and gamer group did not interact with either switch type or CTI, $Fs < 0.9$.

DISCUSSION

Experiment 1 was designed to carefully investigate whether group differences in cognitive control exist between VGPs and nVGPs, using a task switching paradigm as a measure of cognitive control. Within the task switching paradigm, we manipulated the amount of cognitive control needed to complete the task successfully by using several switch types (following Arbuthnott & Frank, 2000), and by varying cue-to-target interval and task set overlap.

A large number of expected main effects and interactions were observed across all participants. We found that all participants had higher switch costs on switch trials compared to repeat trials, and that this effect was magnified on trials with short CTIs and in high task set overlap conditions. We observed interaction effects suggesting that switch costs were greatest for all participants on long CTI switch trials in high task set overlap conditions. The observation of these effects suggest that our task switching paradigm was effective and that participants were effortfully completing the tasks as required.

In the original, unadjusted analysis, we observed a number of group differences. VGPs performed faster overall compared to nVGPs, and performed marginally faster in high task set overlap conditions and on short CTI trials, the most cognitively challenging conditions. We further examined these differences by considering low and high task set conditions separately. In the low task overlap condition, we found that VGPs were overall faster than nVGPs. In the high overlap condition, we also saw an overall effect of gamer group, with VGPs performing faster and having a reduced switch cost compared with nVGPs.

Initially, these effects suggest that VGPs are outperforming nVGPs in speed and switch cost in task switching, particularly in conditions promoting a high need for cognitive effort, such as high task overlap and short CTI. We did not stop our analyses there, because these results cannot be taken at face value if VGPs simply respond faster to all trials than do nVGPs. If this is the case, what appears to be an advantage in cognitively challenging conditions may actually be a by-product of a speeded response ability present in VGPs, not necessarily cognitive in nature. To account for possible baseline differences between VGPs and nVGPs, we re-analysed the data by comparing switch trials to repeat trials, using mean repeat trial performance for each participant as a baseline. In this proportion-adjusted analysis, switch trials are viewed as a proportion of the repeat trials, which are set to 1. This re-analysis produced a very different set of results.

When accounting for baseline differences between VGPs and nVGPs using the proportion-adjusted analysis, we continued to observe the expected main effects of our task switching paradigm, including strong main effects of task set overlap and CTI. The perseverance of these main effects suggests that our analysis did not undermine the original results. However, in this analysis, we observed no overall differences between VGPs and nVGPs. We analyzed low and high task set overlap separately in the proportion-adjusted analysis and found no differences between VGPs and nVGPs, and further broke down this analysis by short and long CTI. VGPs were faster compared with nVGPs in the high task set overlap condition, but only on long CTI trials.

These results suggest that VGPs do have an advantage when compared with nVGPs, but this advantage is not cognitive. Given that the advantage was not apparent in the main proportion-adjusted analysis, it is a small advantage. Importantly, that this advantage was found in long but not short CTI trials suggests that the nature of this advantage is not cognitive. If it were, we would have seen an advantage in the short CTI condition, rather than the long. Under long CTI conditions, participants have much more time (900 ms) to assess the cue, stimulus, and to make their response. While VGPs are able to perform better than nVGPs with more time to prepare in the difficult high task set overlap condition, they perform on par with nVGPs when the time allotted for preparation is short.

EXPERIMENT 2

Experiment 1 found that VGPs did perform better than nVGPs on a task switching task, but only in less cognitively demanding conditions, suggesting that while VGPs do enjoy an advantage in responding, this advantage is not cognitive in nature. Experiment 2 was designed to address the possibility that the results of Experiment 1 were due in some way to our particular informative-cue based design and not to actual differences between VGPs and nVGPs. We wanted to use a traditional task-switching paradigm for Experiment 2, and adopted the 2 x 2 quadrant method of Rogers and Monsell (1995) as a template for this task switching experiment. We adapted this paradigm so that we could continue to compare VGPs and nVGPs on tasks of varying cognitive difficulty. Here, we again manipulate difficulty on three factors: switch type (repeat versus switch), RSI (long versus short), and task set overlap (univalent versus bivalent stimuli). These manipulations allow us to preserve the traditional quadrant task-switching approach while testing for differences in performance according to cognitive difficulty between VGPs and nVGPs.

METHODS

Participants

Participants were 118 participants recruited from the undergraduate student population at McMaster University and compensated either financially or with course credit. All participants were recruited via advertisements for "expert video game players" or "individuals who do not play video games". According to their questionnaire data (see Experiment 1), 63 were classified as gamers and 55 were classified as nongamers. 13 VGPs who participated in Experiment 2 were VGPs who also participated in Experiment 1. For the purposes of analysis, participants were divided into extreme and inclusive VGP and nVGP groups (see results).

Procedure

Experiment 2 asked participants to make speeded responses to one of 2-digit combination stimuli in univalent and bivalent conditions. Within these conditions, we varied the time participants had to prepare between their responses and the presentation of the next stimulus (response-to-stimulus interval, or RSI). RSI was either short (100 ms), giving participants limited time to prepare for the next trial, or long (1000 ms), giving participants ample time to prepare for the next trial. RSI length and valency alternated by block, and starting RSI and valency were counterbalanced across participants.

Stimuli were letter-symbol (e.g., “L %”), number-symbol (e.g., “% 4”), or letter-number combinations (e.g., “L 4”) appearing in one of four sections of a 2 x 2 quadrant, as in the alternating-runs paradigm put forth by Rogers and Monsell (1995). Each stimulus was presented in the quadrant section in clockwise order (upper left, upper right, lower right, lower left, etc.). On each trial, a combination of the letters “A”, “E”, “I”, “U”, “R”, “K”, “G”, “M”, symbols “!”, “;”, “%”, “#”, “*”, “&”, “/”, “?”, and the digits “3”, “5”, “7”, “9”, “2”, “4”, “6”, “8” would appear. In the low task set overlap condition, stimuli consisted of only letter-symbol or number-symbol combination stimuli. On letter-symbol trials, participants were instructed to make a decision about whether the letter was a vowel or a consonant, and respond with a button press. On number-symbol trials, they were instructed to make a decision about whether the number was odd or even and respond using the same button press.

In the high task set overlap condition, stimuli consisted of only letter-number combination stimuli. On these letter-number trials, participants were informed that on trials with stimuli appearing in the upper half of the quadrant, they should respond to the letter stimulus, and on trials with stimuli appearing in the lower half of the quadrant, they should respond to the number stimulus. Upper/lower quadrant number and letter mappings were counterbalanced across participants, such that half of participants responded to letters in the upper quadrant and the other half responded to letters in the lower quadrant. On each trial, the stimulus was terminated upon response and followed by the next quadrant stimulus. Incorrect responses elicited an immediate auditory feedback signal of 1500 ms and 100 Hz square wave.

Each block consisted of 32 trials, and all participants completed 1 block of practice (16 univalent trials, 16 bivalent trials) and 16 experimental blocks.

RESULTS

VGP and nVGP group assignment

Participants were separated into extreme groups of VGPs and nVGPs. Although we agree with the criticism of extreme groups analysis made recently by Unsworth and colleagues (2015), extreme groups analysis is appropriate for this experiment because our hypothesis is that there are no differences between groups. Our purpose was to analyse a set of extreme groups first, in order to see if any differences exist in the most exaggerated conditions of VGP and nVGP, and then expand that analysis to include a set of less-extreme participants who still fit a more relaxed criteria for VGP or nVGP identification.

We separated all participants into extreme groups. Criteria were as follows: For extreme VGP, participants reported a weekly play time of 7 hours or more, AND a high peak weekly play time of 20 hours per week or more, AND they played primarily first-person shooter games. For membership in the extreme nVGP group, participants had to report a weekly play time of 2 hours per week or less, AND report a peak weekly play time of 10 hours or less, AND primarily play first-person shooter games. It was important for us to ensure that nVGPs also played first person shooter games so that the groups were matched for possible skill sets; strategy or puzzle games have not been noted as resulting in the same kinds of cognitive benefits for gamers as person shooter and action video games have.

In order to determine whether the effects we found in the extreme groups analysis would persist in a larger pool of participants with more variable game play experience, we created a set of inclusive groups with slightly relaxed criteria. For membership in the inclusive VGP group, participants had to report at least 2 to 6 hours per week of play time, in addition to 10 to 19 hours per week during their peak play period. This group also included a set of participants who reported moderate amounts of weekly play time (2 to 6 hours) but who also reported high amounts of weekly play during their peak play period (20 hours or more). It was important to include this set of participants in the group analysis because they clearly enjoyed gaming and engaged in it much more often when they were not attending classes; a majority of these participants included a recent holiday from university as their peak play period. In addition to these participants, the inclusive VGP group included the extreme VGP participants described above. All VGP participants in the inclusive group reported primarily playing first person shooter games. For membership in the inclusive nVGP group, participants had to report moderate amounts of weekly play, but 10 hours per week or less at their peak period of play. The inclusive nVGP group also included participants who reported 2 hours or less of weekly play time with moderate amounts of play at their peak play period, of up to 19 hours per week. For the inclusive nVGP group, we also included participants who reported video game play other than first person shooter games. These group criteria successfully categorize our participants by incorporating more information about game play habits than simply hours per week, as most previous studies have done. A simple hours-per-week criterion may not be enough to capture which participants are truly VGPs and which are nVGPs, which may account for some of the inconsistent results in the VGP literature. However, these group divisions did cost us the use of some data in the case of participants who did not meet the membership criteria for any of the groups. These participants had inconsistent play habits, including low weekly play with high peak play (often from several years ago), and participants with high or moderate weekly play times but who did not play first person shooter games, who did not fit appropriately into any group. We also excluded female participants from the analysis because, as is common in the VGP literature, there were not enough female VGPs (according to the criteria we employed here) in order to equate the number of females across groups, resulting in a gender confound. We were able to collect data from 5 female VGPs, and attempted to recruit additional female VGP participants, but were not able to do this.

These criteria resulted in 22 VGPs (mean age = 18.9 years) and 20 nVGPs (mean age = 18.1 years) in the extreme groups analysis, and 48 VGPs (mean age = 18.9 years) and 31 nVGPs (mean age = 18.3 years) in the inclusive groups analysis, leaving 34 male participants (mean age = 20.1 years) who were excluded from analyses due to no clear group membership and 5 excluded female participants. We excluded data from trials on which participants responded unusually slowly or quickly (< 300 ms or > 2500 ms) and data from incorrect trials and one trial post-incorrect response.

Extreme groups analysis

Reaction time, Extreme Groups

Correct RT and accuracy data for the extreme groups were analysed with repeated measures ANOVA with within-subjects factors of task set overlap (univalent, bivalent), switch type (repeat, switch), and RSI (short, long), and a between-subjects variable of gaming expertise (VGP, nVGP).

Figure 2 shows mean RT and accuracy data for Experiment 2 extreme groups separated by task set overlap, switch type, RSI, and gamer group. Typical task switching effects were observed. Responses to repeat trials were faster than responses to switch trials, $F(1, 40) = 241.47$, $p < 0.001$, $\eta_p^2 = 0.86$; trials with long RSIs were faster than short RSIs, $F(1, 40) = 4.65$, $p = 0.037$, $\eta_p^2 = 0.10$; trials with univalent stimuli were faster than trials with bivalent stimuli, $F(1, 40) = 254.70$, $p < 0.001$, $\eta_p^2 = 0.86$. An interaction of task set overlap and switch type indicated a combined effect of task difficulty, reflecting increased switch costs in bivalent stimuli conditions for all participants, $F(1, 40) = 61.20$, $p < 0.001$, $\eta_p^2 = 0.61$, and a marginal interaction of switch type and RSI, reflecting increased switch costs on short RSI trials for all participants, $F(1, 40) = 2.97$, $p = 0.093$, $\eta_p^2 = 0.07$.

We also observed a number of group differences within these characteristic task switching effects. There was no overall effect of group, $F(1, 40) = 2.17$, $p = 0.149$. However, group did interact with other variables. We observed a marginal three-way interaction of group, switch type, and RSI, $F(1, 40) = 3.68$, $p = 0.062$, $\eta_p^2 = 0.08$, reflecting faster responses for VGPs compared to nVGPS in the short RSI condition on repeat trials, but not on switch trials. Interactions of group and valency, group and switch type, group, valency and RSI, and the four-way interaction were not significant, $Fs < 0.7$.

To further evaluate the effect of gaming group on switch costs, we re-analyzed data separately for low (univalent) and high (bivalent) task set overlap conditions. For univalent conditions, strong typical task switching effects of switch type and RSI were observed, mirroring the effects described in the overall analysis above. There was no main effect of group when univalent data were analysed separately, $F < 1.8$. For bivalent conditions, we once more observed strong typical effects of task switching in RSI and switch type. The overall effect of group in bivalent conditions approached significance, $F(1, 40) = 2.25$, $p = 0.141$, $\eta_p^2 = 0.05$. However, the between-subjects group variable was observed in a three-way interaction of group, RSI, and switch type, $F(1, 40) = 5.90$, $p = 0.020$, $\eta_p^2 = 0.13$, reflecting that VGPs had faster performance compared with nVGPs on repeat, long RSI trials in bivalent stimuli conditions. Interactions of RSI and group and switch type and group were not significant in bivalent conditions, $Fs < 0.5$.

To further investigate this group difference, we analysed univalent and bivalent data at short and long RSI separately. In univalent and short RSI conditions, we observed a strong typical effect of switch type, $F(1, 40) = 123.44$, $p < 0.005$, $\eta_p^2 = 0.76$. In these conditions, there was no overall effect of group, $F < 0.8$, and no interaction of switch cost and group, $F < 0.2$. In univalent and long RSI conditions, we again observed a strong effect of switch type, mirroring the above results. In these conditions, there was a marginal overall effect of group, $F(1, 40) = 2.98$, $p = 0.092$, $\eta_p^2 = 0.07$, indicating faster response times for VGPs compared with nVGPs on repeat trials with univalent stimuli and long RSIs. The group variable did not interact with switch type in these conditions, $F < 0.005$. In bivalent conditions and in both short and long RSI conditions, we continued to observe a strong typical effect of switch type. This effect did not interact significantly with the group variable, $F(1, 40) = 2.10$, $p = 0.155$, $\eta_p^2 = 0.05$, and there was no overall effect of group, $F(1, 40) = 2.17$, $p = 0.149$, $\eta_p^2 = 0.05$.

Accuracy, Extreme Groups

Figure 2 shows mean accuracy data for extreme groups in Experiment 2. We analysed accuracy within the main dataset to evaluate differences in accuracy between VGPs and nVGPs in all conditions. As expected, we observed typical task switching effects in the accuracy data. All participants made fewer errors on long compared with short RSI trials, $F(1, 40) = 7.48$, $p = 0.009$, $\eta_p^2 = 0.16$, and on repeat compared with switch trials, $F(1, 40) = 29.92$, $p < 0.001$, $\eta_p^2 = 0.43$. There was no main effect of valency, but valency did interact with switch type, $F(1, 40) = 4.217$, $p = 0.047$, $\eta_p^2 = 0.10$, indicating that all participants made fewer errors on repeat trials in univalent conditions. We observed no interactions including the group variable and no effect of group overall, $Fs < 1.2$.

To further evaluate possible differences in accuracy, we analysed the data from univalent and bivalent conditions separately. In both the univalent and bivalent conditions, we once more observed strong typical task switching effects, with all participants making fewer errors in long compared to short RSI trials, and fewer errors on repeat compared with switch trials. We observed no interactions of these variables with the between-subjects variable in either univalent or bivalent conditions, Fs < 0.6.

<u>*Inclusive Groups*</u>

Reaction time, Inclusive Groups

Correct RT and accuracy data for the inclusive groups were analysed using repeated measures ANOVA as above, with within-subjects factors of task set overlap (univalent, bivalent), switch type (repeat, switch), and RSI (short, long), and a between-subjects variable of gaming expertise (VGP, nVGP). Figure 3 shows mean RT data for Experiment 2 inclusive groups separated by valency, switch type, RSI, and gamer group. Typical task switching effects were observed; all participants were faster on univalent as compared to bivalent trials, $F(1, 77) = 355.07$, $p < 0.001$, $\eta_p^2 = 0.82$, on long RSI compared to short RSI trials, $F(1, 77) = 8.80$, $p = 0.004$, $\eta_p^2 = 0.10$, and on repeat compared to switch trials, $F(1, 77) = 447.42$, $p < 0.001$, $\eta_p^2 = 0.85$. These variables were observed to interact across difficulty manipulations, with all participants showing increased switch cost on trials in bivalent compared to univalent conditions, $F(1, 77) = 77.13$, $p < 0.001$, $\eta_p^2 = 0.50$, and on trials with short compared to long RSIs, $F(1, 77) = 5.44$, $p = 0.022$, $\eta_p^2 = 0.07$, and in a three-way interaction between switch type, valency, and RSI, $F(1, 77) = 4.44$, $p = 0.038$, $\eta_p^2 = 0.06$, reflecting participants' increased switch cost on short RSI bivalent trials. The effect of RSI and valency did not interact significantly with group, $F(1, 77) = 2.07$, $p = 0.154$, $\eta_p^2 = 0.03$. No other main effects or interactions were observed to interact with gaming group, and there was no overall difference observed for group, $Fs < 1.3$.

To further evaluate our inclusive groups data, we analysed data separately for univalent and bivalent trials. In univalent only conditions, we observed strong typical task switching effects of switch type and RSI, mirroring the main analysis above. We observed no interactions of these variables with each other or with the group variable, and no overall effect of group, $Fs < 0.5$. In bivalent only conditions, we observed strong main effects of switch type and RSI, and an interaction of these variables, $F(1, 77) = 9.86$, $p = 0.002$, $\eta_p^2 = 0.11$, indicating that in the bivalent condition, participants had increased switch cost on short RSI trials compared with long RSI trials. This interaction differed marginally by group, $F(1, 77) = 3.37$, $p = 0.07$, $\eta_p^2 = 0.50$, reflecting VGPs' increased switch cost on short RSI bivalent trials compared with nVGPs. There was no effect of group overall in the bivalent inclusive groups data, $F < 1.5$.

Accuracy, Inclusive Groups

Figure 3 shows mean accuracy data for inclusive groups in Experiment 2. We analysed accuracy within the main dataset to evaluate differences in accuracy between VGPs and nVGPs in all conditions. As expected, we observed strong typical task switching effects in the accuracy data. All participants made fewer errors on long compared with short RSI trials, $F(1, 77) = 17.66$, $p < 0.001$, $\eta_p^2 = 0.19$, in univalent compared with bivalent conditions, $F(1, 77) = 4.11$, $p = 0.046$, $\eta_p^2 = 0.05$, and on repeat compared to switch trials, $F(1, 77) = 42.48$, $p < 0.001$, $\eta_p^2 = 0.36$. We observed an expected interaction of valency with switch type, $F(1, 77) = 5.91$, $p = 0.017$, $\eta_p^2 = 0.07$, reflecting more errors on bivalent compared with univalent trials. Some of these effects interacted with the between-subjects group variable. Switch type was observed to interact marginally with gaming group, with VGPs showing a greater amount of errors on switch trials compared with nVGPs, $F(1, 77) = 3.11$, $p = 0.082$, $\eta_p^2 = 0.04$. We also observed a marginal four-way interaction between valency, RSI, switch type, and gaming group, $F(1, 77) = 3.06$, $p = 0.084$, $\eta_p^2 = 0.04$, indicating decreased accuracy demonstrated by VGPs compared with nVGPs on switch trials in short RSI and bivalent conditions.

DISCUSSION

In Experiment 1, VGPs displayed an advantage in task switching until their baseline faster RTs were considered. Taking baseline RTs into account, VGPs performed on par with nVGPs in high cognitive difficulty conditions. Experiment 2 was designed to determine whether the results observed in Experiment 1, which used an explicit cue task switching design, could be replicated using a traditional, quadrant task switching paradigm based on Rogers and Monsell (1995). We adapted their basic quadrant locational cue design to incorporate independent variable manipulations of cognitive difficulty, including manipulations of task set overlap and response-to-stimulus interval. The use of bivalent stimuli increases the cognitive effort needed to overcome task interference because response mappings are the same for both tasks, while univalent stimuli present no interference. Short RSIs give participants little time to prepare for an upcoming task, increasing the cognitive difficulty of the task, while long RSIs provide ample time to prepare. Including these manipulations in Experiment 2 allowed us to examine differences between VGPs and nVGPs in task switching within a well-established task switching paradigm.

For Experiment 2, we divided participants into extreme and inclusive groups, by using very strict, then less strict criteria as to who should be included in groups of VGPs and nVGPs. (In both cases, some participants remained unclassifiable). We first categorized participants who shared the most and least exaggerated gamer characteristics into extreme VGP and nVGP groups. In an extreme groups analysis, differences between groups are unnaturally magnified (Preacher, Rucker, MacCallum, & Nicewander, 2005; Unsworth et al., 2015) and more likely to be statistically significant. We wanted our results to be intensified so that we could be certain that if a difference between groups did exist, we would be sure to detect it. We then expanded these groups to include additional participants who demonstrated a moderate amount of VGP and nVGP characteristics, in order to determine whether any effects we detected in the extreme groups analysis would persist in a more inclusive group of participants. Because a majority of the previous studies on cognitive benefits in VGPs use extreme groups analysis, it is important to determine at what level of gameplay extremity any cognitive benefit might apply.

In the extreme groups analysis, we observed a number of predicted main effects and interactions. We observed that all participants had higher switch costs on switch trials compared to repeat trials, on short RSI compared to long RSI trials, and on bivalent compared to univalent trials. We also observed interaction effects among these variables demonstrating that all participants had higher switch costs on bivalent, short RSI switch trials, the most cognitively challenging trial type. These effects suggest that our difficulty manipulation variables did not interfere with obtaining the expected effects of a task switching paradigm, and that these variables increased task difficulty as predicted.

In this extreme set of VGPs and nVGPs, we found that VGPs had increased switch costs compared with nVGPs on short RSI trials in the overall analysis, and on long RSI trials in the separate univalent and bivalent analyses. Switch cost represents the difference between a baseline repeat trial response time and a more difficult switch trial response time. Generally, increased switch cost might suggest that switch trials are more difficult for VGPs to perform compared with nVGPs, but it appears that the increase in this case is due to VGPs responding more quickly to repeat trials compared with nVGPs, and performing no differently from nVGPs on switch trials. This conclusion is supported by the majority of secondary analyses, in which we found no interaction of the group variable with the switch type variable.

We expected to see the same effects to a smaller extent in the inclusive groups analysis, accounting for the more relaxed criteria for identification as either VGP or nVGP. Our initial inclusive groups analysis suggested that VGPs and nVGPs were performing equally well in this task and displaying characteristic performance for a task switching paradigm. Switch cost was increased for both VGPs and nVGPs as a result of our independent variables making the task more difficult, which showed that our manipulations of task set overlap and RSI successfully adapted the traditional task switching paradigm into one with multiple aspects and levels of cognitive demand. However, when we separated the data for further examination, we found that VGPs had increased switch cost in the bivalent condition. As above, this result might initially suggest that VGPs are actually performing worse than nVGPs at task switching. However, as in Experiment 1, it is the case that VGPs are displaying an increased switch cost because they are responding more quickly to repeat trials, not because switch trials are causing them to respond more slowly. In the inclusive groups, VGPs and nVGPs once more performed on par for switch trials, but VGPs were significantly faster in responding to repeat trials.

In the inclusive groups analysis, we also saw that VGPs were more likely to make errors on switch trials compared to nVGPs. This decreased accuracy for VGPs on switch trials was apparent in all conditions, but was especially pronounced in bivalent conditions and on short RSI trials, the most cognitively challenging conditions. Taken together with the RT results above, these results show that when the task is difficult, and when they are given less time to prepare, VGPs do not show an RT benefit compared to nVGPs, and in fact make more errors than nVGPs.

Comparison between the results of the extreme groups analysis and the inclusive groups analysis reveals a similar pattern for both sets of groups. In the extreme groups analysis, VGPs responded more quickly to repeat trials in the overall analysis and in the secondary univalent- and bivalent-only analyses. In the inclusive groups analysis, the same result persisted, but was only apparent in a four-way interaction in the bivalent condition on short RSI trials. This suggests that the effect is being driven by the extreme group VGPs (who were also part of the inclusive VGP group), but that more casual VGPs in the inclusive group might not be as likely to show the same pattern. In effect, this result suggests that VGPs are able to respond more quickly to stimuli when the task is easy, as it is on repeat trials. When the task becomes increasingly difficult, as it does on switch trials, this benefit disappears. The effect does represent a benefit for VGPs compared to nVGPs, but this benefit is not cognitive. It may represent an ability to respond quickly to easy targets, which may be similar to the actions required to perform well on first-person shooter games. In addition, we observed that in the extreme groups analysis, there were no differences in accuracy between VGPs and nVGPs, despite the faster performance of VGPs on repeat trials. However, the inclusive groups analysis showed that VGPs were more likely to make errors on switch trials in all conditions than nVGPs. These effects suggest that VGPs are generally less cautious than nVGPs in responding to targets, and that casual VGPs are less cautious and less skilled than serious VGPs at responding accurately to targets when cognitive demands are high.

GENERAL DISCUSSION

We conducted two experiments to investigate claims of cognitive advantages for expert VGPs compared to novices. Experiment 1 used an explicit verbal cue task switching paradigm and varied stimulus overlap and CTI to determine whether VGPs would perform better than nVGPs in cognitively challenging conditions, such as on switch trials, in high stimulus overlap conditions, and when only a short amount of time to process cues is available between cue and target presentation. Experiment 2 used a traditional quadrant Rogers and Monsell (1995) task switching paradigm adapted to vary cognitive difficulty by manipulating task set overlap and RSI to determine whether a traditional task switching paradigm would find similar results to Experiment 1. Experiment 2 also divided participants into extreme and inclusive groups to determine how criteria for determining group identification might affect results.

Initial analysis for Experiment 1 suggested that VGPs were performing faster overall than VGPs in all conditions. When we analysed data from low and high task overlap conditions separately, we found that VGPs were performing faster compared to nVGPs in the most cognitively challenging of conditions, on switch trials in high task set overlap conditions with short CTI. Taken at face value, these results would certainly be evidence for cognitive benefits in VGPs compared with nVGPs. However, when we re-analysed the data to account for baseline differences in RT, we observed that VGPs performed no differently than nVGPs. Further analyses revealed that VGPs did perform better than nVGPs in high task set overlap conditions, but only when they were given ample time to prepare (long CTI trials). These results suggest that while VGPs do enjoy an advantage in RT, this advantage is not cognitive in nature, as it is not evident when cognitive demands are high (short CTI trials).

Experiment 2 found that VGPs had an overall increased switch cost compared to nVGPs, a result suggesting that rather than enjoying a cognitive benefit, VGPs were actually performing worse in cognitively difficult tasks than nVGPs. However, further analyses revealed that this was not the case. VGPs responded faster to repeat trials in all conditions, but performed on par with nVGPs on switch trials, leading to the appearance of a larger switch cost. Switch cost is considered to be an increase in the difference in RT between repeat and switch trials resulting from the increased cognitive demands resulting from a switch trial. As in Experiment 1, baseline differences in response time led to misleading results. Upon further analysis, we determined that VGPs responded more quickly on repeat trials, but not on switch trials, than nVGPs. In addition, when moderate VGPs were included in the analyses, VGPs made more errors than nVGPs on switch trials. These results suggest that VGPs enjoy a speeded response advantage over nVGPs when task conditions are not cognitively demanding, and that this may be due in part to a speed-accuracy tradeoff, particularly in moderate compared to extreme VGPs.

What advantage are VGPs displaying if not a cognitive advantage? In both Experiment 1 and the extreme group of VGPs in Experiment 2, only participants who played first-person shooter games were considered VGPs. In these participants, we observe a tendency to respond faster when easy tasks are presented, and no differently than nVGPs when cognitive demands are increased. It appears that participants who play video games seriously are able to perceive stimuli, process cues quickly and respond accurately according to the task rules more quickly than those who do not. In first-person shooter environments, games are fast-paced and often require simple responses to a limited variety of stimuli. If responses are not made quickly enough in such an environment, the player rapidly "dies." When we included moderate gamers in the inclusive groups in Experiment 2, we observed that although the tendency to respond faster than nVGPs to repeat stimuli persisted, it was less pronounced and not present in all conditions. Additionally, the inclusion of moderate VGP participants resulted in decreased accuracy for VGPs compared with nVGPs on switch trials. The criteria for inclusion in the inclusive VGP group did not include first-person shooter play, suggesting that the speeded response benefit is particular to participants who do play first-person shooter games, rather than general action games or other genres, such as strategy or puzzle games. In both Experiment 1 and Experiment 2, we manipulated independent variables to create differing levels of cognitive difficulty within our task switching paradigms. Because VGPs did not show any advantages compared to VGPs in more difficult conditions, we conclude that the benefit displayed by VGPs in these experiments cannot be considered a cognitive benefit.

In the above experiments, we observe differences between VGPs and nVGPs in task switching performance. We argue that these differences are not the result of a cognitive benefit that can be associated with expert VGP group identification. Why might reliable differences exist in task switching performance between VGPs and nVGPs? The processes involved in successful task switching performance may have different time courses for VGPs and nVGPs.

Switch cost can be considered as reflecting a number of discrete processes. As seen in the experiments above, various manipulations to the cueing paradigm have effects on the resulting switch cost. Reduction in switch cost (represented by decreased RT and error rates) has been observed as a result of increasing preparation (Monsell, 2003). Increasing the time between a cue and target, or between any stimulus in a task switching paradigm and the next stimulus (stimulus-onset asynchrony, SOA; in the case the above experiments, CTI and RSI) allows participants time to prepare their response because they know which task they will have to perform next. This link between SOA and reduced switch cost has led to the reconfiguration model (Mayr & Kliegl, 2000; Meiran, Chorev, & Sapir, 2000; Rogers & Monsell, 1995). The reconfiguration model suggests that participants use preparation time in order to effortfully reconfigure the task set from the previously used set to the set that is appropriate for the currently required task. This reconfiguration may involve updating memory, inhibition of the prior task set, task set activation, and activation of procedural memory related to the required task (Meiran et al., 2000; Rubinstein, Meyer, & Evans, 2001). Many task switching studies have shown that increasing preparation time leads to a reduction in switch cost (Hoffmann et al., 2003; Kiesel & Hoffmann, 2004; Koch, 2001; Mieran, 1996; Mieran et al., 2000; Monsell, 2003; Monsell & Mizan; 2006). Although preparation does reduce the switch cost, it does not eliminate it; the benefits of preparation appear to be limited to approximately 600 ms and a residual cost remains (Monsell, 2003). Some researchers have contended that part of preparation time, in particular in reference to time between trials, is necessary for the task set active on the preceding trial to "decay" or become inactive before preparation for the upcoming trial can occur (Altmann, 2005; Koch, 2001; Mieran et al., 2000).

An alternative to the reconfiguration model is the task-set inertia model put forth by Allport and colleagues (Allport, Styles, & Hsieh, 1994; Mieran et al., 2000; Monsell, 2003; Wylie and Allport 2000). This model explains the reduction in switch costs observed with large SOA intervals as time during which the task set from the previous trial dissipates. In this account, the first task set must be inhibited in order to activate and perform the second task (in much the same way participants must inhibit word-reading in order to name font colour in a Stroop task; Monsell, 2003). Both the reconfiguration model and the task-set inertia model can be considered two-stage models of switch-specific processing. In these models, two stages of processing must occur for the switch to take place: one stage prior to stimulus presentation (regardless of whether the stimulus is a cue or locational target), and one stage after stimulus presentation, but before a response is made (Kiesel et al., 2010; Mayr & Kliegl, 2000; Meiran, 2000; Rogers & Monsell, 1995; Rubinstein et al., 2001; Sigman & Dehaene, 2006). Monsell (2003) explained the two-stage reconfiguration model in terms of an endogenous component, occurring after response but before the next stimulus appears, and an exogenous component, which is activated upon stimulus presentation. This idea is supported by reduction of switch costs as a result of increasing RSI (Rogers & Monsell, 1995), a variable that was successfully manipulated to produce increased difficulty in Experiment 2. Difficulty is increased in short RSI conditions on switch trials because the amount of time to complete reconfiguration is larger on switch compared with repeat trials. If participants do not have enough time to complete reconfiguration prior to the presentation of the next stimulus, they may take longer to respond, resulting in increased switch cost and a higher likelihood of an incorrect response. Meiran (2000) described these processes in terms of the sets of stimulus sets and response sets, which must be activated appropriately for the current task. If stimulus and response sets overlap through the use of task set overlap and bivalent stimuli manipulations (as in the current experiments), the amount of time needed to reconfigure for an upcoming trial is necessarily longer. This lengthened reconfiguration time may also be viewed as a form of proactive interference between two tasks.

Proactive interference refers to a reduction in performance in a current task that is due to performance, or expectations about performance, in a previous task. Here, the activation of the previous task suppresses the activation of the upcoming task either because the previous task was very recently more relevant, or because the upcoming task had been recently suppressed in order to activate the previous task (Kiesel et al., 2010; Allport & Wylie, 1994). Increasing proactive interference in task switching paradigms can be done by increasing task set overlap through the use of bivalent stimuli and overlapping stimulus-response mappings. Evidence for the role of proactive interference in switch costs comes from switch-cost asymmetry, a phenomenon wherein switch costs are asymmetrical for a pair of tasks with different difficulty levels. When participants switch from an "easy" task to a "difficult" task, switch cost is lower than switching from a difficult to an easy task. This counterintuitive result is explained by the greater amount of interference generated by the "difficult" task. If there is overlap across stimuli and response mappings (as in the case of bivalent stimuli), proactive interference from the first-activated task set will result in an increased switch cost. Conversely, reducing proactive interference between task sets results in decreased switch cost. Yeung and Monsell (2003) demonstrate that although switching to a recently practiced task increased switch cost, having participants engage in active, endogenous preparation for a switch eliminated this effect, suggesting that decay time can be at least somewhat decreased. Meiran and colleagues (2000) argue that a reconfiguration or task-set inertia account alone cannot explain switch cost, but that the cost itself can be divided into distinct components reflecting aspects of both reconfiguration and task-set inertia: preparatory, residual, and dissipating. Miyake and colleagues found supporting results (2000) in a latent variable analysis investigating the components of executive function, using structural equation modeling to separate three clearly distinguishable components of executive function: "shifting," "updating," and "inhibition."

If VGPs and nVGPs differed in terms of cognitive ability, we would expect to see differences in the amount of time these processes require. In order to conclude that a VGP benefit exists for task switching, we should observe that VGPs behaviourally demonstrate reduced switch cost, and that VGPs are less affected than nVGPs by independent variable manipulations that should increase the amount of time needed to complete reconfiguration and task set activation for the upcoming task. The above experiments do show that VGPs are able to respond more quickly than nVGPs on repeat trials and trial types resulting in low interference (long CTI and long RSI conditions). However, when interference is maximized by the manipulations of task set overlap, bivalency, and shortened amounts of time to complete reconfiguration, VGPs do not perform differently than nVGPs. While these results suggest that VGPs do not show a cognitive control advantage compared with nVGPs, we can conclude that VGPs may possess an ability to activate the currently relevant task set more quickly than nVGPs once reconfiguration is complete, resulting in faster performance in conditions where extra time was not needed for reconfiguration (long CTI and long RSI trials).

These results complement a host of studies that have shown that VGPs have attentional benefits. VGPs have been to shown to perform better than nVGPs at many tasks recruiting attentional and perceptual abilities, including visual attention (Castel et al., 2005; Chisholm & Kingstone, 2012; Green & Bavelier, 2003, 2006a, 2006b, 2007), spatial attention (Feng et al., 2007), response time (Bialystok, 2006; Castel et al., 2005), visual search (Chisholm, et al., 2010; Hubert-Wallander et al., 2011), temporal processing (Donohue et al., 2010; West et al., 2008), multisensory processing (Donohue et al., 2010), tracking objects at high speeds and visual short term memory (Blacker & Curby, 2013; Boot et al., 2008) memory ability (Colzato et al., 2013; McDermott et al., 2014) contrast sensitivity function (Li et al., 2009), and oculomotor performance (West et al., 2013). These findings have led researchers to conclude that VGPs enjoy cognitive benefits compared to nVGPs (Granic et al., 2014; Green et al., 2012; Powers et al., 2013; Spence & Feng, 2010).

There has been uncertainty about whether a VGP benefit exists (Karle et al., 2010; Powers et al., 2013, Unsworth et al., 2015). Although many studies have found evidence of VGP benefits, others have found evidence of no differences in visual attention tasks (Boot et al., 2008; Castel et al., 2005; Irons et al., 2011; Murphy & Spencer, 2009; Wilms, Peterson, & Vangkilde, 2013). A recent meta analysis shows that while most published quasi-experimental studies examining self-identified VGPs and nVGPs find evidence for a VGP benefit, effect sizes and sample sizes have been small (Powers et al., 2013; Unsworth et al., 2015). One possible factor contributing to this uncertainty is that researchers have not distinguished clearly enough between possible attentional and perceptual benefits and cognitive control or executive function benefits. Task switching paradigms provide a unique insight into endogenous and exogenous cognitive control processes, which can be separated and behaviourally observed. In the current study, we have employed two such paradigms and systemically varied the time periods in which each stage of processing occurs, in order to show that the benefit VGPs display does not extend to cognitive control.

Chapter 3

INTRODUCTION

N-back tasks, the most frequently-used assessment of working memory, have been accepted as a measure of executive function and higher-level cognitive ability. These tasks require attention to and processing of incoming stimuli at a continuous rate, maintaining previously presented stimuli in working memory throughout interference from new stimuli and previous responses, and matching of retrieved items to current items. Despite the apparent difficulty of n-back tasks, some have argued that working memory tasks may be successfully completed using a familiarity strategy rather than actively engaging working memory ability (Kane, Conway, Miura, and Colflesh, 2007; Jaeggi, Buschkuehl, Perrig, and Meier, 2010). However, such a strategy may be effective only in simple n-back designs, while more complex n-back designs require engagement of endogenous cognitive control. In the current study, we aim to assess group differences in VGPs and nVGPs by varying levels of cognitive difficulty in a sequential series of n-back tasks. We also address whether effects obtained generalize to groups defined by both extreme and inclusive criteria to determine their extent.

METHODS

Participants

Participants were the same 118 undergraduate participants who participated in Experiment 2 of Chapter 2. All participants were categorized into VGP and nVGP extreme and inclusive groups as per the group assignment in Experiment 2 of Chapter 2.

Stimuli and apparatus

All stimuli were presented via a 19-inch computer monitor and a Pentium 4 computer using Presentation (v.12. 0, http: www.neurobs.com) experimental software and a Windows XP operating system. Participants were seated approximately 60 cm from the monitor screen. Participants completed two sets of verbal and two sets of spatial n-back experiments (detailed description below). The verbal n-back presented a series of digit stimuli in 24-point Arial black at the centre of the screen, against a grey background. The spatial n-back presented a set of 1.5 cm outlined squares arranged in a circle.

Procedure

Participants completed a series of four n-back tasks consecutively, in the following order: 2-back verbal, 2-back spatial, 3-back verbal, 3-back spatial. This order was not counterbalanced across participants because we expected that presentation order would result in practice effects and wanted these effects to be equal across participants. All participants completed one practice block, followed by 12 blocks of 22 trials each. Blocks alternated every other block by cognitive difficulty level (low, high; see below), with starting difficulty counterbalanced across participants.

For each task, participants were presented with a sequence of stimuli and asked on each trial to determine whether the current stimulus matched the stimulus presented n (2 or 3) trials previous. Participants began responding on the 3rd or 4th trial in 2-back and 3-back tasks respectively. Responses were made using two button presses (match, nonmatch) on each trial. Stimuli were presented for 1000 ms. Trials terminated upon response or after 3000 ms and were followed by an inter-trial interval (ITI) of 1000 ms. Incorrect responses elicited an immediate auditory feedback signal of 100 ms and 100 Hz square wave.

In the verbal condition, stimuli consisted of a sequence of digits. This condition is referred to as verbal because presentation of a sequence of digits in the same location activates the name of the digit (e.g., "nine"), rather than the digit's location in space. Participants were required to indicate whether the current stimulus matched the target stimulus presented n trials previous.

In the spatial condition, stimuli consisted of a series of ten outlined squares arranged in a circle pattern. The current stimulus was indicated by a filled square, which remained filled for 1000 ms, and then reverted to an outline. Participants were required to indicate whether the location in the circle of the current filled stimulus matched the target stimulus presented n trials previous. All outlined square stimuli remained onscreen for the duration of the spatial tasks.

Cognitive difficulty was manipulated using memory load and lures. In the low difficulty condition, participants were presented with target and filler stimuli. Target stimuli were matches to the stimulus that was presented n trials previous and filler stimuli were nonmatches. In the high difficulty condition, participants were presented with targets, fillers, and strategically placed lures. Lures were stimuli that were presented within close temporal proximity to the target, but that did not match the target. Lures appeared in either a pre-target or post-target position. For example, in a 3-back task, a lure might appear in a 4-back (pre) or 2-back (post) position. Memory load was either 2-back or 3-back.

This design does not intend to, as a traditional n-back task would, assess working memory ability in participants. Rather, we intend to use this n-back design with incorporated manipulations of cognitive difficulty to measure whether there are differences in the ability to discriminate among stimulus types, when cognitive demands are high, between VGPs and nVGPs. As mentioned above, we have incorporated filler and lure stimuli in order to create low and high levels of cognitive difficulty. In the low cognitive difficulty condition, filler stimuli are dissimilar from target stimuli and thus easily distinguished, allowing participants to rely on a feeling of familiarity in order to complete the task successfully. Effortful monitoring and updating of stimulus information is not necessary to perform well in this condition, and we expect participants to adopt a familiarity strategy. However, the high cognitive difficulty condition incorporates lures that, if participants are relying on familiarity, will incorrectly identified as targets. If participants rely on familiarity in this condition, they will perform poorly (and receive immediate feedback that they are doing so). By structuring the order of tasks to be the same across participants, and having participants complete both 2-back tasks prior to the 3-back tasks, we induce a reliance on familiarity. If there is a difference between groups in cognitive ability, it should become apparent in high cognitive difficulty and high (3-back) memory load conditions, when this reliance will no longer result in accurate task completion. If VGPs possess a cognitive control benefit, we expect to observe better performance by VGPs compared to nVGPs in high cognitive difficulty conditions compared to nVGPs.

RESULTS

Extreme groups

Reaction time, extreme groups, all participants, target versus filler

Correct RT and accuracy data were analysed using repeated measures ANOVA with within-subject factors of memory load (2-back, 3-back), modality (verbal, spatial), cognitive difficulty (low, high), and stimulus type (target, filler), and a between-subjects group variable (VGP, nVGP). Figure 1 shows mean RT data for the overall ANOVA separated by n-back, modality, cognitive difficulty, trial type, and gamer group. We observed that all participants performed faster on 3-back tasks compared to 2-back tasks, $F(1, 40) = 6.70$, $p = 0.013$, $\eta_p^2 = 0.14$, and on filler stimuli compared to target stimuli, $F(1, 40) = 68.99$, $p < 0.001$, $\eta_p^2 = 0.64$. A number of interactions among these conditions revealed combined effects of task difficulty in the overall analysis. In spatial conditions, all participants responded more quickly in 3-back tasks compared to 2-back tasks, $F(1, 40) = 6.89$, $p = 0.01$, $\eta_p^2 = 0.15$, and in low cognitive difficulty conditions compared to high cognitive difficulty conditions, $F(1, 40) = 3.62$, $p = 0.064$, $\eta_p^2 = 0.08$. In 3-back tasks compared with 2-back tasks, participants were marginally faster on low cognitive difficulty trials compared to high cognitive difficulty trials, $F(1, 40) = 3.13$, $p = 0.084$, $\eta_p^2 = 0.07$, and faster on filler compared to target stimuli, $F(1, 40) = 7.43$, $p = 0.009$, $\eta_p^2 = 0.16$. The three-way interaction of modality, memory load, and cognitive difficulty was significant, $F(1, 40) = 8.42$, $p = 0.006$, $\eta_p^2 = 0.817$, reflecting faster performance for all participants on easy trials in 3-back tasks and in spatial conditions. The three-way interaction of memory load, cognitive difficulty, and stimulus type was also significant, $F(1, 40) = 4.82$, $p = 0.034$, $\eta_p^2 = 0.11$, reflecting faster performance for all participants in 3-back tasks, in low cognitive difficulty conditions, on trials with filler compared to target stimuli. There was no overall effect of group and no interaction effects involving the group variable.

Reaction time, extreme groups, target versus lure

In order to analyse the comparison of targets versus lures, we conducted a separate ANOVA on data from the high cognitive difficulty condition (no lures were present in the low cognitive difficulty condition). All participants were faster on lure trials compared to target trials, $F(1, 40) = 6.71$, $p = 0.002$, $\eta_p^2 = 0.14$, and marginally faster in 3-back tasks when conditions were spatial and when stimuli were lures compared to target or filler stimuli, $F(1, 40) = 3.44$, $p = 0.037$, $\eta_p^2 = 0.08$. Participants were also faster on lure trials when the lure was placed in the post-target position (further away from the current stimulus), $F(1, 40) = 8.11$, $p = 0.007$, $\eta_p^2 = 0.17$.

Accuracy and d', extreme groups, target versus filler

Accuracy and d' can be seen in Figures 2 and 3. All participants responded more quickly to target stimuli compared to filler stimuli, in both low and high cognitive difficulty conditions, and responded more quickly to pre-target position lures than to post-target position lures in high cognitive difficulty conditions. All participants were more accurate on filler stimuli compared to target stimuli, and more accurate in 2-back tasks compared to 3-back tasks. In order to carefully assess the accuracy data, we calculated mean d' values for each trial type. We use d' as a useful measure of a sensitivity, or a participant's ability to accurately discriminate between targets and other stimulus types.

We calculated d' values for comparison of target stimuli to filler stimuli. The d' values were calculated by subtracting each participant's proportion of correct responses (correctly identifying a target; hits) from their proportion of incorrect responses (incorrectly identifying a filler or lure stimulus as a target; false alarms). To better evaluate group differences in the ability to discriminate between stimulus types, we conducted further analyses on d' values compared to filler and lure stimulus types.

In the ANOVA for target and filler stimuli, we observed that there was a main effect of memory load, reflecting better discrimination between target stimuli and filler stimuli for all participants in 2-back compared with 3-back tasks, $F(1, 40) = 37.95$, $p < 0.001$, $\eta_p^2 = 0.49$. We also observed that this ability differed by group, reflecting better discrimination by VGPs in 2-back tasks, $F(1, 40) = 3.01$, $p = 0.091$, $\eta_p^2 = 0.07$. We also observed VGPs discriminate between target and filler stimuli more accurately than nVGPs in spatial compared to verbal conditions in a modality by group interaction, $F(1, 40) = 6.07$, $p = 0.018$, $\eta_p^2 = 0.13$. However, there was no overall group difference in this analysis. We then separately analysed responses to targets and lures in the cognitively difficult condition. In this analysis, we observed no significant effects.

Reaction time, extreme groups, high performing participants, target versus filler

We noted that a wide range of individual differences in task performance appeared to exist in our data. In order to determine whether group differences were being obscured by the poor task performance of some participants, we calculated d' for overall performance for each participant. Participants who had subzero rates of d' in at least one condition (i.e., who were not completing the tasks successfully and were performing at chance levels) were excluded from subsequent analyses. We excluded 8 participants from the VGP group and 7 participants from the nVGP group; it should be noted that the number of excluded participants was equivalent across groups, and does not suggest a systemic difference in ability to perform this task between VGPs and nVGPs. These exclusions resulted in extreme groups of VGP ($n = 14$) and nVGP ($n = 13$). In the overall RT analysis for these high-performing groups, we again observed a main effect of faster responding to filler stimuli than to target stimuli, $F(1, 25) = 64.17$, $p < 0.001$, $\eta_p^2 = 0.72$. We also observed an interaction effect of modality and cognitive difficulty level, $F(1, 25) = 4.95$, $p = 0.035$, $\eta_p^2 = 0.17$, reflecting faster responses for all participants in the spatial tasks and low cognitive difficulty conditions. We also observed a marginal overall effect of group, $F(1, 25) = 2.90$, $p = 0.101$, $\eta_p^2 = 0.10$, reflecting slightly faster response times in all conditions for VGPs compared to nVGPs.

Reaction time, extreme groups, high performing participants, target versus lure

For the same high-performing participants in the extreme groups, we separately analysed reaction times for target and lure stimuli in high cognitive difficulty conditions, and observed faster responses for all participants to lure stimuli compared to target stimuli, $F(1, 25) = 3.76$, $p = 0.030$, $\eta_p^2 = 0.13$. We also observed a marginal interaction of modality and memory load, $F(1, 25) = 2.99$, $p = 0.096$, $\eta_p^2 = 0.10$, reflecting faster RTs in spatial conditions when the task was 3-back compared to 2-back, and an interaction of memory load and stimulus type, $F(1, 25) = 6.76$, $p = 0.003$, $\eta_p^2 = 0.21$, demonstrating faster RTs to lure stimuli compared with target stimuli in 3-back tasks. There was a marginal three-way interaction of modality, stimulus type, and group, $F(1, 25) = 2.86$, $p = 0.067$, $\eta_p^2 = 0.10$, with VGPs performing faster than nVGPs on lure trials in the spatial tasks. The group variable did not interact with any other variables, and there were no overall between-subjects effect, $Fs < 2$.

To further understand the effects of lure position, we conducted an ANOVA comparing reaction times for pre-target and post-target lures in the high-performing extreme groups. We found a main effect of lure type, $F(1, 25) = 7.94$, $p = 0.009$, $\eta_p^2 = 0.24$, demonstrating that all participants responded more quickly to lures in the post-target position compared to lures in the pre-target condition. An interaction of modality and memory load mirrored results above. This analysis also revealed a three-way interaction of modality, lure position, and group, $F(1, 25) = 5.88$, $p = 0.023$, $\eta_p^2 = 0.19$, reflecting the faster responses of VGPs to post-target lures in the spatial tasks.

D', extreme groups, high performing participants

To better examine the performance of our high-performing groups, we conducted a separate analysis of discrimination between targets and other stimulus types. We again found a main effects of memory load, $F(1, 25) = 20.50$, $p < 0.001$, $\eta_p^2 = 0.45$, reflecting all participants' better discrimination between targets and filler stimuli in 2-back compared to 3-back tasks. However, this analysis also revealed a significant interaction between modality and group, $F(1, 25) = 10.33$, $p = 0.004$, $\eta_p^2 = 0.29$, with VGPs able to discriminate between stimulus types more effectively than nVGPs in spatial, but not verbal, conditions. There was also a marginal overall effect of group, $F(1, 25) = 3.22$, $p = 0.085$, $\eta_p^2 = 0.11$, demonstrating VGPs to have a slight advantage in stimulus discrimination over nVGPs in all conditions. We subsequently analysed the low and high cognitive difficulty conditions separately and determined that the VGP advantage was stemming from a marginal main effect of modality in the high difficulty condition, $F(1, 25) = 3.04$, $p = 0.094$, $\eta_p^2 = 0.11$, and an interaction of this effect with group, $F(1, 25) = 9.88$, $p = 0.004$, $\eta_p^2 = 0.28$, reflecting the more discriminative performance of VGPs compared to nVGPs in spatial conditions.

Inclusive groups

Reaction time, inclusive groups

We conducted the same analyses on our inclusive groups (VGP n = 48, nVGP n = 31). Results from inclusive groups analyses can be seen in Figure 4. In an ANOVA on reaction times, we found a main effect of modality, $F(1, 77) = 3.92$, $p = 0.051$, $\eta_p^2 = 0.05$, reflecting faster RTs for all participants on spatial compared to verbal tasks. This effect did not interact with group, $F < 0.6$. We again observed a main effect of memory load, $F(1, 25) = 19.86$, $p < 0.001$, $\eta_p^2 = 0.21$, with all participants responding more quickly on 3-back compared with 2-back tasks, and a main effect of stimulus type, $F(1, 25) = 124.73$, $p < 0.001$, $\eta_p^2 = 0.62$, demonstrating faster performance on filler stimuli compared to target stimuli. Within the main RT analysis, we also observed a number of interactions of variables, revealing combined effects of task difficulty. RTs were faster in spatial tasks when the task was 3-back compared to 2-back, $F(1, 77) = 5.83$, $p = 0.018$, $\eta_p^2 = 0.07$, and in spatial tasks when cognitive difficulty was low, $F(1, 77) = 5.12$, $p = 0.026$, $\eta_p^2 = 0.06$. We observed an interaction of memory load and cognitive difficulty, $F(1, 77) = 3.82$, $p = 0.054$, $\eta_p^2 = 0.05$, reflecting a combined effect of high cognitive difficulty and 3-back conditions resulting in decreased RTs in these conditions. Memory load also interacted significantly with stimulus type, $F(1, 77) = 20.40$, $p < 0.001$, $\eta_p^2 = 0.21$, reflecting faster responses to filler stimuli compared to target stimuli on 3-back tasks. A three-way interaction between modality, memory load, and cognitive difficulty level, $F(1, 77) = 7.38$, $p = 0.008$, $\eta_p^2 = 0.09$, showed that participants responded faster in the spatial condition when cognitive difficulty and memory load were high. An additional 3-way interaction between memory load, cognitive difficulty and stimulus type, $F(1, 77) = 4.11$,

$p = 0.046$, $\eta_p^2 = 0.05$, showed that participants responded faster to filler stimuli compared to target stimuli in 3-back and high cognitive difficulty conditions. There were no significant interactions involving the group variable, and no overall effect of group, $Fs < 2.6$.

We conducted a separate ANOVA to examine reaction times in relation to stimulus type in the high cognitive difficulty conditions. In this analysis, we again observed decreased response times for all participants on 3-back trials, $F(1, 77) = 21.33$, $p < 0.001$, $\eta_p^2 = 0.22$, and an interaction of memory load with modality, $F(1, 77) = 2.93$, $p = 0.091$, $\eta_p^2 = 0.04$, reflecting faster response times in 3-back tasks in the spatial modality. We observed a main effect of stimulus type, $F(1, 77) = 6.53$, $p = 0.014$, $\eta_p^2 = 0.07$, reflecting faster responses to lures compared with targets, and this effect was magnified in 3-back tasks compared to 2-back tasks, $F(1, 77) = 13.16$, $p = 0.001$, $\eta_p^2 = 0.15$. We also observed a three-way interaction effect of modality, memory load, and stimulus type, $F(1, 77) = 4.34$, $p = 0.041$, $\eta_p^2 = 0.05$, reflecting particpants' faster responses to non-target stimuli in 3-back spatial tasks. No variables interacted significantly with group, and there was no overall group differene, $Fs < 2.6$.

D', inclusive groups

We analyzed d' values to evaluate task efficacy for inclusive groups. D' for inclusive groups and high-performing inclusive groups can be seen in Figure 4. We observed a main effect of memory load, $F(1, 77) = 96.98$, $p < 0.001$, $\eta_p^2 = 0.56$, indicating better performance for all participants on 2-back tasks. The main effect of modality was not significant, $F < 1$. However, the modality variable interacted significantly with group, $F(1, 77) = 5.48$, $p = 0.022$, $\eta_p^2 = 0.07$, reflecting an increased ability to accurately distinguish target and filler stimuli for VGPs compared to nVGPs in spatial, but not verbal, tasks. There was no overall effect of group in this analysis, $F < 1.4$. To further understand the effects of stimulus type, including lures, we conducted a separate analysis of d' values in the high cognitive difficulty condition. In this condition, we observed a main effect of modality, $F(1, 77) = 4.60$, $p = 0.035$, $\eta_p^2 = 0.06$, but this effect did not interact with group, $F < 1$. We also observed a main effect of memory load, $F(1, 77) = 6.00$, $p = 0.017$, $\eta_p^2 = 0.07$, indicating increased ability to distinguish between lures and targets in 2-back, compared to 3-back, tasks. This effect was marginally magnified in spatial, compared to verbal, conditions, $F(1, 77) = 2.70$, $p = 0.104$, $\eta_p^2 = 0.03$. There was no overall effect of group in this analysis, $F < 0.5$.

Reaction time, inclusive groups, high performing participants

As with the extreme groups, we noted a wide range of individual differences in task performance within the inclusive groups. In order to determine whether differences between VGPs and nVGPs were obscured by this variability, we calculated overall d' performance scores for each participant, and excluded participants who performed at subzero d' levels in one or more conditions. We excluded 16 VGPs and 17 nVGPs from the inclusive groups; it should again be noted that an equal number of participants were excluded from each group. These exclusions resulted in high-performing inclusive groups of VGP ($n = 25$) and nVGP ($n = 14$).

In the overall RT analysis for these high-performing inclusive groups, we observed a strong main effect of stimulus type, $F(1, 37) = 71.65$, $p < 0.001$, $\eta_p^2 = 0.66$, indicating faster responses for all participants on filler compared to target trials. This effect was magnified when memory load was high on 3-back tasks, $F(1, 37) = 21.89$, $p < 0.001$, $\eta_p^2 = 0.37$. An interaction of modality and cognitive difficulty level, $F(1, 37) = 5.88$, $p = 0.020$, $\eta_p^2 = 0.14$, reflected decreased RTs for all participants in high cognitive difficulty on spatial tasks compared to verbal tasks. This effect was marginally magnified when memory load was high in 3-back tasks, $F(1, 37) = 2.99$, $p = 0.092$, $\eta_p^2 = 0.08$, indicating faster responses in spatial, high cognitive difficulty 3-back tasks. In this analysis, we observed a marginal interaction of the group variable with cognitive difficulty level and stimulus type, $F(1, 37) = 2.70$, $p = 0.104$, $\eta_p^2 = 0.03$, reflecting decreased reaction times for VGPs on filler trials in high cognitive difficulty conditions. Group did not interact with any other variable in this analysis, $Fs < 2$, but there was a marginal overall effect of group, $F(1, 37) = 3.15$, $p = 0.084$, $\eta_p^2 = 0.08$, reflecting slightly faster responses for VGPs in all conditions.

To further evaluate the effects of stimulus type on reaction time in the high-performing inclusive groups, we conducted a separate ANOVA for high cognitive difficulty conditions only. In this condition, we observed several interaction effects among our manipulated variables. An interaction of memory load and stimulus type, $F(1, 37) = 17.63$, $p < 0.001$, $\eta_p^2 = 0.32$, indicated that participants were responding more quickly to lure stimuli than to target stimuli in 3-back tasks. This effect interacted marginally with the group variable, $F(1, 37) = 3.60$, $p = 0.066$, $\eta_p^2 = 0.09$, indicating that

VGPs were likely to respond more quickly than nVGPs to lure stimuli when memory load and cognitive difficulty were high. Finally, in high cognitive difficulty conditions, we observed an interaction of modality, memory load, and stimulus type, $F(1, 37) = 4.60$, $p = 0.039$, $\eta_p^2 = 0.11$, reflecting faster performance for all participants on lure trials in spatial tasks when memory load was high. Group did not interact with any other variables, $Fs < 0.8$, but there was a marginal overall group difference in reaction time, $F(1, 37) = 3.32$, $p = 0.076$, $\eta_p^2 = 0.08$, indicating that in our high-performing inclusive groups, VGPs were likely to respond faster than nVGPs in all conditions.

D', inclusive groups, high-performing participants

We again analysed d' values to evaluate task performance in the high-performing inclusive groups participants (Figure 4). We continued to observe a strong main effect of memory load, $F(1, 37) = 30.78$, $p < 0.001$, $\eta_p^2 = 0.45$, reflecting better stimulus discrimination on 2-back tasks compared to 3-back tasks for all participants. We observed a marginal group difference across memory load conditions, $F(1, 37) = 2.78$, $p = 0.104$, $\eta_p^2 = 0.07$, with VGPs performing more accurately than nVGPs in 3-back conditions. There was no difference in d' values between spatial and verbal tasks, but there was a significant interaction of modality and group, $F(1, 37) = 10.74$, $p = 0.002$, $\eta_p^2 = 0.23$, indicating that VGPs were able to more effectively discriminate between target and filler stimuli then nVGPs in spatial, but not in verbal, conditions. The overall group effect in this analysis was marginally significant, $F(1, 37) = 2.60$, $p = 0.115$, $\eta_p^2 = 0.07$.

Finally, we analysed d' values separately for the cognitively difficult condition in order to assess the discriminative ability between targets and lures. In this difficult condition, the effect of memory load was no longer significant, $F < 1.5$, but the effect of memory load interacted with modality, $F(1, 37) = 5.38$, $p = 0.026$, $\eta_p^2 = 0.13$, with all participants performing more accurately in the 2-back compared to 3-back tasks. This interactive effect did not differ by group, $F < 1$. However, modality again interacted significantly with group, $F(1, 37) = 6.11$, $p = 0.018$, $\eta_p^2 = 0.14$, demonstrating an increased ability in VGPs compared to nVGPs for accurate discrimination between lure and target stimuli in spatial, but not verbal, tasks. The overall group difference in this analysis was not significant, $F < 0.5$.

DISCUSSION

We conducted a series of n-back tasks to investigate claims of cognitive benefits for VGPs compared to nVGPs in working memory. We manipulated modality, memory load and cognitive difficulty level to create a series of tasks with varying levels of cognitive demand. For both verbal and spatial modalities, participants completed two 2-back and two 3-back tasks, one each for low and high cognitive difficulty level. Cognitive difficulty was manipulated using misleading lure stimuli and memory load.

In a majority of the analyses, we observed marginal overall group differences, with VGPs performing more quickly than nVGPs. Most interestingly, we did observe a strong and reliable group difference across all of the tasks; VGPs were more able to accurately and effectively distinguish target stimuli from lure and filler stimuli than nVGPs in spatial conditions. This significant advantage did not extend to the verbal n-back tasks, on which VGPs and nVGPs performed no differently from one another. This effect persisted across all group divisions and analyses, including both extreme and inclusive group analyses, and became more pronounced when we removed low-performing participants in both our extreme and inclusive groups divisions. These results suggest that the effect is not limited to only very extreme gamers, but also extends to VGPs who are more casual about their gaming habits.

Many studies finding a cognitive advantage for VGPs have done so using tasks related to visual attention, and the current results are not incompatible with these findings. We differ in concluding that the benefit is not cognitive. VGPs in this study were better able to distinguish filler and lure stimuli from target stimuli in spatial tasks than nVGPs. Taken together with the VGP literature, this suggests that the VGP benefit may be attributed to representation in high-level visual attention. The benefit is more high-level than strictly perceptual; although VGPs do seem to have perceptual benefits, our spatial task required making difficult distinctions between stimuli that were only a few centimetres apart from one another in space. That VGPs can perform this task more accurately than nVGPs, and can continue to do so when faced with misleading, strategically placed lure stimuli, suggests that their visuospatial ability is functionally higher resolution than nVGPs'.

In testing for group differences using cognitive tasks, it is crucial to revisit the models for these tasks. Most researchers would argue that n-back tasks represent working memory ability. The traditional view of working memory organization put forth by Baddeley and Hitch in 1974 suggests three components involved in working memory processes: the central executive, which acts as an attentional control system, and its slave systems, the visuopatial sketchpad and the phonological loop, which can each manipulate and process information within the visual and auditory domains. This account of a domain-free attentional control centre is consistent with other accounts of memory function, including Norman and Shallice's (1986) Supervisory Attentional System, a higher-level executive attention mechanism controlling lower-level responses to incoming information via an action-selection process. Engle and colleagues (Engle et al., 1992; Kane et al., 2001; Turner & Engle, 1989) also explain working memory function as a domain-free, task-independent ability in which specific domains rely on a higher-level, controlled-attention component. Kane et al. (2001) argue that working memory capacity reflects a general ability to maintain information, such as currently relevant task goals, in an active state. Kane and Engle (2002) relate a hierarchical system of working memory including short-term memory, representational components and a general executive attention component to prefrontal cortical function. This account explains the executive attention component of working memory as the ability to maintain pieces of relevant information (goals, task sets, action plans, stimuli, and other information) in an active state, in which interference may hinder this function. Kane & Engle (2002) maintain that this ability is most taxed in the presence of interfering information, because when no interference is present, it is easy to correctly retrieve relevant information from long-term memory stores. In active task environments where interfering information must be inhibited in order to successfully complete a task, executive attention must correctly identify and process incoming information. These authors further suggest that individual differences in working memory capacity may be explained by differences in high level, modality independent attentional capability, and the ability to maintain attentional focus when faced with mental or environmental distractor information.

These accounts express working memory as a portion of a larger cognitive control ability, which is necessary for successful completion working memory tasks, and, importantly, applies across all domains. In the current study, we examined working memory as a construct of cognitive control by incorporating manipulations into our n-back tasks that would increase interference or cognitive load, taxing cognitive control ability and making it more difficult to complete the task. We were interested in whether VGPs and nVGPs would differ in ability to use cognitive control to correctly discriminate targets from lures in the high cognitive difficulty condition. In low cognitive difficulty conditions, when the tasks included only filler and target stimuli, filler stimuli would be dissimilar enough from target stimuli to allow successful completion of the task by relying on familiarity alone, rather than actively maintaining the necessary number of previously presented stimuli in working memory. However, in the high cognitive difficulty condition, this reliance on familiarity would not allow successful completion of the task, because participants would incorrectly identify strategically placed lure stimuli as targets, while still correctly rejecting filler stimuli.

Investigation of the n-back task as a valid assessment of working memory has suggested that n-back may not be representative of active maintenance of items in working memory, but rather is a measure of how participants use recognition and familiarity to identify previously presented stimuli (Jaeggi et al., 2010; Kane et al., 2007). In this view, the current stimulus in an n-back task is assessed by the participant based on its level of familiarity, and the participant may use this information to estimate how many trials ago this item was previously presented. This familiarity strategy is less effortful than actively maintaining two or three stimuli in working memory while completing the task, but it may not result in successful stimulus identification when conditions present increased levels of interference. Using familiarity to identify and assess incoming stimuli requires minimal cognitive control. When interference is increased through greater memory load and distracting lure stimuli, the task requires greater cognitive control.

Our results suggest that our participants relied on a familiarity strategy in order to complete the tasks. In all conditions, participants demonstrated faster response times and increased accurate identification of filler and lure stimuli compared to target stimuli. However, in high cognitive difficulty conditions, all participants demonstrated decreased ability to distinguish between targets and lure or filler stimuli. Notably, there were no differences in performance between VGPs and nVGPs in high cognitive difficulty conditions, demonstrating that VGPs do not enjoy a cognitive advantage over nVGPs. That we observe a reliable advantage for VGPs compared to nVGPs in spatial conditions only suggests that a VGP benefit does exist, but is limited to aspects of visual attention and visuospatial representation. If this benefit were truly cognitive, we would expect to observe it across all domains of working memory.

Our design and sequence of n-back tasks was designed to induce a strategy of familiarity for participants. Participants learned in the first two low memory load tasks that they could successfully identify stimuli using a feeling of familiarity. We then presented high memory load, cognitively challenging conditions, and examined whether VGPs and nVGPs would change their task completion strategy to adapt to the increased cognitive load. One criticism of inducing a familiarity strategy in an n-back task is that all participants might be using this strategy to complete all the tasks, and as a result, the tasks no longer assess cognitive load. Although we did observe a large range of individual differences in task performance in the high memory load conditions, and it was necessary to remove a portion of low-performing participants, we also observed a majority of participants completing the tasks with a high degree of accuracy. These high-performing participants would not have been able to perform so well if they had continued to rely on familiarity because of the misleading lures in high cognitive difficulty conditions. In order to distinguish among stimulus types so well, they must have stopped relying on familiarity and started actively holding stimuli in working memory, a challenging task with high endogenous cognitive demands.

Why did such a large range of task performance exist among our participants? To create our high-performing groups, we excluded participants who were performing at subzero performance in at least one of the task conditions (15 excluded for low performance in extreme groups and 33 excluded for low performance in inclusive groups). We believe that there is a large range of individual differences in cognitive ability as measured by working memory tasks. However, our task design manipulated levels of cognitive difficulty by varying memory load and by adding misleading lure stimuli, creating some conditions that required a higher level of executive control to complete successfully. We suggest that the low-performing participants had sufficient ability to complete the tasks, but in the difficult conditions did not alter their task completion strategy from reliance on familiarity in less challenging conditions to using effortful cognitive control in more challenging conditions. Engaging endogenous control would require processing incoming stimuli at a continuous rate, while also holding previously presented stimuli in working memory and comparing each new stimulus to those recently seen to check for stimulus matches. In this case, some participants were able to adapt and switch strategies, but others did not and this reliance on familiarity in more challenging conditions resulted in unsuccessful task completion. High performing participants were those who were able to recognize that familiarity was no longer a reasonable strategy as task difficulty increased. It was especially within this high-performing group of participants that we looked for differences between VGPs and nVGPs because we could be certain that cognitive control was being used to complete the tasks, and if an advantage in cognitive control existed for VGPs, it would be evident in the performance of these participants. As noted above, equal numbers of VGPs and nVGPs were excluded for low performance, and the exclusion criteria did not represent a systemic difference between groups. Within the high-performing participants, the VGP benefit in the spatial domain was magnified.

The results of the current study add to a growing literature citing a VGP benefit in tasks requiring lower levels of effortful cognitive control that do not persist when task difficulty or complexity is increased. Karle et al. (2010) found that VGPs demonstrated an advantage in a simple task switching design with no response mapping overlap, but observed no difference between VGPs and nVGPs when response overlap was increased. This work also demonstrated that factors decreasing cognitive load resulted in increased VGP benefit, including increased time intervals between stimuli, and increased informativeness of cues in a task switching paradigm. Similarly, Blacker et al. (2014) demonstrated using a training study that playing an action video game resulted in increases in visual working memory capacity compared to playing a control game, but that the benefit did not persist when the working memory tasks were made more complex. McDermott et al. (2014) found that VGPs performed no differently than nVGPs on a complex n-back task requiring up to 7 stimuli to be held in working memory throughout the task, but found a VGP benefit for both speed and accuracy using a more simple change detection paradigm. Powers et al. (2013) found that while several quasi-experimental designs comparing pre-existing groups of VGPs and nVGPs have found significant group differences, the effect sizes of a majority of these effects is small, and that the effect sizes of training studies finding a VGP benefit is even smaller. Taken together, these results may suggest that the cognitive benefit for VGPs found in many studies may in fact represent a domain-specific visuospatial processing advantage that is present in cognitively undemanding tasks. Because modern video games, particularly first-person shooter style games, present complex, detailed, rapidly changing environments that require skill in visual attention and memory, it is not unreasonable to conclude that individuals who spend a good deal of time playing such games have an advantage in these low-level visual skills over those who do not.

Our goal was to determine whether VGPs would demonstrate a cognitive benefit compared to nVGPs, using a working memory with varying levels of cognitive difficulty. While VGPs do show a benefit, it is not a benefit that can likely be considered cognitive in nature. VGPs did not perform better than nVGPs on any condition designed to maximize cognitive control needed to complete the task. There were no differences in performance between VGPs and nVGPs when we increased endogenous cognitive demand of the task. We found that VGPs were better only in the spatial domain, suggesting that VGPs enjoy an advantage in spatial processing and visuospatial attention compared to nVGPs. That this effect was magnified in 2-back compared to 3-back conditions, further suggests that the benefit is apparent only in less challenging conditions. If the advantage shown here by VGPs was truly a cognitive benefit, we would expect to observe it in both spatial and verbal domains. That it exists in only the spatial domain suggests that the VGP benefit is related specifically to spatial processing, and is not an overall cognitive benefit.

Chapter 4

INTRODUCTION

In the previous chapters, we investigated whether VGPs held any benefits in cognitive control in comparison to nVGPs using task switching and working memory paradigms. In those experiments, we found evidence of a visuospatial advantage and a tendency to have lower baseline reaction times in VGPs, but no evidence of an advantage in cognitive control. In Chapter 4, we examine group differences in cognitive control using tasks designed to measure the ability to inhibit automatic responses, or inhibitory control.

For this experiment, we chose three well-established tasks that are known to engage inhibitory control, or the ability to inhibit an automatic response: flanker, Stroop, and go no-go. These tasks are endogenously effortful, and require constant monitoring in order to perform well. In each of the following experiments, we deliberately attempted to increase automaticity in responding by manipulating the proportion of trials requiring inhibition. For example, in conditions where a majority of trials contain distracting information that is congruent with target information, it is more difficult to inhibit the automatic response to the rare trial with incongruent information, on which the automatic response is no longer appropriate. Using these three tasks and manipulating proportion congruency in each of them, we hope to carefully determine whether any robust advantage in inhibitory control exists for VGPs compared to nVGPs.

Experiment 1: *Flanker task*

This flanker experiment is designed to measure whether differences exist between VGPs and nVGPs using a well-established measure of attentional capacity and the ability to inhibit misleading information from flanker stimuli. Typical results of flanker tasks show that incompatible distractor (flanker) stimuli result in slower and less accurate responses to target stimuli than do compatible flanker stimuli, and this effect is known as the compatibility or "flanker" effect (Lavie, 1995). Here, we manipulate flanker stimuli and the proportion of trials on which compatible flanker stimuli can be expected, to observe whether VGPs and nVGPs show differential ability to inhibit flanker information. This experiment employs a traditional Eriksen flanker design (Eriksen & Eriksen, 1974).

METHODS

Participants

For all three inhibitory control experiments, participants were the same 118 undergraduate participants who participated in Experiment 2 of Chapter 2 (task switching) and Experiments 1 through 4 of Chapter 3 (working memory), with the same extreme and inclusive group divisions.

For the flanker task, we excluded data from trials on which participants responded unusually quickly or slowly (< 200 ms or > 1000 ms) and data from incorrect trials and one trial post-incorrect response. One nVGP participant was excluded from further flanker analysis due to poor accuracy (performing greater than 3 standard deviations below all other participants). This participant's data was included in the Stroop and go no-go analyses.

Stimuli and apparatus

For all three inhibitory control experiments, stimuli were presented via a 19-inch computer monitor and a Pentium 4 computer using Presentation (v.12.0, http: www.neurobs.com) experimental software and a Windows XP operating system. Participants were seated approximately 60 cm from the monitor screen.

Procedure

On each trial of the flanker task, a target stimulus arrow symbol “<” or “>” was presented in 48 point Arial font in the centre of the display until the participants responded. A trial was considered “congruent” if the target stimulus was flanked by two identical stimuli on each side and “incongruent” if the target was flanked by two opposite direction arrows on each side. All stimuli were presented in white font on a black background. Target and flanker stimuli appeared simultaneously. Participants were instructed that they should indicate on each trial whether the arrow pointed right or left using the left and right shift keys on a standard keyboard, and were told to respond as quickly and accurately as possible. All stimuli remained onscreen until the participant made a response on each trial. Upon response, a 1000 ms inter-trial interval preceded the next trial. Participants completed one practice block of 24 trials followed by 12 identical blocks of 24 trials. Participants initiated each block using a spacebar press and were encouraged to rest between blocks.

We manipulated the proportion of congruent and incongruent trials in each block to be either high proportion congruency (80% congruent trials, 20% incongruent trials) or low proportion congruency (80% incongruent trials, 20% congruent trials). Proportion congruency alternated by block and the condition of the beginning block was counterbalanced across participants.

RESULTS

Extreme groups proportion congruency analysis

Reaction time

Correct reaction time (RT), accuracy, and calculated d' values were analysed with repeated measures ANOVA with within-subjects factors of block proportion congruency (high proportion congruency, low proportion congruency) and stimulus congruency (congruent, incongruent), and the between-subjects variable of gamer group (VGP, nVGP).

Figure 1 shows mean RT, accuracy, and d' data for flanker separated by proportion congruency, stimulus congruency, and gamer group. Strong typical flanker effects were observed. Participants responded faster to congruent trials compared to incongruent trials, $F(1, 39) = 176.02$, $p < 0.001$, $\eta_p^2 = 0.12$. We did not observe differences in RT across high and low proportion congruency conditions, $F(1, 39) = 0.15$, $p = 0.706$, $\eta_p^2 < 0.1$. As expected, we did observe an interaction of stimulus congruency and proportion congruency, $F(1, 39) = 16.50$, $p < 0.001$, $\eta_p^2 = 0.30$, reflecting faster responses on congruent trials in high proportion congruency conditions for all participants. These effects did not differ across groups, and there was no overall group effect, Fs < 1.5.

Accuracy

We again observed strong, typical flanker effects. Participants were more accurate on congruent trials compared to incongruent trials, $F(1, 39) = 73.80$, $p < 0.001$, $\eta_p^2 = 0.65$. We also observed a strong effect of proportion congruency in accuracy, $F(1, 39) = 27.34$, $p < 0.001$, $\eta_p^2 = 0.41$, demonstrating that all participants were more accurate in high proportion congruency conditions. These effects did not interact with the group variable and there was no main effect of gaming group, Fs < 1.

In order to carefully assess the accuracy data, we calculated mean d' values for each trial type. This is a useful measure of sensitivity, or a participant's ability to accurately discriminate between stimuli. This is particularly important in tasks of inhibitory control, because participants must use control to suppress incorrect responses. We calculated d' values for congruent trials in both levels of proportion congruency and incongruent trials in both levels of proportion congruency. To better evaluate group differences in the ability to discriminate between stimuli, we conducted further analyses on the resultant d'prime values. All participants were more likely to correctly identify targets in high proportion congruency conditions compared to low congruency conditions, $F(1, 39) = 11.95$, $p = 0.001$, $\eta_p^2 = 0.24$. This effect did not interact with group and there was no overall difference between groups, $Fs < 0.5$.

Extreme groups order effects analysis

In addition to a traditional analysis comparing proportion congruency levels as a factor, we wanted to assess how performance on each trial may be related to the events of the previous trial, or what effects the order of different stimuli might have on performance.

The effect of preceding trial type in congruency experiments is well known. Typically, trials preceded by identical trials elicit faster responses than trials invoking interference from the preceding trial; interference is created by a conflict between trial types. For example, an incongruent trial preceded by a congruent trial is generally responded to more slowly than an incongruent trial preceded by another incongruent trial, despite the fact that congruent trials typically evoke speeded responses than incongruent trials. This effect is known as the conflict adaptation, or Gratton, effect (Gratton, Coles, & Donchin, 1992). Evidence from computational and functional neuroimaging suggests that this effect is mediated by trial-by-trial adjustments in top-down cognitive control (Botvinick et al., 2001; Kerns et al., 2004).

Recall that proportion congruency alternated by block. For these order effects analyses, we collapsed across blocks and re-categorized each trial type according to the trial type immediately preceding it. This re-categorization resulted in four trial types: congruent trial preceded by congruent trial; incongruent trial preceded by congruent trial; congruent trial preceded by incongruent trial; and incongruent trial preceded by incongruent trial. We then re-analysed all flanker data to determine whether differences exist between VGPs and nVGPs in order effects.

Reaction time

Order effects data were analysed with repeated measures ANOVA with within-subjects factors of preceding trial type (congruent, incongruent) and stimulus type (congruent, incongruent), and a between-subjects variable of gaming group (VGP, nVGP).

Correct RT, accuracy, and d' data for order effects can be seen in Figure 2. We continued to observe a strong flanker effect, $F(1, 39) = 225.19$, $p < 0.001$, $\eta_p^2 = 0.85$, indicating that all participants were faster on congruent compared to incongruent trials. The flanker effect was magnified in trials that were preceded by congruent trials, $F(1, 39) = 43.06$, $p < 0.001$, $\eta_p^2 = 0.53$, demonstrating that participants were faster on congruent trials that were preceded by congruent trials. There were no significant effects involving the group variable, $Fs < 1.6$.

Accuracy

We observed strong typical flanker effects, with participants making fewer errors on congruent compared to incongruent trials, $F(1, 39) = 95.82$, $p < 0.001$, $\eta_p^2 = 0.71$. In these data, we also observed a strong main effect of preceding trial type, $F(1, 39) = 52.69$, $p < 0.001$, $\eta_p^2 = 0.56$, indicating that participants were more accurate on trials that were preceded by congruent trials. We observed this effect interact with stimulus congruency, $F(1, 39) = 73.09$, $p < 0.001$, $\eta_p^2 = 0.65$, such that all participants were more accurate on incongruent trials that had been preceded by incongruent trials. In congruent trials, all participants performed near ceiling. This interaction differed significantly by group, $F(1, 39) = 14.41$, $p = 0.042$, $\eta_p^2 = 0.10$, indicating that VGPs were less accurate than nVGPs on incongruent trials preceded by congruent trials, and more accurate than nVGPs on incongruent trials preceded by incongruent trials. In other words, there was a larger difference in VGP performance between these two trial types than the difference demonstrated by nVGPs. There was no overall difference between groups, $F < 0.5$.

In the d' analysis for order effects, we observed a strong main effect of preceding trial type, $F(1, 39) = 176.02$, $p < 0.001$, $\eta_p^2 = 0.12$, reflecting greater ability for all participants to more effectively distinguish between congruent and incongruent stimuli when the preceding trial was congruent. Reflecting the group interaction in accuracy data above, we observed this effect differ marginally by group, $F(1, 39) = 2.35$, $p = 0.13$, $\eta_p^2 = 0.06$, with nVGPs demonstrating slightly higher d' values for both congruent and incongruent stimuli preceded by congruent trials. However, there was no overall group difference in d' values, $F < 0.5$.

<u>Inclusive groups proportion congruency analysis</u>

Reaction time

We conducted the same proportion congruency analyses for inclusive groups (VGP = 48, nVGP = 30), the results of which can be seen in Figure 3. The same participant that was excluded for low accuracy in extreme groups was also excluded in the inclusive groups analyses. Mean RT data for correct responses in the inclusive groups mirrored the extreme groups analysis above; all participants responded faster to congruent trials than to incongruent trials, and this effect was magnified in high proportion congruency conditions. A marginal 3-way interaction of stimulus type, proportion congruency, and group, $F(1, 76) = 2.29$, $p = 0.13$, $\eta_p^2 = 0.03$, reflected faster performance for VGPs compared to nVGPs in high proportion congruency conditions and on congruent trials. The overall effect of group was not significant, $F < 0.5$.

Accuracy

Accuracy results for inclusive groups indicated similar results to the extreme groups analyses. We observed main effects of proportion congruency and stimulus congruency, and a strong interaction of these two factors, $F(1, 76) = 58.07$, $p < 0.001$, $\eta_p^2 = 0.43$, indicating that all participants in inclusive groups were more accurate on congruent trials in high proportion congruency conditions. These effects did not differ across gaming groups, and there was no overall effect of group, Fs < 05.

Analysis of d' values for inclusive groups again mirrored results for extreme groups. We observed a strong main effect of proportion congruency wherein all participants were more able to effectively discriminate between congruent and incongruent stimuli, $F(1, 76) = 20.43$, $p < 0.001$, $\eta_p^2 = 0.21$, but this effect did not interact with group, and there was no overall effect of group**,** Fs < 1.5.

Inclusive groups order effects analysis

Reaction time

As with the extreme groups above, we also analysed the order effects for inclusive groups to determine how preceding trials might affect performance. Results for inclusive groups order effects can be seen in Figure 4. In order effects RT for inclusive groups, we observed a strong main effect of stimulus congruency, $F(1, 76) = 521.95$, $p < 0.001$, $\eta_p^2 = 0.87$, and an interaction of this effect with congruency of the preceding trial, $F(1, 76) = 109.79$, $p < 0.001$, $\eta_p^2 = 0.59$, demonstrating faster responses for all participants on congruent trials when the preceding trial was also congruent. There were no interactions of these effects with group and no overall difference between groups, Fs < 1.

Accuracy

Results of inclusive groups order effects in accuracy data were similar to those of extreme groups. We observed strong main effects of stimulus congruency and congruency of the preceding trial, and preceding trial congruency interacted marginally with group,

$F(1, 76) = 2.42$, $p = 0.12$, $\eta_p^2 = 0.03$, demonstrating that VGPs had slightly higher accuracy than nVGPs on incongruent trials preceded by incongruent trials, and slightly lower accuracy than nVGPs on incongruent trials preceded by congruent trials. This interaction was more pronounced in the extreme groups analysis. There was no overall effect of group, $F < 0.5$.

The values of d' for inclusive groups order effects, like those for extreme groups, showed a strong main effect for preceding trial congruency, $F(1, 76) = 34.85$, $p < 0.001$, $\eta_p^2 = 0.31$, demonstrating better stimulus discrimination for all participants when the preceding trial was congruent. This effect differed marginally by group, $F(1, 76) = 2.78$, $p = 0.10$, $\eta_p^2 = 0.04$, with nVGPs performing slightly better than VGPs in trials preceded by congruent trials.

DISCUSSION

In this flanker experiment, we manipulated proportion congruency to create differences in cognitive demand across proportions. In high proportion congruency conditions, most trials were congruent, requiring minimal inhibitory control. Incongruent trials created response conflict, which was reflected by increased RTs and decreased accuracy for incongruent trials, and these effects were exaggerated in high proportion congruency conditions. These results indicate that participants were not preparing cognitively on each trial for the possibility of incongruence, a reasonable strategy given that incongruent trials appeared only on a minority of trials. We observed no differences in performance between VGPs and nVGPs in proportion congruency analyses.

One possibility regarding participant strategy is that participants might not operate in a flanker task using a block-by-block strategy, but rather react to individual stimuli on only a trial-by-trial basis. In this case, performance on each trial would be most affected only by the congruency of the preceding trial, and not by the proportion congruency in the overall block. Although we saw no differences between groups in the proportion congruency analyses, we wanted to examine every possibility for differences between VGPs and nVGPs. We re-categorized our data to reflect each trial in relation to the trial immediately preceding it to determine whether differences in order, or Gratton, effects would exist between gaming groups.

In order effects analyses, we observed differences between VGPs and nVGPs. VGPs were less accurate than nVGPs on incongruent trials when those trials were preceded by congruent trials, and more accurate than nVGPs on incongruent trials preceded by identical incongruent trials. This effect was reflected in marginally higher d' values for nVGPs compared to VGPs on all trials preceded by congruent trials. These results suggest that VGPs and nVGPs are affected differentially by changes from one trial type to another, on a trial-by-trial basis.

These differences in order effects between VGPs and nVGPs might be understood as a reflection of differences in strategy between the two groups. An underlying assumption of our task, and part of the reason we manipulated proportion congruency, was that participants would gain an awareness of the proportion congruent from block to block and adjust their expectations accordingly. In this way, we induced more automaticity in responding in high proportion congruency conditions. Participants were aware that on a majority of trials, the target would be congruent with the flanker stimuli, and that the cognitive control needed to inhibit flanker stimuli would be minimal. In these conditions, adopting a strategy of automaticity has a large payoff in terms of RT, accuracy, and d' on congruent trials. The cost of automaticity is increased error and lower RT on rare incongruent trials. Conversely, in low proportion congruency conditions, we observe that participants are prepared for the conflict created by incongruency on each trial, and their strategy is to be slower and more cautious on every trial, resulting in increased RTs compared to high proportion congruency blocks.

The larger discrepancy in accuracy between congruent and incongruent preceding trial types for VGPs, compared to the smaller discrepancy for nVGPs, suggests that VGPs were more likely to rely on automaticity in responding in this task. VGPs were faster than nVGPs when the preceding trial type matched the current trial type, regardless of the congruency of the stimuli. When asked to switch from an incongruent trial to a congruent trial, VGPs were less able to switch effectively than nVGPs. The generally slower, but more accurate, performance of nVGPs suggests that they were exhibiting a greater amount of inhibitory control on each trial, rather than relying on automaticity generated by the preceding trial type.

This behaviour may coincide with previous findings in the literature in which VGPs demonstrate an advantage in speeded responses at the expense of accuracy (Irons et al., 2011; Nelson & Strachan, 2009), but previously published results suggest that although VGPs do demonstrate speeded responses, they do not show deficits in accuracy (Dye et al., 2009; Green & Bavelier, 2006a). A possible confound of previous studies using flanker tasks to assess cognitive control in VGPs is that flanker tasks are commonly spatial. For example, Green and Bavelier (2003) used a flanker task in which target stimuli could appear in any of six locations arranged in a circle, with the distractor stimulus appearing outside of the circle. In such a task, VGPs might well perform better due to a purely visual or visuospatial processing advantage that is unrelated to enhanced inhibitory control. To avoid this confound, we used a nonspatial Eriksen-style flanker task, with target and flanker stimuli appearing in close proximity in the centre of the display. The lack of group differences in this flanker experiment, taken together with the spatial advantage demonstrated by VGPs in the previous (working memory) chapter, suggest that previous findings in inhibitory control advantages for VGPs may have been unintentionally tapping into visuospatial benefits.

Experiment 2: Stroop

METHODS

Procedure

Our second measure of inhibitory control was a traditional Stroop task. Participants were shown words denoting a colour, that were presented in a separate font colour and asked to inhibit interference from reading the word while naming the font colour of the word. For example, the word "yellow" may be presented in a blue font, and the participant's task is to respond "blue," inhibiting the automatic reading response of "yellow."

On each trial of our Stroop task, a stimulus word ("blue", "green", or "red") was presented in 48 point Arial font in blue, green, or red font at the centre of the display for 1000 ms. A trial was considered "congruent" if the verbal meaning of the word matched the display font colour, and "incongruent" if the verbal meaning of the word did not match the display font colour. Participants were instructed that they should indicate on each trial whether the font colour of the word was blue, green, or red, using 3 button presses ("m", "n", and "b" keys on standard keyboard), being as fast and accurate as possible in their responses (the "b" key did not correspond to the "blue" response). Upon response, a 2000 ms inter-trial interval of blank screen was presented, followed by the next word stimulus. Participants completed one practice block of 24 trials, followed by 12 identical blocks of 24 trials each. Participants initiated each block using a spacebar press, and were encouraged to rest briefly between blocks.

As in the flanker procedure above, we manipulated the proportion of congruent and incongruent trials in each block to be either high proportion congruency (80% congruent trials, 20% incongruent trials) or low proportion congruency (80% incongruent trials, 20% congruent trials). Proportion congruency alternated by block and the condition of the beginning block was counterbalanced across participants.

RESULTS

Extreme groups analysis

Correct reaction time (RT), accuracy, and calculated d' values for extreme groups were analysed with repeated measures ANOVA with within-subjects factors of proportion congruency (high proportion congruency, low proportion congruency) and stimulus congruency (congruent, incongruent), and the between-subjects variable of gamer group (VGP, nVGP). Responses that were faster than 300 ms or slower than 1500 ms, and data from incorrect trials and one trial post-incorrect response, were excluded from further analysis.

Reaction time

Figure 5 shows mean RT, accuracy, and d' data for Stroop separated by PC, stimulus congruency, and gamer group. Strong typical Stroop effects were observed. Participants responded faster to congruent trials compared to incongruent trials, $F(1, 40) = 176.02$, $p < 0.001$, $\eta_p^2 = 0.12$, but there was no effect of proportion congruency, $F < 2$. Proportion congruency did interact with stimulus congruency, $F(1, 40) = 4.70$, $p = 0.036$, $\eta_p^2 = 0.11$, indicating that all participants made faster responses on congruent trials in high proportion congruency conditions. Neither of these effects interacted with group, but there was a marginal overall difference in RT between groups, $F(1, 40) = 2.94$, $p = 0.094$, $\eta_p^2 = 0.07$, with VGPs responding more quickly than nVGPs.

Accuracy

In accuracy, we observed a main effect of stimulus congruency, $F(1, 40) = 10.75$, $p = 0.002$, $\eta_p^2 = 0.21$, indicating that all participants were more accurate on congruent compared to incongruent trials. The effect of proportion congruency was marginal, $F(1, 40) = 2.80$, $p = 0.102$, $\eta_p^2 = 0.07$, but the effect of stimulus congruency differed across proportion congruency conditions, $F(1, 40) = 9.97$, $p = 0.003$, $\eta_p^2 = 0.20$, indicating that participants were more accurate on congruent trials in high proportion congruency conditions. There was no overall group effect and no interactions involving the between-groups variable, $Fs < 2.5$.

Analysis of d' values for extreme groups indicated an interaction between proportion congruency and gaming group, $F(1, 40) = 4.30$, $p = 0.045$, $\eta_p^2 = 0.10$, reflecting better ability to discriminate between stimulus types in nVGPs compared to VGPs. The overall effect of group was not significant, $F < 1.5$.

<u>*Inclusive groups analysis*</u>

Reaction time

To investigate the extent of the differences observed in our extreme groups analysis, we expanded our analysis to the inclusive groups (VGP = 48, nVGP = 31). Mean RT, accuracy, and d' data for inclusive groups can be seen in Figure 6. The results of this analysis mirrored the effects found in the extreme groups analysis above. We observed a strong main effect of stimulus congruency, with faster responses for congruent stimuli, and a main effect of proportion congruency, with faster responses in high proportion congruency conditions. The interaction of these effects was also significant, $F(1, 77) = 11.36$, $p = 0.001$, $\eta_p^2 = 0.13$, indicating decreased response times for congruent trials in high proportion congruency conditions for all participants. There were no differences between groups in RT, $Fs < 1.5$.

Accuracy

Accuracy analysis for inclusive groups also reflected the effects above. We again observed main effects of stimulus congruency and proportion congruency, and an interaction between these two variables, with participants demonstrating higher accuracy on congruent trials in high congruency conditions. No differences were observed between groups in effects or overall, $Fs < 1.5$. In the d' analysis for inclusive groups, we observed that the effect of proportion congruency differed marginally by group, with nVGPs slightly better able to distinguish accurately between stimuli compared to VGPs in low proportion congruent conditions, $F(1, 77) = 2.95$, $p = 0.090$, $\eta_p^2 = 0.04$. The overall group effect was not significant, $F < 0.5$.

DISCUSSION

In this Stroop task, we manipulated levels of inhibitory control required to complete the task successfully by varying levels of proportion congruency across blocks. High proportion congruency blocks require less monitoring, generally resulting in higher costs in RT and accuracy on incongruent trials, while low proportion congruency blocks have more cognitively demanding incongruent trials on a majority of trials, resulting in more effortful and slower responses.

Across all analyses, we observed strong, typical Stroop effects, with all participants responding more quickly and accurately when stimuli were congruent, and often we observed that high proportion congruency conditions also resulted in decreased RTs, increased accuracy, and increased d' values for all participants. We did observe some group differences between VGPs and nVGPs. In general, VGPs were more likely to respond faster than nVGPs. Congruency of the trial did not appear to influence this result. Both VGPs and nVGPs performed near ceiling on congruent trials in high congruency conditions, but our accuracy and d' data show that nVGPs were more accurate and had higher d' values than VGPs, especially in low proportion congruency conditions. These results suggest that VGPs responded in the general pattern of a speed-accuracy tradeoff, in which they responded more quickly at the expense of correct responses.

VGPs performed numerically, though not statistically, better than nVGPs in high proportion congruency conditions. This pattern of results suggests that VGPs are able to respond very quickly with a deficit in accuracy in conditions that promote automatic responding, such as high proportion congruency conditions. In these conditions, VGPs fall into a pattern of responding automatically, which allows for speeded, correct responses as long as trials remain congruent. When incongruent trials interrupt the automatic response pattern, VGPs are faced with response conflict and interference, resulting in decreased accuracy. In contrast, nVGPs appear to be less susceptible to automatic responding in the congruent condition, taking more time to respond and responding more efficiently and accurately when an incongruent trial interrupts the pattern of repeated congruent trials in the high proportion congruency condition. However, the group differences in this task were marginal in extreme groups analyses, and even more marginal when we repeated them with inclusive groups, suggesting that there are no differences in inhibitory control between VGPs and nVGPs as measured by this task.

The marginal results observed here mirror the results of the flanker task above, in which we observed VGPs demonstrating a deficit in performance compared to nVGPs in conditions where switches between trial types were required, resulting in disruptions in automaticity-based responding. In light of these results, it is possible that some of the literature citing a cognitive benefit for VGPs may be observing the same benefit in automaticity that does not extend to conditions requiring more effortful cognitive control (e.g., Karle, 2010).

Experiment 3: Go No-go

Our third measure of inhibitory control was a go no-go task, an established measure of inhibitory control.

METHODS

Procedure

In this task, participants viewed a continuous stream of two stimuli (“M” and “W”) and were instructed to respond with a button press (right arrow key) to “M” stimuli (“go” trials), and to withhold any response to “W” stimuli (“no-go” trials). On each trial of the go no-go task, a stimulus appeared for 1000 ms and was followed by a 2000 ms inter-trial interval. For this task, a “go” trial can be considered to be congruent, and a “no-go” trial can be considered to be incongruent.

As in the flanker and Stroop procedures above, we manipulated the proportion of trials in each block to be either high proportion congruent “go” (80% congruent “go” trials, 20% incongruent “no-go” trials) or low proportion congruency (80% incongruent “no-go” trials, 20% congruent “go” trials). Proportion congruency alternated by block and the condition of the beginning block was counterbalanced across participants. Responses that were faster than 200 ms or slower than 1000 ms, and data from incorrect trials and one trial post-incorrect response, were excluded from further analysis.

RESULTS

Reaction time from “go” trials, accuracy, and calculated d’ values for extreme groups were analysed with repeated measures ANOVA with within-subjects factors of proportion congruency (high proportion congruency, low proportion congruency) and the between-subjects variable of gamer group (VGP, nVGP). Responses that were faster than 200 ms or slower than 1000 ms were excluded from further analysis. Participants completed one practice block of 24 trials, followed by 12 identical blocks of 24 trials each. Participants initiated each block using a spacebar press, and were encouraged to rest briefly between blocks.

Extreme Groups

Reaction time

Figure 7 shows mean RT, accuracy, and d' data for extreme groups go no-go (on "go" trials only) separated by proportion congruency and gamer group. Strong typical go no-go effects were observed. Participants responded faster in high proportion congruency compared to low proportion congruency conditions, $F(1, 40) = 257.29$, $p < 0.001$, $\eta_p^2 = 0.87$, but this effect did not interact with the group variable, $F < 1$. There was a marginal overall difference between groups, $F(1, 40) = 3.71$, $p = 0.061$, $\eta_p^2 = 0.09$, reflecting faster responses for VGPs compared with nVGPs.

Accuracy

Accuracy analysis of hit rates revealed no effects of proportion congruency or group, Fs < 2. Accuracy analysis of false alarm rate showed a strong effect of proportion congruency, $F(1, 40) = 207.41$, $p < 0.001$, $\eta_p^2 = 0.84$, indicating that all participants were more likely to make false alarms in blocks that were high proportion congruency. In other words, in blocks where 80% of trials were "go" trials, participants were much more likely to incorrectly respond to a "no-go" trial. This effect did not interact with group, and there was no overall group difference in accuracy, Fs < 0.5.

A strong effect of proportion congruency was seen in the d' values, $F(1, 40) = 416.11$, $p < 0.001$, $\eta_p^2 = 0.91$, indicating that all participants were less able to effectively inhibit false alarms in high congruency conditions. This effect did not differ across groups, and there was no overall group effect, $Fs < 1$.

<u>*Inclusive groups*</u>

Reaction time

We conducted the same analyses using our inclusive groups of VGPs (N = 48) and nVGPs (N = 31). RT, accuracy, and d' data for inclusive groups can be seen in Figure 8. Once more, we observed a strong effect of proportion congruency in RT, $F(1, 77) = 461.83$, $p < 0.001$, $\eta_p^2 = 0.86$, indicating that all participants were faster in high proportion congruency conditions. This effect did not differ by group, $F < 0.5$. However, we did observe a marginal overall difference between VGPs and nVGPs, $F(1, 77) = 3.05$, $p = 0.085$, $\eta_p^2 = 0.04$, reflecting faster responses for VGPs compared to nVGPs in inclusive groups.

Accuracy

Accuracy analysis of hit rates revealed no effects of proportion congruency or group, $Fs < 2$. Accuracy analysis of false alarm rates showed a strong effect of proportion congruency, $F(1, 77) = 346.22$, $p < 0.001$, $\eta_p^2 = 0.82$, indicating that all participants were more likely to make false alarms in blocks that were high proportion congruency, or on "no-go" trials in 80% "go" conditions. This effect did not vary across groups and we observed no group difference in accuracy overall, Fs < 1.5.

D' analysis for inclusive groups showed a strong effect of proportion congruency, $F(1, 40) = 683.16$, $p < 0.001$, $\eta_p^2 = 0.90$, indicating that all participants were less able to effectively inhibit false alarms in high congruency conditions. This effect did not differ across groups, and there was no overall group effect, Fs < 1.6.

DISCUSSION

In this go no-go task, we observed that the extreme group of VGPs were marginally faster than nVGPs in responding to "go" trials. This marginal effect persisted at a lower F value in the inclusive groups, suggesting that the faster performance of VGPs may be related to membership in VGP groups. However, this effect was marginal in both cases, and we observed no differences in accuracy or d' values across groups. In this Go No-go task, no differences in inhibitory control between VGPs and nVGPs are apparent.

Dye and colleagues (2009) remark on the "impulsivity" of VGPs, in which VGPs are more likely to respond in a pattern of faster RTs, but increased anticipatory errors. Using a Test of Variables of Attention (TOVA), a task requiring responses to frequent or rare targets in spatial locations that is similar to a Go No-go task, these researchers found that VGPs were able to respond faster then nVGPS with no deficits in accuracy, while continuously engaging in sustained attention. The authors use VGP performance in this task to demonstrate that VGPs respond with less "impulsivity" than nVGPs. As mentioned in the discussion of flanker experiment results above, and taken together with the spatial advantage demonstrated by VGPs in the previous (working memory) chapter, it is possible that the results of Dye and colleagues were influenced by a VGP advantage in the visuospatial domain. The TOVA used in their 2009 assessment of impulsivity in VGPs presented "go" and "no-go" stimuli in several different spatial locations of the display. The spatial nature of the display may have allowed VGPs in that experiment to perform better than nVGPs, but the difference may have been a result of a domain-specific visuospatial processing advantage rather than equivalent performance in impulsivity, as the authors concluded.

GENERAL DISCUSSION

In this set of experiments, we used three measures of inhibitory control to carefully investigate whether differences in cognitive control might exist between VGPs and nVGPs. Overall, we observed minimal differences between groups. In the flanker task, VGPs were more likely than nVGPs to be influenced by the preceding trial, on a trial-by-trial basis. In the Stroop task, we observed a marginal speed advantage, but decreased ability to distinguish among stimuli for VGPs compared to nVGPs. We observed no differences between groups in a Go No-go task. Taken together, these results suggest that VGPs may rely more on automaticity in responding than nVGPs.

This result is perhaps not surprising in consideration of the general requirements of first-person shooter games. To perform well in FPS conditions, the player must respond to rapidly appearing stimuli, but the responses needed do not vary widely. In a majority of cases, the incoming stimulus in such conditions is likely to be an enemy that the player must shoot. A strategy of shooting all incoming stimuli as fast as possible with little discrimination among stimuli has no adverse consequences within the game; there are few or no situations in which a response must be inhibited, or in which the stimulus must be distinguished from a different stimulus in any careful or effortful way. It is possible that VGPs have developed this response bias as a result of extended amounts of time engaged in video game play, but it is also possible that VGPs held this response bias prior their game play.

It was not the purpose of this paper to determine whether the act of playing video games causes changes in cognitive ability, but only to carefully and robustly determine whether differences between VGPs and nVGPs exist in cognitive control. Using three well-established measures of inhibitory control, we have demonstrated that while possible differences in biases for response patterns may exist between the groups, VGPs do not appear to demonstrate an advantage in inhibitory control over nVGPs.

Chapter 5

GENERAL DISCUSSION

This aim of this dissertation was to investigate differences in cognitive control between VGPs and nVGPs previously reported in the literature. Assessing cognitive control as an ability with three separable components (Miyake et al., 2000) and using three sets of experiments designed to measure differing levels of cognitive control according to the defined components, the results of these experiments suggest that while VGPs do demonstrate benefits in some domains, these advantages do not extend to cognitive control.

Miyake et al. (2000) used factor analysis to identify three components of cognitive control: shifting mental set, monitoring and updating items in working memory, and inhibiting automatic responses. Chapter 2 used a set of two task switching experiments to carefully examine differences between VGPs and nVGPs in the ability to shift task sets, the first component of cognitive control. Experiment 1 used a comprehensive design to measure switch cost between all possible trial types, while Experiment 2 used a traditional locational cue design, to ensure results in Experiment 1 were not due to the novelty of task design. Experiment 1 manipulated levels of cognitive demand by varying the degree of task set overlap and the length of cue-to-target interval, and Experiment 2 manipulated degree of cognitive demand by varying the valency of cues and length of response-to-stimulus interval. In each of these experiments, we observed that although

VGPs initially appeared to have an advantage in task switching as measured by switch cost and response time, when baseline differences in response speed between groups were adjusted for, no differences in performance remained between VGPs and nVGPs. These results suggest that there are no differences between VGPs and nVGPs in the ability to shift mental set.

Chapter 3 assessed the second component of cognitive control, the ability to monitor and update information in working memory. In this chapter, a series of verbal and spatial n-back tasks with varying degrees of memory load and difficulty, based on the presence or absence of misleading lure stimuli, measured working memory performance across four levels of cognitive demand. These experiments demonstrated that VGPs were able to perform significantly better than nVGPs in spatial, but not verbal, conditions. These results complement many previous demonstrations of a visuospatial benefit for VGPs in the previous literature (e.g., Castel et al., 2005; Chisholm et al., 2010; Feng et al., 2007; Green & Bavelier, 2006; Powers et al., 2013). However, no differences were observed in performance between VGPs and nVGPs across levels of cognitive demand in these tasks. The results of working memory experiments in Chapter 3 suggest that while VGPs do possess an advantage in visuospatial processing, they do not differ from nVGPs in the ability to monitor and update working memory.

In Chapter 4, the final component of cognitive control as put forth by Miyake et al. (2000) was assessed in VGPs and nVGPs. The ability to inhibit automatic responses was tested in a set of experiments employing three well-established measures of cognitive control: flanker, Stroop, and go no-go tasks. In each of these measures, the likelihood of automaticity-based responding was increased by varying the proportion of congruent trials. The ability to respond to a rare incongruent trial in high proportion congruency conditions is an excellent measure of inhibitory control. Across these tasks, we observed that although VGPs demonstrated an advantage in speeded response compared to nVGPs, they were more likely than nVGPs to engage in automated responding, and demonstrated decreased ability to distinguish among stimuli than nVGPs. This set of experiments demonstrates that although VGPs do have an advantage in speeded response ability compared to nVGPs, there is no difference in inhibitory control between VGPs and nVGPs.

Taken together, and in the context of Miyake's (2000) identification of components in cognitive control, the results of this dissertation provide evidence that VGPs do not have a benefit in cognitive control compared with nVGPs. The results presented in the preceding chapters do demonstrate some advantages for VGPs in the domains of visuospatial processing and the ability to make speeded responses, but these benefits do not extend to cognitive control. The evidence presented here is robust; in each experiment, the degree of cognitive control required to complete tasks was manipulated to vary across levels for the purpose of comparison. In the most cognitively demanding conditions, for each experiment, we observed VGPs performing on par with nVGPs. Overall, we do observe differences between groups, but these differences are not in the domain of cognitive control.

The importance of comprehensive data analysis and careful interpretation

In studies investigating group differences in cognitive control, carefully distinguishing between cognitive control ability and the other abilities required to complete any cognitive task is of the utmost importance. Previous studies concluding a benefit for VGPs in cognitive control have not clearly separated this ability from other domains of ability necessary for task completion (e.g., visuospatial processing, perceptual and motor abilities), calling their conclusions into question. With the exception of Karle et al. (2010)'s investigation of task switching, no study has attempted to systematically vary cognitive demand within tasks. Green et al. (2012)'s comparison in task switching ability between VGPs and nVGPs did address the concern of baseline differences in response times, but found that when these differences were accounted for, their previously significant results were marginal. These results highlight the need of all group comparisons to carefully design experimental paradigms to ensure that the ability in question is testable within the paradigm, and to control for baseline differences among groups in order to correctly interpret experimental results.

The experiments in this dissertation also highlight the importance of caution in data analysis and interpretation. At first glance, both task switching experiments in Chapter 1 had misleading results, and it was only after closer inspection and further analyses that a clearer picture emerged. In Experiment 1, the data first appeared to suggest a VGP advantage, with gamers showing faster RTs on the most cognitively challenging trial types (switch trials, short CTIs, and high task set overlap conditions). However, when we accounted for baseline differences in RT by using a proportion-adjusted analysis, we found that VGPs performed no differently than nVGPs – they were faster at responding, overall. In the second task switching experiment, initial data analyses suggested the opposite of a VGP advantage; a VGP deficit. VGPs seemed to be suffering from an increased switch cost as a result of our difficulty manipulation variables. Subsequent analyses revealed that although VGPs had increased switch cost compared to nVGPs, this effect was driven not by impairment on switch trials, but rather by faster RTs on repeat trials. In fact, on switch trials, VGPs were performing no differently than nVGPs. This pattern was reflected in the results of the flanker task in Chapter 4; we observed no group differences in proportion congruency analysis, but examining the data for order effects revealed an important difference in task strategy between VGPs and nVGPs.

Methodological issues in comparing VGPs and nVGPs

A number of issues in methodology are relevant to comparing cognitive ability across VGPs and nVGPs. It is often most tractable to use a quasi-experimental design, dividing participants into extreme groups of VGPs and nVGPs based on self-report, or questionnaire data. However, fundamental differences may already exist between these groups, making it difficult to interpret results (Boot et al., 2011; Kane & Engle, 2015; Kristjánsson, 2013; Unsworth et al., 2015). Boot and colleagues (2011) point out that recruiting procedures usually call for participants with “video game expertise,” leading participants to know that their gaming ability is being studied. This can create demand characteristics, wherein VPGs are more motivated than nVPGs to perform well, especially on tasks they believe are related to game play.

Experiment 1 of Chapter 1 initially attempted to address some of these issues by using a noninformative recruitment advertisement, but the amount of time it would have taken to accumulate sizeable groups of expert and novice VGPs was prohibitive, and it was necessary to recruit expert VGPs and nVGPs with an informative advertisement. However, participants completed the questionnaire only after completing the experimental tasks in an effort to minimize the relation of the experiments to video game play. Training studies can provide a better platform for studying the possible causal effects of video games, but placebo effects may still exist due to the nature of the games and tasks being investigated. Boot et al. (2011) point out that participants trained on action and non-action games may note the similarity of the skills being used between games and cognitive tests, and even the realization that their training game is related to a task being studied may lead them to perform better on some tasks than others (e.g., training on a game such as Tetris seems likely to produce improvement in a mental rotation task), creating another confounding factor in this type of study.

The use of extreme groups analysis in exploring possible differences between VGPs and nVGPs has been cited as problematic (Unsworth et al., 2015). Most studies investigating potential group differences have collected questionnaire data from participants outlining their video game play habits, and categorize these data into VGPs (usually 5 or more hours of video game play per week), nVGPs (usually less than one hour of play per week), and are left with an amount of participants who do not clearly belong in either group. Data from the VGP and nVGP groups is analyzed, resulting in an exaggerated comparison between groups. This method is used largely because it allows comparisons between experts and novices to emerge without statistical effects being lost due to noise from participants who do not qualify for membership in either group. These designs result in large amounts of unusable data and can lead to greater chances of making a Type 1 error (Conway et al., 2005; Preacher, Rucker, MacCallum, & Nicewander, 2005; Unsworth et al., 2015). Variability can be unequal between groups in such designs, with nVGPs reporting relatively uniform minimal play, and VGPs reporting a very large range of play hours (in the current experiment, VGPs reported between 7 and 80 hours of weekly play). This variability in the VGP range can result in an inaccurate comparison between groups (Latham et al., 2013; Unsworth et al, 2015). Additionally, recruited participants may have vastly inaccurate notions about their own group membership; some participants in the experiments presented here considered themselves to be VGPs or nVGPs, but according to group membership criteria, actually belonged to the opposite group. These issues also include the general unreliability of self-report and asking participants to estimate the number of hours spent in game play across months and years. As mentioned in Chapter 2, one frequent issue encountered with self-report of game play hours is that a large subset of participants were very disciplined in controlling their play during the school semester, playing 0-2 hours per week during classes, but would play 20+ hours per week during vacations. It is difficult to categorize such participants as either VGP or nVGP.

The experiments in this dissertation attempted to address some of these issues by taking an extreme and inclusive groups approach to examine whether results found using extreme groups analysis would be reflected in a larger, more moderate sample of participants. This approach was useful for determining whether differences apparent in extreme groups analyses would persist in a more variable sample. In addition, the vast majority of VPGs are male; females are underrepresented in the literature, and current assessment paradigms are not taking into account possible differences across gender (Boot et al., 2011). Data collection for the current dissertation did include some female VGP participants, but their inclusion in group analyses would have created a confounding variable, as we observed many more female participants associated with nVGP group membership. This has been the case in virtually all published quasi-experimental comparisons of VGPs and nVGPs. Future studies comparing female only VGPs and nVGPs may elucidate possible sex differences in VGP benefits.

It is unclear and beyond the scope of this paper to determine whether differences between VGPs and nVGPs derive as a result of playing video games. Quasi-experimental designs, such as the designs of the experiments in this dissertation, are unable to determine whether differences between groups were a result of the separating variable (in this case, video game play) or whether participants were drawn to group membership as a result of pre-existing characteristics. For example, the results of Chapter 2 find that VGPs enjoy an advantage in visuospatial processing. It is possible that people who enjoy playing video games enjoy them precisely because they possess a visuospatial benefit causing them to perform well, resulting in a rewarding payoff for engaging in game play. It is also possible that frequent play of video games, and in particular action and first-person shooter style games, in which fast paced, constantly-changing environments must be responded to correctly and rapidly, might result in gains in response time and spatial processing, though there is evidence to suggest that practice in these skills demonstrate minimal transfer to other domains (Baniqued et al., 2014; Boot et al., 2011). If transfer does occur, it is likely to interact with gamers' pre-existing ability levels in domains such as spatial attention, with increased gains for those who enjoyed greater prior advantages. This interaction will make it difficult to distinguish the causal effects of video game play from individual differences. Recent work by Colzato and colleagues (2014) has linked successful skill transfer in task switching as a result of FPS game play to a specific genotype related to dopamine levels (COMT $Val^{158}Met$ genotype), and this association did not interact with sex, IQ, or time spent playing video games. Kristjánsson (2013) suggests that longitudinal studies on video game training will provide more valid evidence of its possible effects. However, the current dissertation did not attempt to evaluate these issues. It was not the purpose of this paper to determine whether the act of playing video games causes changes in cognitive ability, but only to carefully and robustly determine whether differences between VGPs and nVGPs exist in cognitive control.

There are a number of possible reasons that VGPs do not show an advantage in cognitive control compared to nVGPs. Given the results of the experiments presented here, it seems that VGPs are able to respond more quickly than nVGPs, and that this speed results from a greater reliance on automaticity-based responses. In Chapter 4, VGPs were more likely than nVGPs to be influenced by the preceding trial, and were more likely than nVGPs to respond more slowly and inaccurately when faced with incongruent stimuli. These results suggest that the advantages seen in VGPs may be limited to faster responding to unchallenging and predictable stimuli, rather than an advantage in cognitive control. If VGPs have a pre-existing propensity for spatial attention and visuospatial processing, they may be drawn to engage in video game play. However, engaging in FPS game play is unlikely to foster increases in cognitive control or any executive functioning because the games do not engage these skills.

Conclusion

As video game play continues to gain popularity, it is important and worthwhile to fully understand the effects that can be associated with large amounts of game play. While previous research has demonstrated a number of cognitive effects that seem to represent an advantage for VGPs compared to nVGPs, the results of other research and of this dissertation cast doubt on these conclusions. Research demonstrating a cognitive benefit for VGPs has been largely publicized in the media due to implications for therapeutic use in the clinical and developmental domains. However, particularly in light of these implications, it is important to carefully conduct and independently replicate research suggesting that video game play may result in cognitive benefits.

The aim of this dissertation was to carefully examine differences in cognitive control between VGPs and nVGPs. Based on Miyake's (2000) distinction of components in cognitive control, this ability was tested in three sets of experiments. No differences between VGPs and nVGPs were noted in the ability to shift mental set, the ability to monitor and update working memory, and the ability to inhibit automated responses. The experiments described here were designed to assess cognitive control by manipulating cognitive demand levels within the tasks, and comparing performance across demand levels in VGPs and nVGPs. These experiments demonstrated that VGPs enjoy benefits in some domains, but that these benefits do not appear to extend to cognitive control.

References

Allport, A., Styles E. A., & Hsieh, S. (1994). Shifting intentional set: Exploring the dynamic control of tasks. In: Umilta C., Moscovitch M. (Eds.), *Attention and performance XV* (pp.421–452). Cambridge, MA: MIT Press.

Allport, A., & Wylie, G. (1999). Task switching: Positive and negative priming of task-set. In G. W. Humphreys, J. Duncan, & A. M. Treisman (Eds.), *Attention, space and action: Studies in cognitive neuroscience* (pp. 273–296). Oxford, England: Oxford University Press.

Altmann, E. M. (2005). Repetition priming in task switching: Do the benefits dissipate? *Psychonomic Bulletin & Review, 12*, 535–540.

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

Anguera, J. A., Boccanfuso, J., Rintoul, J. L., Al-Hashemi, O., Faraji, F., Janowich, J., Kong, E., Larraburo, Y., Rolle, C., Johnston, E., & Gazzaley, A. (2013). *Nature, 501,* 97-101.

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

Baddeley, A. D. (1986). *Working memory*. Oxford: Oxford University Press.

Baddeley, A. D., & Hitch, G. (1974). *Working memory.* In G.H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 8, pp. 47–89). New York: Academic Press.

Bailey, K. West, R., & Anderson, C. A. (2010). A negative association between video game experience and proactive cognitive control. *Psychophysiology, 47,* 34-42.

Baniqued, P. L., Lee, H., Voss, M. W., Basak, C., Cosman, J. D., DeSouza, S., Severson, J., Salthouse, T. A., & Kramer, A. F. (2013). Selling points: What cognitive abilities are tapped by casual video games? *Acta Psychologica, 142,* 74-86.

Baniqued, P. L., Kranz, M. B., Voss, M. W., Lee, H., Cosman, J. D., Severson, J., & Kramer, A. F. (2014). Cognitive training with casual video games: Points to consider. *Frontiers in Psychology: Cognition, 4,* 1-19.

Bavelier, D., Green, C. S., Pouget, A., & Schrater, P. (2012). Brain plasticity throughout the life span: Learning to learn and action video games. *Annual Review of Neuroscience, 35,* 391-416.

Bialystok, E. (2006). Effect of bilingualism and computer video game experience on the Simon task. *Canadian Journal of Experimental Psychology, 60,* 68-79.

Blacker, K. J., & Curby, K. M. (2013). Enhanced visual short-term memory in action videogame players. *Attention, Perception, & Psychophysics, 75*, 1128–1136.

Blacker, K. J., Curby, K. M., Klobusicky, E., & Chein, J. M. (2014). Effects of action video game training on visual working memory. *Journal of Experimental Psychology: Human Perception and Performance, 40*(5), 1992-2004.

Boot, W. R., Blakely, D. P., & Simons, D. J. (2011). Do action video games improve perception and cognition? *Frontiers in Psychology, 2,* 1-6.

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.

Boot, W. R., Simons, D. J., Stothart, C., & Stutts, C. (2013). The pervasive problem with placebos in psychology: Why active control groups are not sufficient to rule out placebo effects. *Perspectives on Psychological Science, 8,* 445-454.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108,* 624-652.

Braver, T. S., Gray, J. R., & Burgess, G. C. (2007). Explaining the many varieties of working memory variation: Dual mechanisms of cognitive control. In A. R. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J.N. Towse (Eds.), *Variation in working memory* (pp. 76–106). New York: Oxford.

Cain, M. S., Landau, A. N., & Shimamura, A. P. (2012). Action video game experience reduces the cost of switching tasks. *Attention, Perception, & Psychophysics, 74*, 641–647.

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*(3), 667-671.

Chisholm, J. & Kingstone, A. (2012). Improved top-down control reduces oculomotor capture: The case of action video game players. *Attention, Perception, & Psychophysics, 74,* 257-262.

Clark, K., Fleck, M. S., & Mitroff, S. R. (2011). Enhanced change detection performance reveals improved strategy use in avid action video game players. *Acta Psychologica, 136*, 67-72.

Colzato, L. S., van Leeuwen, P. J., van den Wildenberg, W. P., & Hommel, B. (2010). DOOM'd to switch: Superior cognitive flexibility in players of first person shooter games. *Frontiers in Psychology*, 1, 1-5.

Colzato, L. S., van den Wildenberg, W. P. M., Zmigrod, S., & Hommel, B. (2013). Action video gaming and cognitive control: Playing first person shooter games is associated with improvement in working memory but not action inhibition. *Psychological Research, 77*, 234–239.

Colzato, L. S., van den Wildenberg, W. P. M., & Hommel, B. (2014). Cognitive control and the COMT $Val^{158}Met$ polymorphism: genetic modulation of videogame training and transfer to task-switching efficiency. *Psychological Research, 78,* 670-678.

Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review, 12*, 769–786.

Donohue, S. E., Woldorff, M. G., & Mitroff, S. R. (2010). Video game players show more precise multisensory temporal processing abilities. *Attention, Perception, & Psychophysics, 72,* 1120-1129.

Dye, M. W. G., Green, C. S., & Bavelier, D. (2009). Increasing speed of processing with action video games. *Current Directions in Psychological Science*, 18, 321–326.

Entertainment Software Association. (2013). 23 Essential Facts about the Computer and Video Game Industry. Retrieved from: http: http://www.theesa.com/facts/pdfs/ESA_EF_2013

Engle,R. W., Cantor, J., & Carullo, J. J. (1992). Individual differences in working memory and comprehension: A test of four hypotheses. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 18*, 972-992.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16*, 143-149.

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

Glass, B. D., Maddox, W. T., & Love, B. C. (2013). Real-time strategy game training: Emergence of a cognitive flexibility trait. *PLoS ONE, 8(8*), Article e70350. Retrieved from http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0070350

Granic, I., Lobel, A., & Engels, C. M. E. (2014). The benefits of playing video games. *American Psychologist, 69,* 66-78.

Gratton, G., Coles, M. G. H., & Donchin, E. (1992). Optimizing the use of information: Strategic control of activation of responses. *Journal of Experimental Psychology: General, 4*, 480–506.

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

Green, C. S., & Bavelier, D. (2006a). The cognitive neuroscience of video games. In L. Humphreys & P. Messaris (Eds.), *Digital Media: Transformations in Human Communication* (pp. 211-223). New York: Peter Lang.

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. (2007). Action-video-game experience alters the spatial resolution of vision. *Psychological Science, 18*, 88–94.

Green, C. S., Sugarman, M. A., Medford, K., Klobusicky, E., & Bavelier, D. (2012). The effect of action video game experience on task switching. *Computers in Human Behavior, 28,* 984-994.

Hoffmann, J., Kiesel, A., & Sebald, A. (2003). Task switches under go/no go conditions and the decomposition of switch costs. European Journal of Cognitive Psychology, 15, 101–128. doi:10.1080/09541440244000003

Hubert-Wallander, B., Green, C. S., Sugarman, M. & Bavelier, D. (2011). Changes in search rate but not in the dynamics of exogenous attention in action videogame players. *Attention, Perception, and Psychophysics, 73*, 2399-2412.

Irons, J. L., Remington, R. W. and McLean, J. P. (2011). Not so fast: Rethinking the effects of action video games on attentional capacity. *Australian Journal of Psychology*, *63*, 224–231.

Jaeggi, S. M., Buschkuehl, M., Perrig, W. J., & Meier, B. (2010). The concurrent validity of the N-back task as a working memory measure. *Memory, 18*(4), 394-412.

Jersild, A. T (1927). Mental set and shift. *Archives of Psychology, no. 89*.

Kane, M. J., Bleckley, M. K., Conway, A. R. A., & Engle, R. W. (2001). A controlled-attention view of working-memory capacity. *Journal of Experimental Psychology: General, 130*, 169-183.

Kane, M. J., Conway, A. R. A., Miura, T. K., & Colflesh, G. J. H. (2007). Working memory, attention control, and the n-back task: A question of construct validity. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*(3), 615-622.

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., & 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.

Kerns, J. G., Cohen, J. D., MacDonald, A. W., III, Cho, R. Y., Stenger, V. A., & Carter, C. S. (2004). Anterior cingulate conflict monitoring and adjustments in control. *Science, 303*, 1023–1026. doi:10.1126/science.1089910

Kiesel, A., & Hoffmann, J. (2004). Variable action effects: Response control by context-specific effect anticipations. *Psychological Research, 68*, 155–162. doi:10.1007/s00426-003-0152-7

Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, A. M., & Koch, I. (2010). Control and interference in task switching: a review. *Psychological bulletin, 136,* 849-874.

Koch, I. (2001). Automatic and intentional activation of task sets. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*, 1474–1486.

Kristjánsson, Á. (2013). The case for causal influences of action videogame play upon vision and attention. *Attention, Perception & Psychophysics, 75,* 667-672.

Latham, A. J., Patston, L. L. M., & Tippett, L. J. (2013). Just how expert are “expert” video-game players? Assessing the experience and expertise of video-game players across “action” video-game genres. *Frontiers in Psychology, 4*, Article 941. Retrieved from http://journal.frontiersin.org/article/10.3389/fpsyg.2013.00941/full

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 21*, 451–468. doi: 10.1037/0096-1523.21.3.451.

Lenhart, A., Kahne, J., Middaugh, E., Macgill, A. R., Evans, C., & Vitak, J. (2008). Teens, video games, and civics. Pew Internet & American Life Project. Retrieved from http://www.pewinternet.org/Reports/2008/Teens-Video-Games-and-Civics.aspx

Li, R., Polat, U., Makous, W., & Bavelier, D. (2009). Enhancing the contrast sensitivity function through action video game training. *Nature Neuroscience, 12,* 549-551.

Mayr, U., & Kliegl, R. (2000). Task-set switching and long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*, 1124–1140. doi:10.1037/0278-7393.26.5.1124

McDermott, A. F., Bavelier, D., & Green, C. S. (2014). Memory abilities in action video game players. *Computers in Human Behavior*, 34, 69–78.

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance.

Journal of Experimental Psychology: Learning, Memory, and Cognition, 22, 1423–1442.

Meiran, N. (2000). Modeling cognitive control in task-switching. *Psychological Research, 63*, 234–249.

Meiran, N., Chorev, Z., & Sapir, A. (2000). Component processes in task switching. *Cognitive Psychology, 41*, 211–253. doi:10.1006/cogp.2000.0736

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howerter, A., Wager, T. (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.

Monsell, S. (2003). Task switching. *Trends in cognitive sciences, 7,* 134-140.

Monsell, S., & Mizon, G. A. (2006). Can the task-cuing paradigm measure an endogenous task-set reconfiguration process? *Journal of Experimental Psychology: Human Perception and Performance, 32*, 493–516. doi:10.1037/0096-1523.32.3.493

Murphy, K., & Spencer, A. (2009). Playing video games does not make for better visual attention skills. *Journal of Articles in Support of the Null Hypothesis, 6*, 1–20.

Nelson, R. A., & Strachan, I. (2009). Action and puzzle video games prime different speed/accuracy tradeoffs. *Perception, 38*(11), 1678-1687.

Norman, D. A., & Shallice, T. (1986). *Attention to action* (pp. 1-18). Springer US.

NPD Group. (2011). The video game industry is adding 2–17-year-old gamers at a rate higher than that age group's population growth. Retrieved from: http://www.npd.com/wps/portal/npd/us/news/pressreleases/pr_111011

Powers, K. L., Brooks, P. J., Aldrich, N. J., Palladino, M. A., & Alfieri, L. (2013). Effects of video-game play on information processing: A meta-analytic investigation. *Psychonomic Bulletin & Review, 20*, 1055–1079.

Preacher, K. J., Rucker, D. D., MacCallum, R. C., & Nicewander, W. A. (2005). Use of the extreme groups approach: A critical reexamination and new recommendations. *Psychological Methods, 10*, 178–192.

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

Rubinstein, J. S., Meyer, D. E., & Evans, J. E. (2001). Executive control of cognitive processes in task switching. *Journal of Experimental Psychology: Human Perception and Performance, 27,* 763-797.

Sigman, M., & Dehaene, S. (2006). Dynamics of the central bottleneck: Dual-task and task uncertainty. *PLoS Biol 4(7):* e220. DOI: 10.1371/journal.pbio.0040220

Spence, I., & Feng, J. (2010). Video games and spatial cognition. *Review of General Psychology, 14*, 92–104.

Strobach, T., Frensch, P. A., & Schubert, T. (2012). Video game practice optimizes executive control skills in dual-task and task-switching situations. *Acta Psychologica, 140,* 13-24.

Sungur, H., & Boduroglu, A. (2012). Action video game players form more detailed representation of objects. *Acta Psychologica, 139*(2), 327-334

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory & Language, 28*, 127-154.

Unsworth, N., Redick, T. S., McMillan, B. D., Hambrick, D. Z., Kane, M. J., & Engle, R., (2015). Is playing video games related to cognitive abilities? *Psychological*

Science, 1-16. Retrieved from doi:10.1177/0956797615570367

Vandierendonck, A., Liefooghe, B., & Verbruggen, F. (2010). Task switching: Interplay of reconfiguration and interference control. *Psychological Bulletin, 136*, 601–626.

West, G. L., Al-Aidroos, N., & Pratt, J. (2013). Action video game experience affects ocuolomotor performance. *Acta Psychologica, 142,* 38-42.

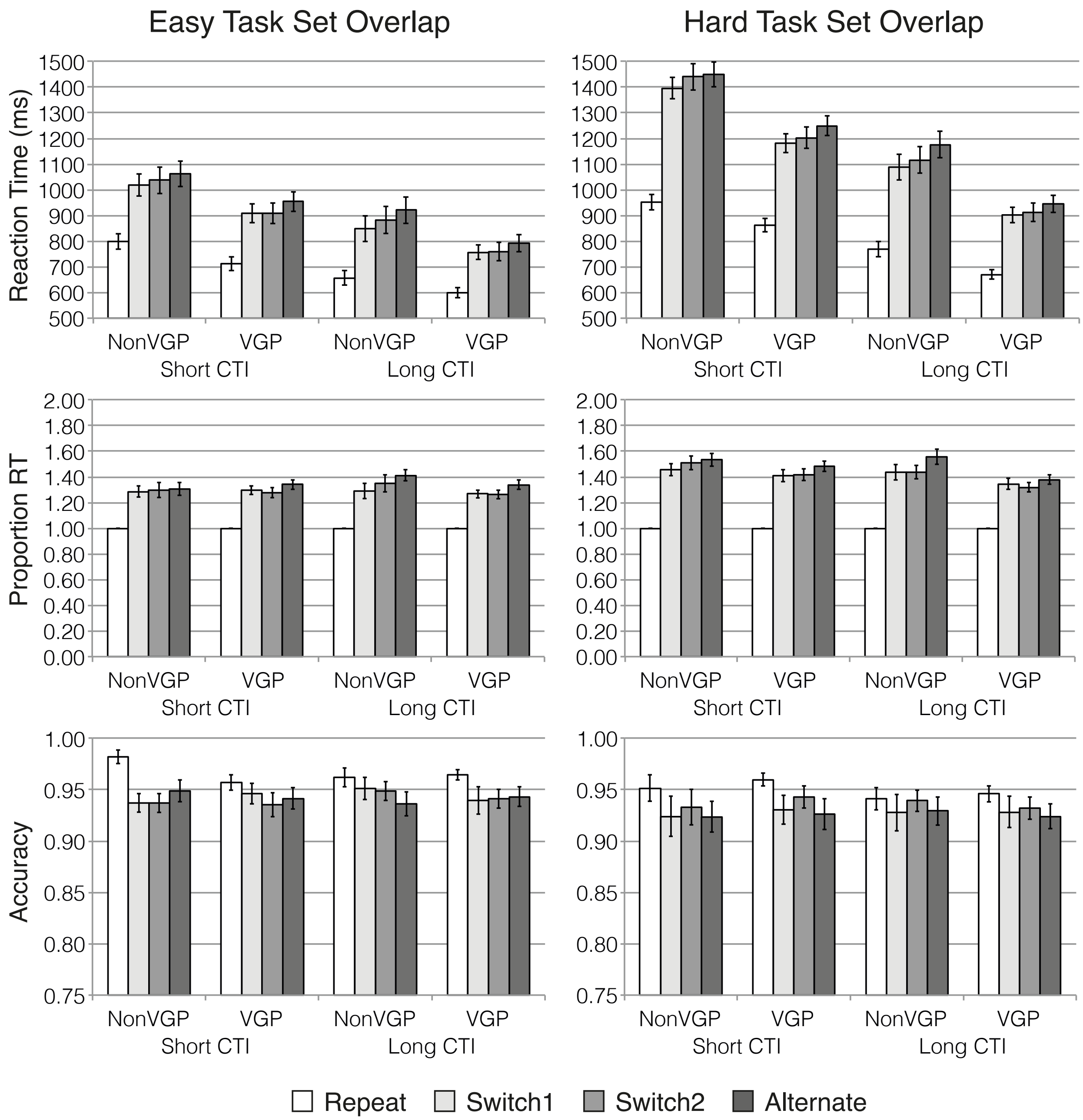
West, G. L., Stevens, S., Pun, C., & Pratt, J. (2008). Visuospatial experience modulates attentional capture: evidence from action video game players. *Journal of Vision, 8,* 1-9.

Wilms, I. L., Petersen, A., & Vangkilde, S. (2013). Intensive video gaming improves encoding speed to visual short-term memory in young male adults. *Acta Psychologica*, *142*, 108–118.

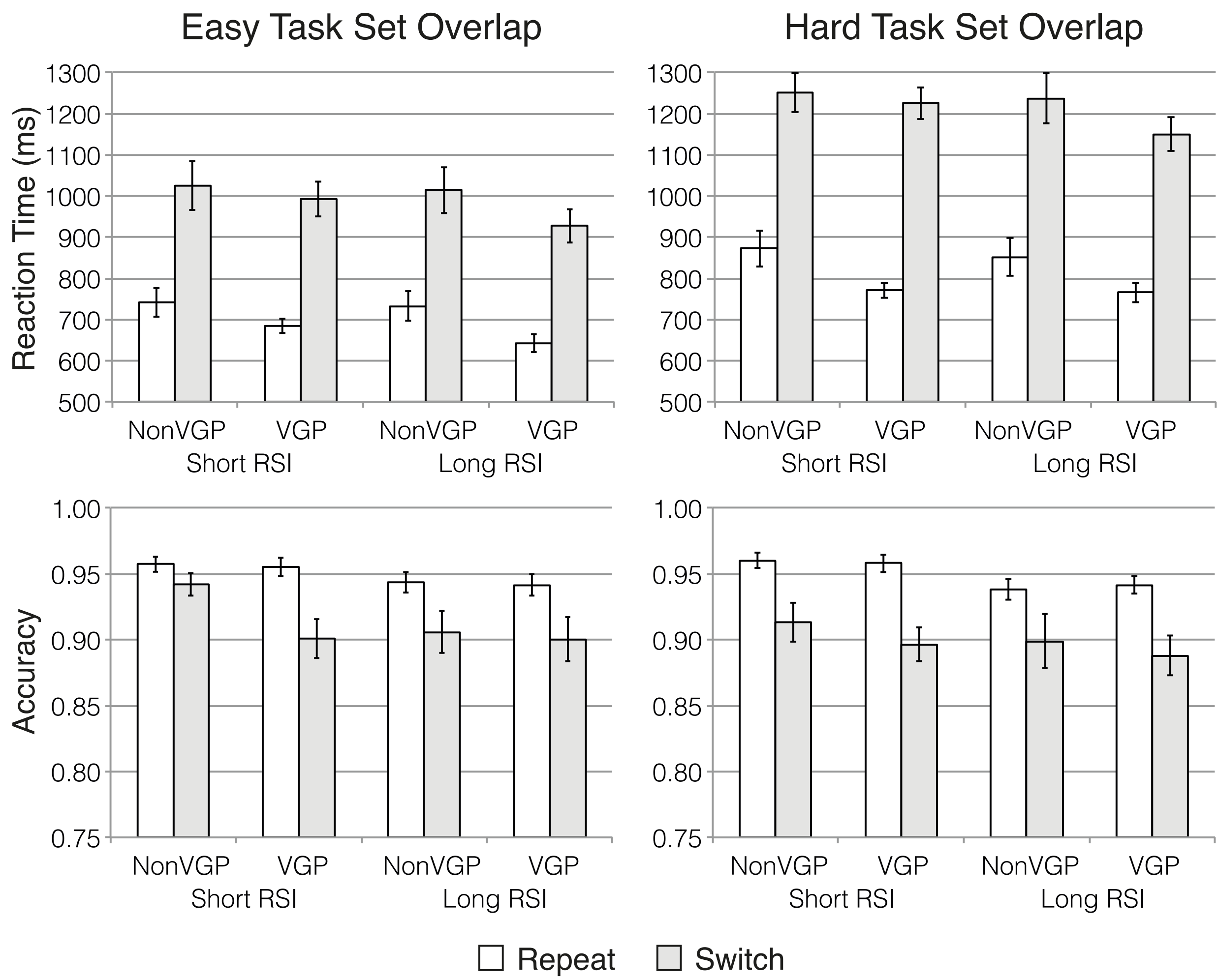
Wylie, G., & Allport, A. (2000). Task switching and the measurement of "switch costs." *Psychological Research, 63,* 212-233.

Yeung, N., & Monsell, S. (2003). The effects of recent practice on task switching. *Journal of Experimental Psychology, 29,* 919-936.

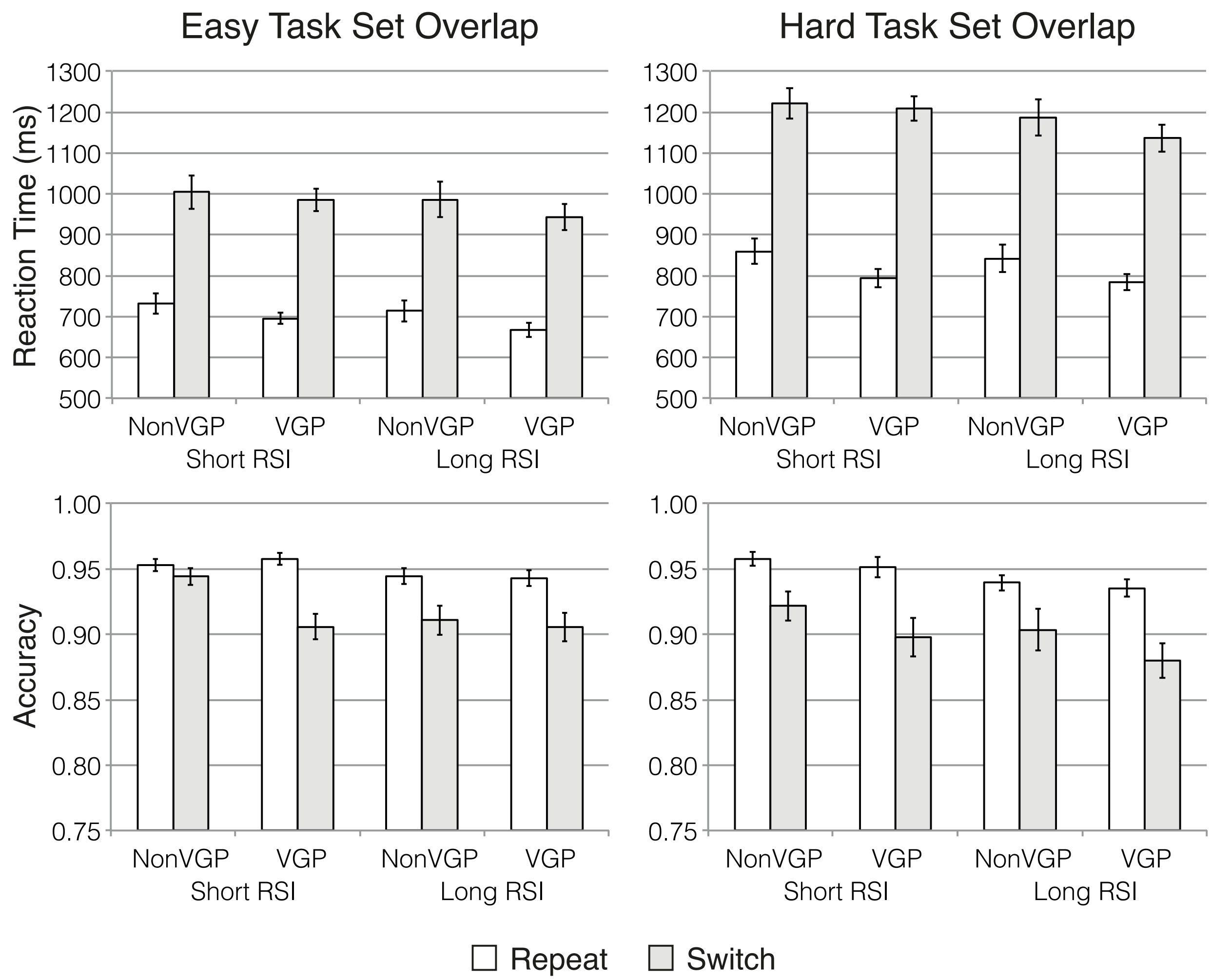
Figures



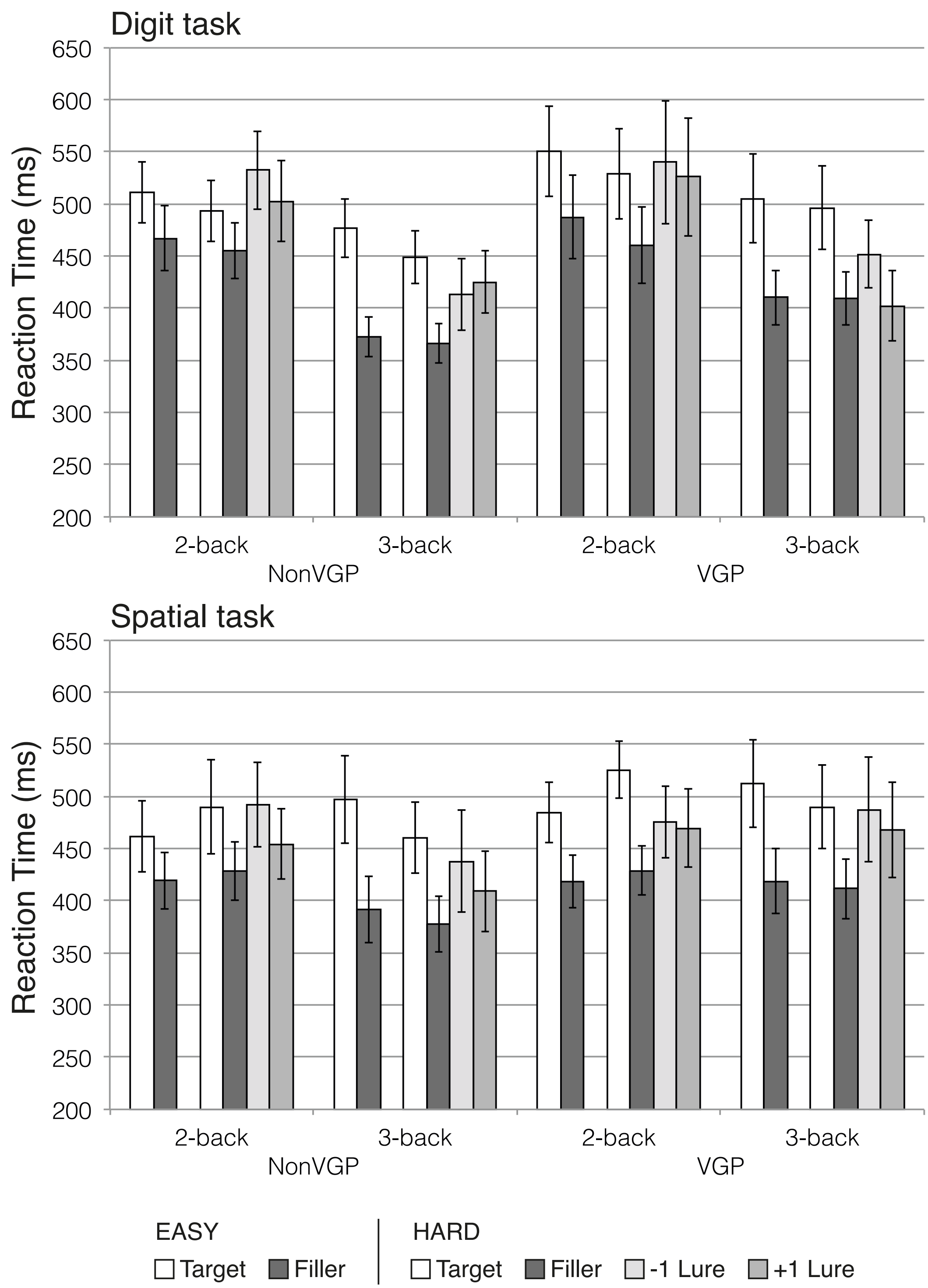
Chapter 2, Figure 1. Task switching performance data for Experiment 1. Error bars represent standard errors.



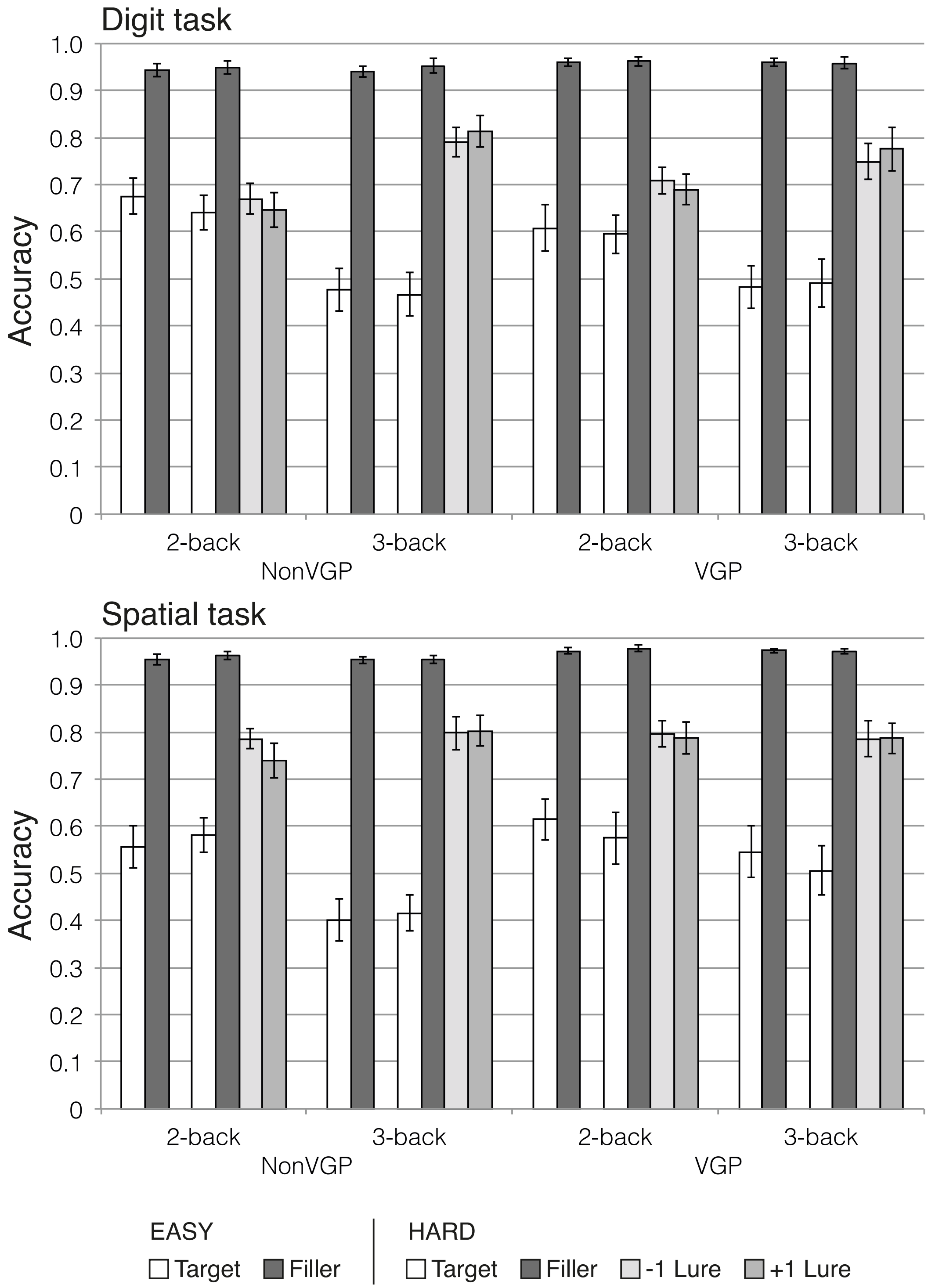
Chapter 2, Figure 2. Task switching performance data for exclusive groups for Experiment 2. Error bars represent standard errors.



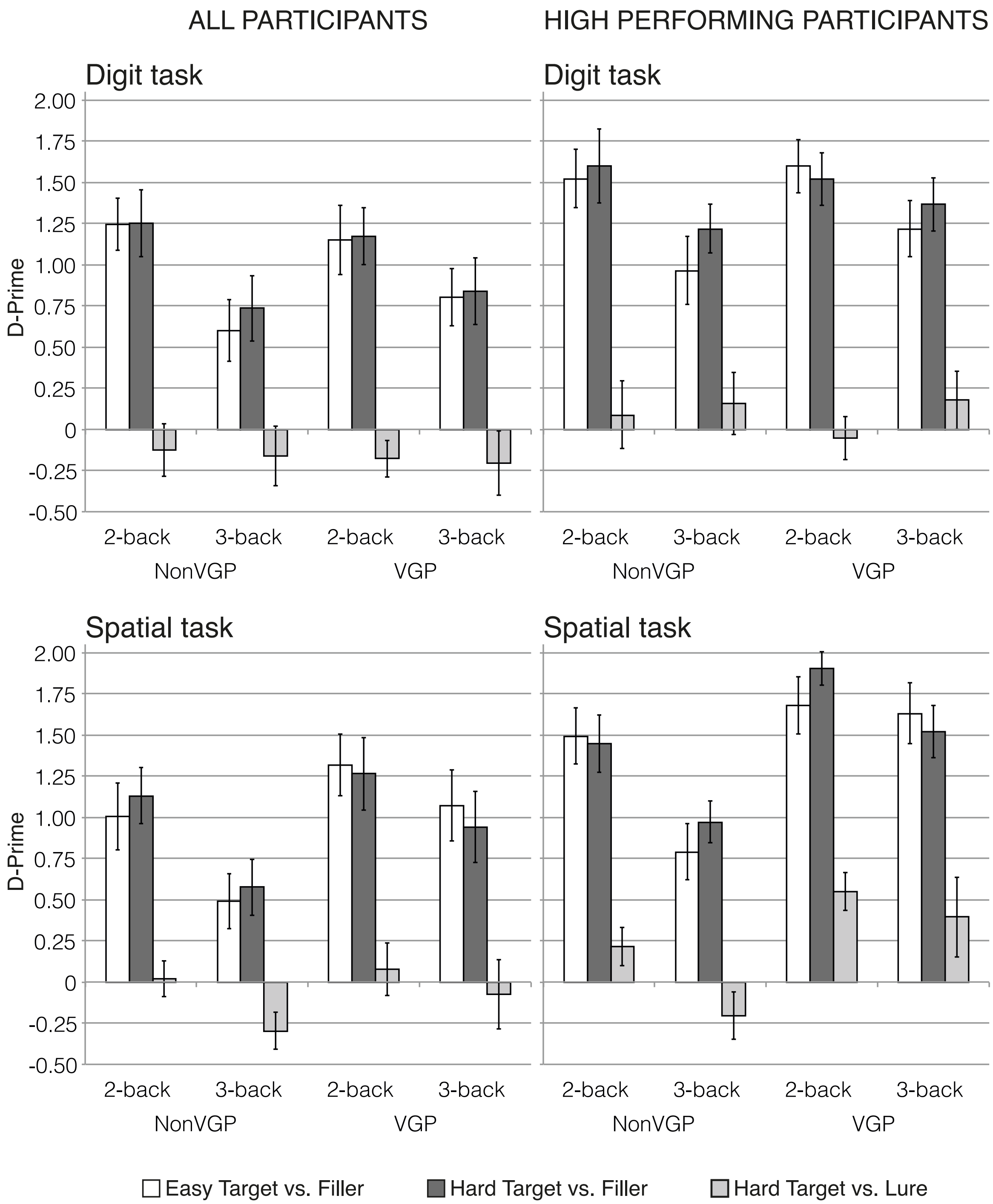
Chapter 2, Figure 3. Task switching performance data for inclusive groups for Experiment 2. Error bars represent standard errors.



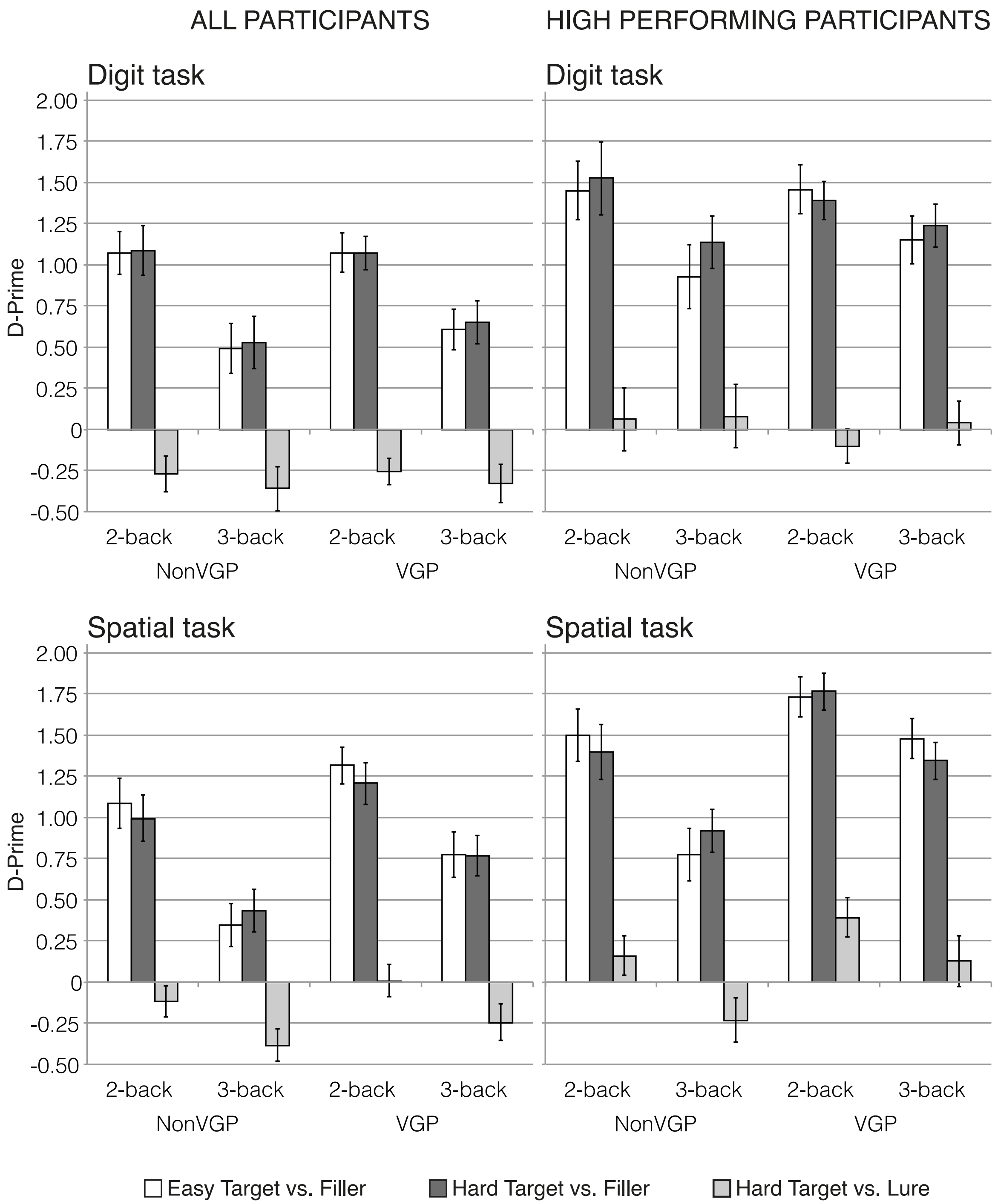
Chapter 3, Figure 1. Reaction time data for n-back performance, for exclusive groups. Error bars represent standard errors.



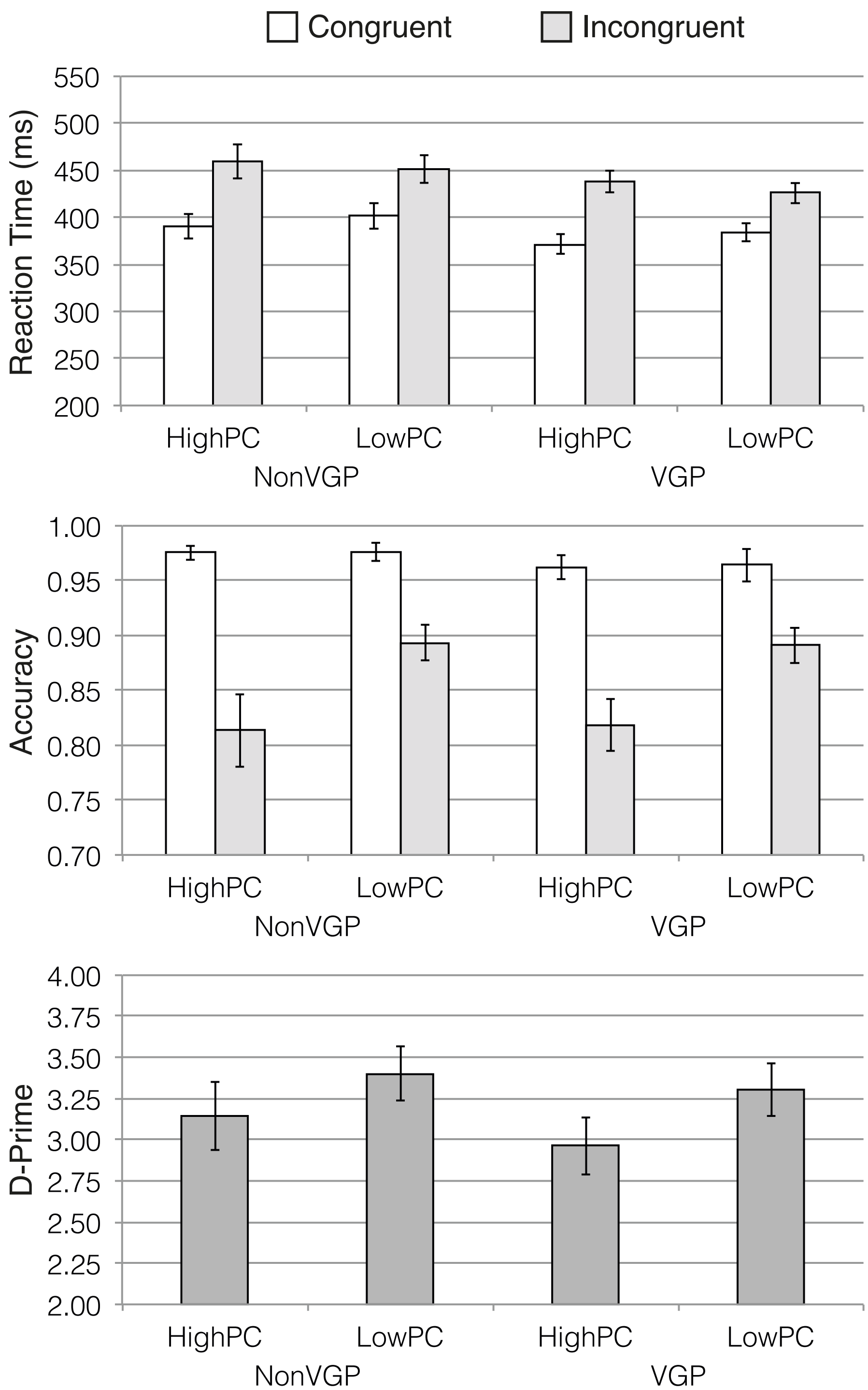
Chapter 3, Figure 2. Accuracy data for n-back performance, for exclusive groups. Error bars represent standard errors.



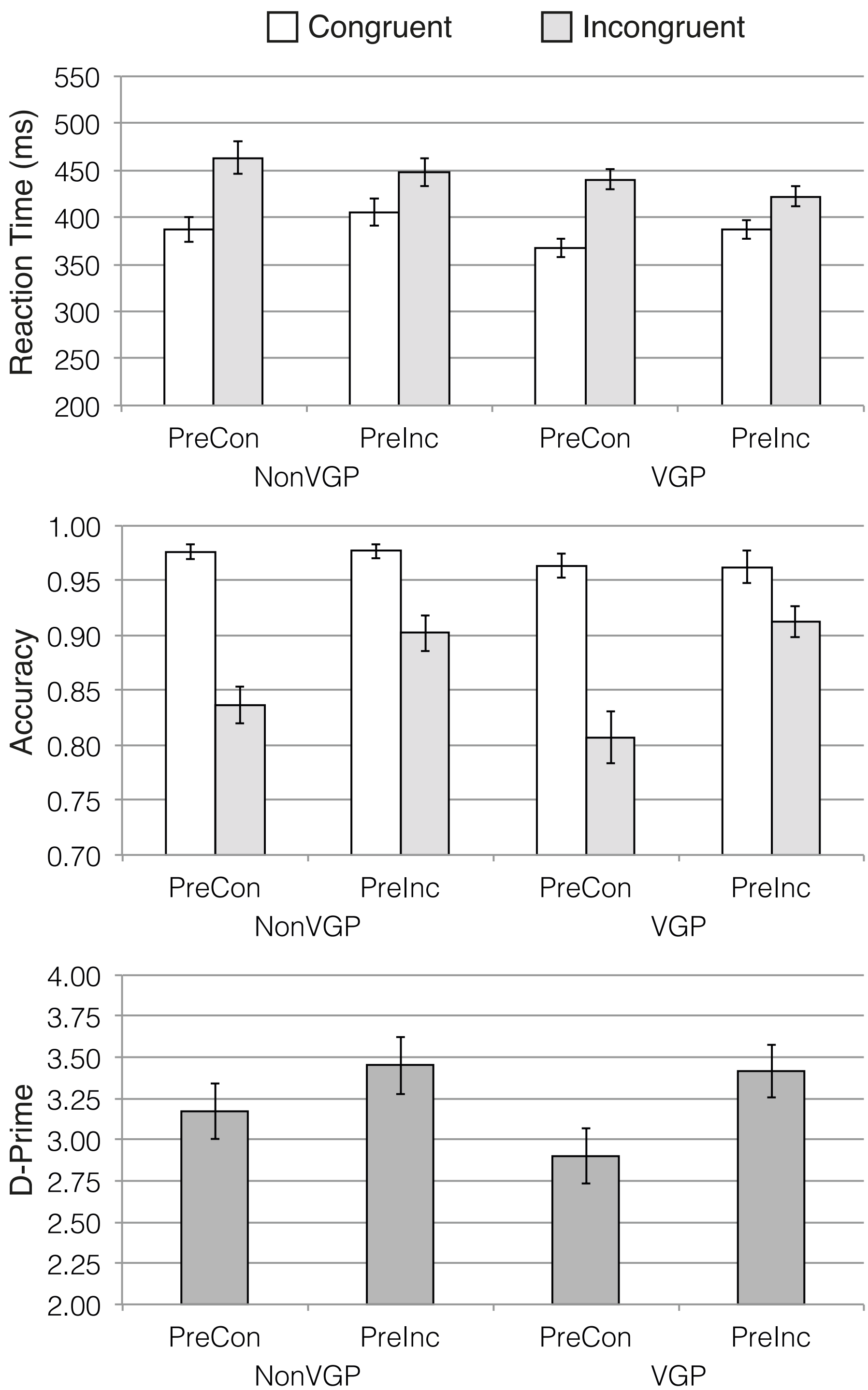
Chapter 3, Figure 3. D-Prime data for n-back performance, for exclusive groups (all participants, and a subset of high-performing participants). Error bars represent standard errors.



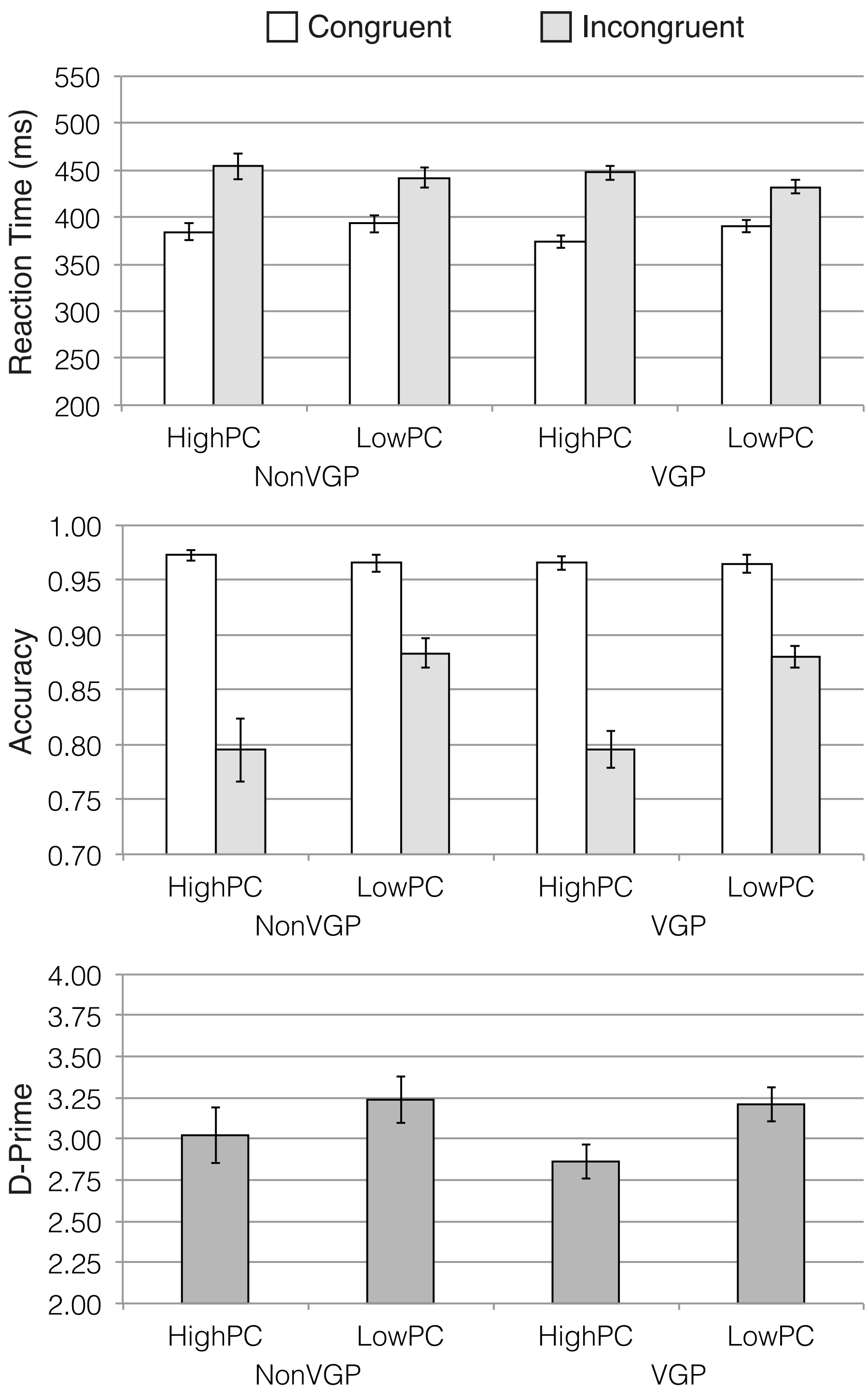
Chapter 3, Figure 4. D-Prime data for n-back performance, for inclusive groups (all participants, and a subset of high-performing participants). Error bars represent standard errors.



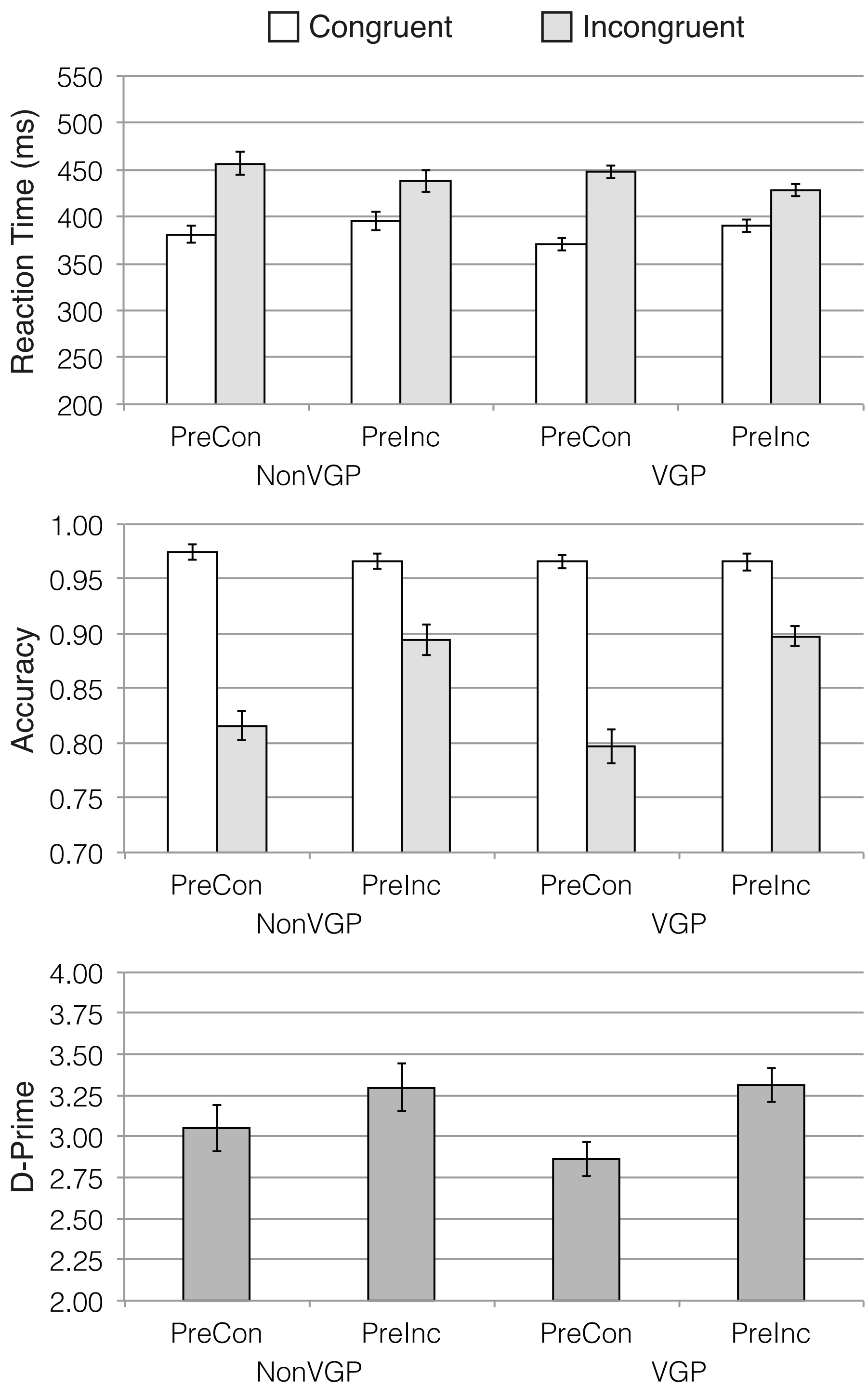
Chapter 4, Figure 1. Flanker task performance for exclusive groups, grouped by proportion congruency (PC). Error bars represent standard errors.



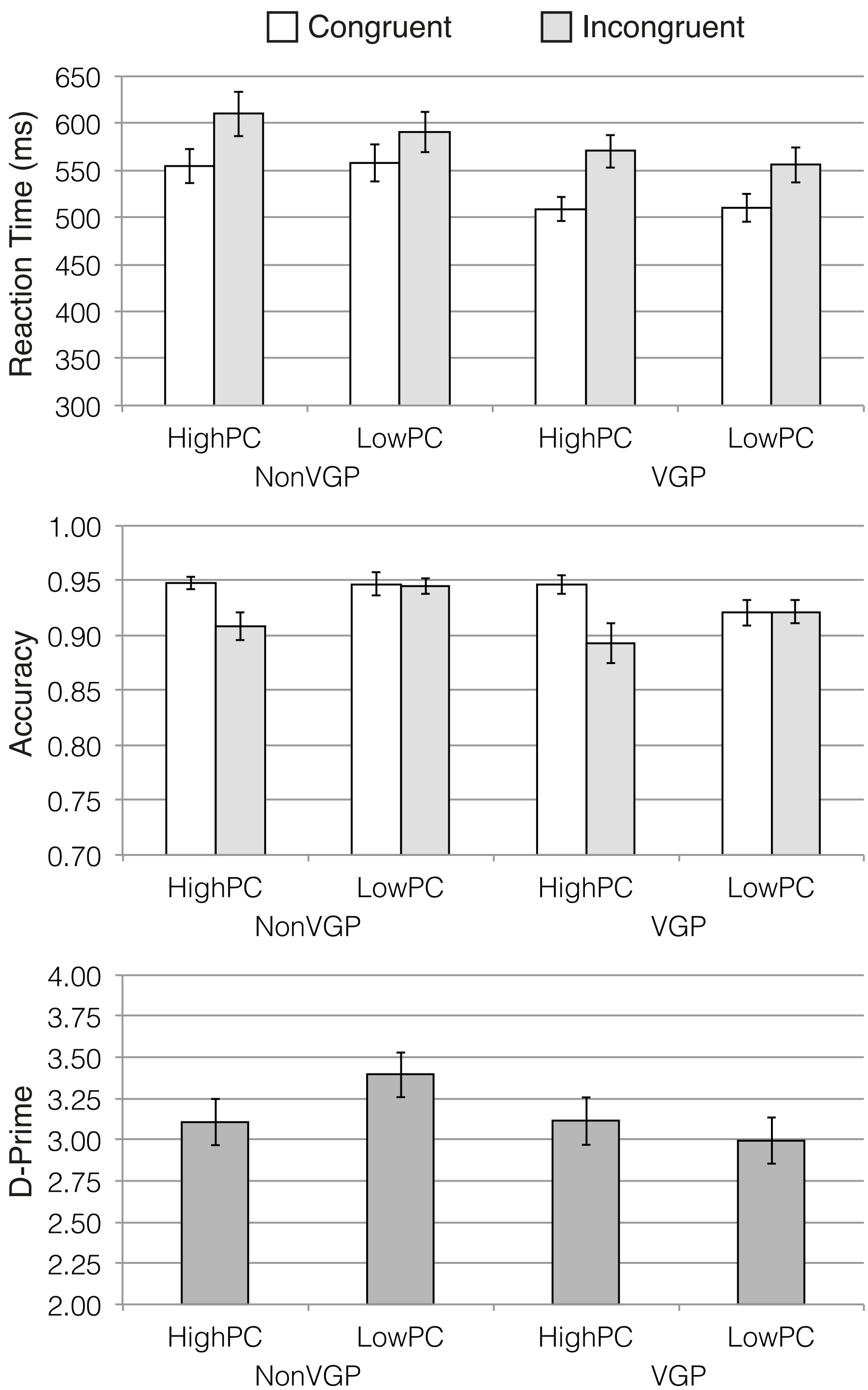
Chapter 4, Figure 2. Flanker task performance for exclusive groups, grouped by previous trial congruency (PreCon = previous congruent, PreInc = previous incongruent). Error bars represent standard errors.



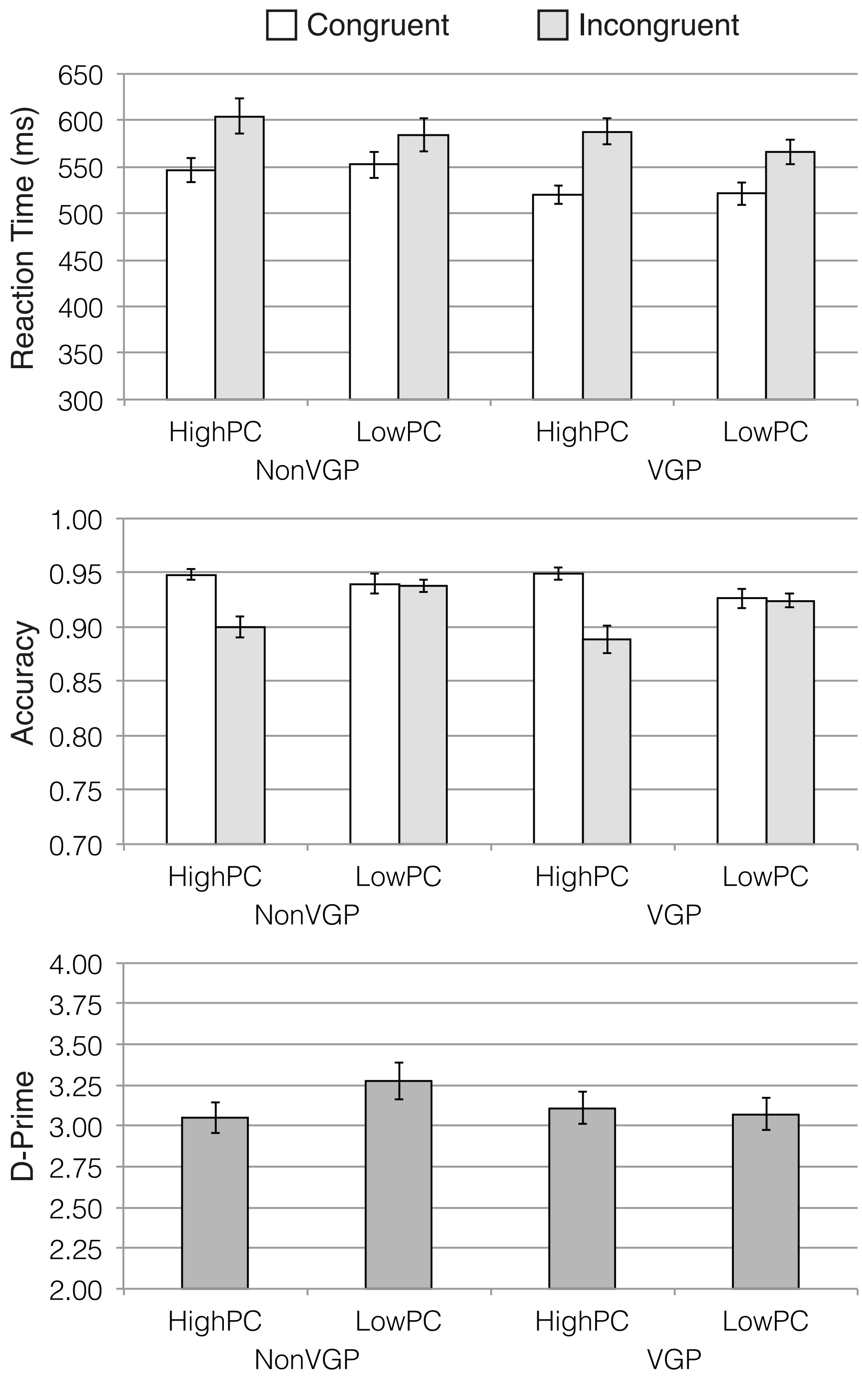
Chapter 4, Figure 3. Flanker task performance for inclusive groups, grouped by proportion congruency (PC). Error bars represent standard errors.



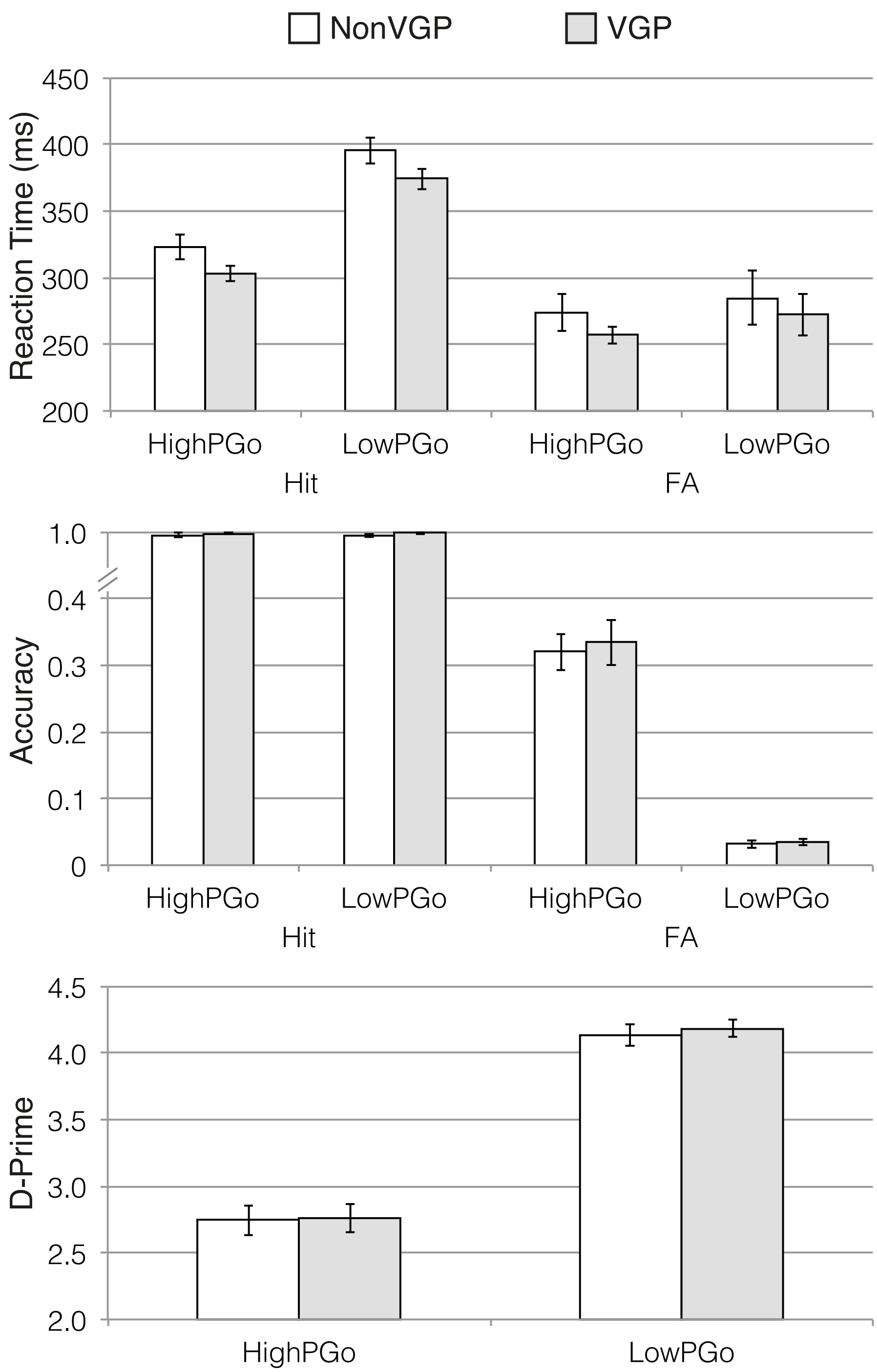
Chapter 4, Figure 4. Flanker task performance for inclusive groups, grouped by previous trial congruency (PreCon = previous congruent, PreInc = previous incongruent). Error bars represent standard errors.



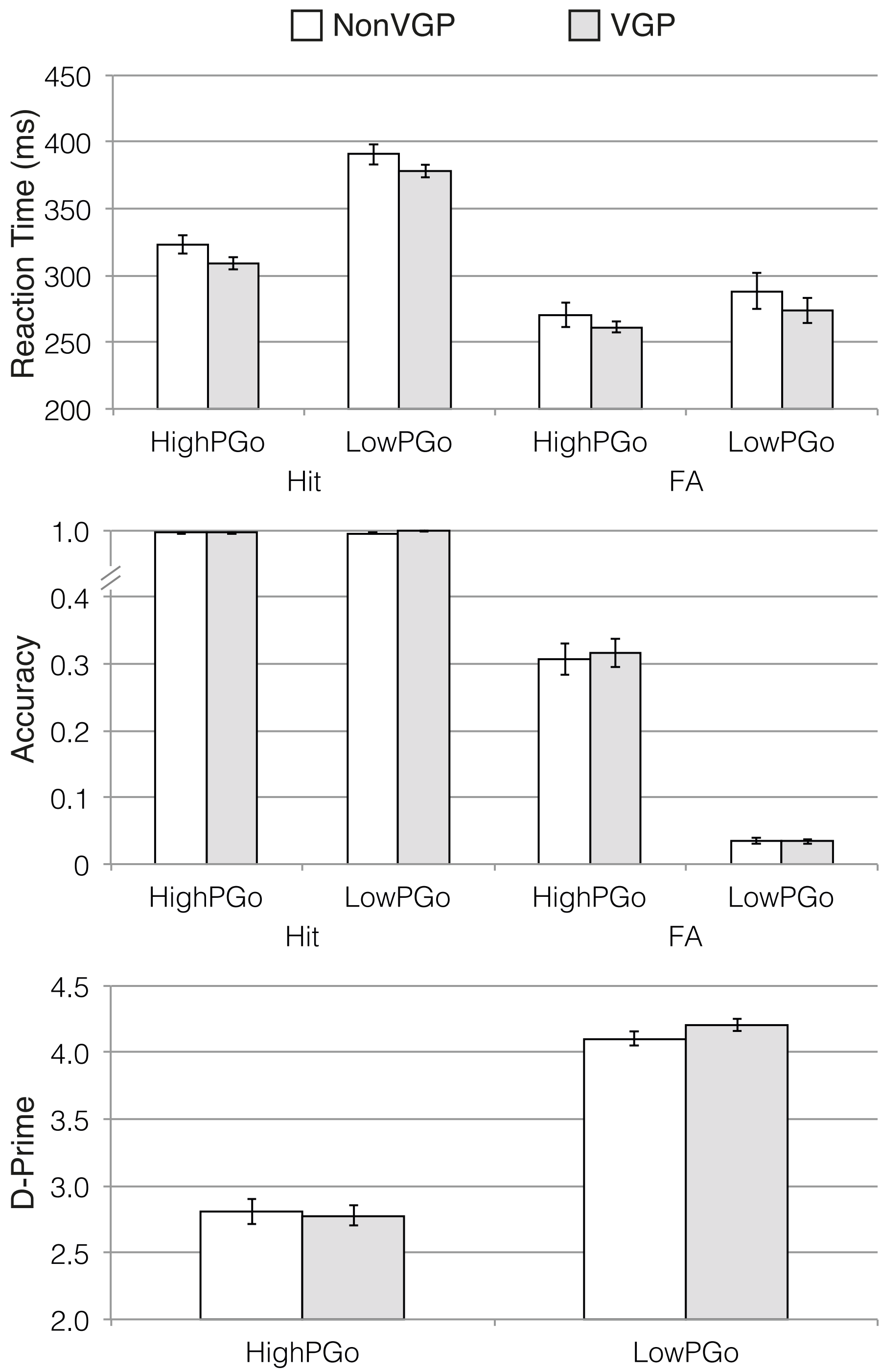
Chapter 4, Figure 5. Stroop task performance for exclusive groups, grouped by proportion congruency (PC). Error bars represent standard errors.



Chapter 4, Figure 6. Stroop task performance for inclusive groups, grouped by proportion congruency (PC). Error bars represent standard errors.



Chapter 4, Figure 7. GoNogo task performance for exclusive groups, grouped by proportion Go trials (PGo). Error bars represent standard errors.



Chapter 4, Figure 8. GoNogo task performance for inclusive groups, grouped by proportion Go trials (PGo). Error bars represent standard errors.

Appendix – Video Game Play Questionnaire

Video Game Questionnaire

Game Play History

For Experimenter Use Only:

Experiment: ____________

Subject #: ____________

Surname: ____

Given Name: ____

Middle Initial(s): ______________________ Age: ______________________

Gender: MALE / FEMALE Handedness: LEFT / RIGHT

1. Approximately, how many hours a week do you play video games? If zero, have you played videogames 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)?

First Person Shooters	________
Action Adventures	________
Turn-Based Strategy	________
Massively Multiplayer	________
Racing	________
Adventure Games	________
Real-Time Strategy	________
Tactical Shooters	________
Sports	________
Role-Playing	________
Other Strategy	________
Dance/Music	________
Online	________
Other	________

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	________
Action Adventures	________
Turn-Based Strategy	________
Massively Multiplayer	________
Racing	________
Adventure Games	________
Real-Time Strategy	________
Tactical Shooters	________
Sports	________
Role-Playing	________
Other Strategy	________
Dance/Music	________
Online	________
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?