Individual differences in oculomotor control:

The case of action video game players

by

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Abstract

A growing field of research has highlighted that experience with action video games, characterized by being particularly fast paced and attentionally demanding, yields performance improvements across a host of cognitive paradigms. The prevailing account is that extensive action video game experience gives rise to improvements in the control of selective attention. By recording eye movements in a series of experiments where participants completed an oculomotor capture task, the present dissertation aims to use a more direct measure of the spatial allocation of attention to further examine the basis for the improvements demonstrated by action video game players (AVGPs) relative to non-video game players (NVGPs). Chapter 2 examines the basis for AVGPs' reported resistance to distracting information. In addition to demonstrating that the AVGP advantage extends to overt attention, the results reveal that AVGPs are better able to avoid distraction by making fewer shifts of attention to salient task-irrelevant information. Chapter 3 examines whether the AVGPs' resistance to distraction is a result of improvements in selection and/or response-based processes. Evidence is provided to suggest that AVGPs' performance is enhanced via benefits to both processes. Independent of video game experience, Chapter 4 examines the influence that distractor awareness has on oculomotor control and reveals that it can benefit performance. This knowledge was applied in Chapter 5 to assess whether distractor awareness interacts with AVGP and NVGP performance. Results demonstrate that distractor awareness can eliminate the AVGP advantage. Chapter 6 examined whether AVGP would outperform NVGPs when biologically relevant stimuli was added to search displays. Results reveal that AVGP benefits generalize to more

complex stimuli. Chapter 7 provides a test of the recently proposed learning to learn account of AVGP performance benefits and disconfirms this explanation. Collectively, the dissertation demonstrates how improved attentional control can be manifested in AVGPs to reduce distraction from salient visual information. Importantly, the conclusions drawn from this body of work are consistent with the notion that AVGPs experience more efficient processing of sensory information than NVGPs, providing a possible mechanism subserving the general AVGP advantage observed across a variety of cognitive tasks.

Preface

All of the work presented in this dissertation was conducted in the Brain and Attention Research Laboratory at the University of British Columbia, Point Grey campus. All projects and associated methods were approved by the University of British Columbia's Research Ethics Board [certificate # H10-00527 & # H04-80767].

A version of Chapter 2 has been published [Chisholm, J. D. & Kingstone, A. (2012). Improved top-down control reduces oculomotor capture: The case of action video game players. *Attention, Perception, & Psychophysics*, *74*(2), 257-262.]. I was the lead investigator, responsible for all major areas of concept formation, data collection and analysis, as well as manuscript composition. All co-authors were involved in the early stages of concept formation and contributed to manuscript edits.

A version of Chapter 4 has been published [Chisholm, J.D. & Kingstone, A. (2014). Knowing and avoiding: The influence of distractor awareness on oculomotor capture. *Attention, Perception & Psychophysics, 76*(5), 1258-1264]. I was the lead investigator, responsible for all major areas of concept formation, data collection and analysis, as well as manuscript composition. Kingstone A was involved throughout the project and contributed to manuscript edits.

I was the lead investigator for the projects reported in Chapters 3, 5, 6, and 7 where I was responsible for all major areas of concept formation, data collection and analysis, as well as the majority of manuscript composition. Kingstone A, was the supervisory author and was involved throughout the projects in concept formation and manuscript edits.

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1 Cognition and video games

1.1 Introduction

The past few decades have seen a marked increase in the popularity of video games. From humble beginnings in the 1970s, recent industry reports have indicated that approximately 50% of both Canadian and US households possess a dedicated gaming console (Entertainment Software Association of Canada, 2012; Entertainment Software Association, 2012). This figure does not include the ubiquitous presence of personal computers in households, which are also frequently used for gaming. Having established itself as a multi-billion dollar industry, the time individuals spend playing video games rivals, and often exceeds, the time spent with other forms of leisure/pastime activities (e.g. reading, watching movies/television). However, far from a passive activity, modern video games present players with complex, and often rewarding, interactive experiences. This increase in exposure to video games has generated growing scientific interest in understanding the potential effects video game experience has on its players.

Research investigating the effects of video games on cognitive processes began in the early 1980s, shortly after a surge in video game popularity. Comments from Patricia Greenfield (1984, 2009), one of the first to scientifically investigate the effects of video game use, argued that technology, such as video games, could provide users with a type of informal education (i.e. learning that occurs outside the standard educational system/school). Based on this notion, the potential effects of video game use became a very interesting question from both a developmental and rehabilitative perspective. Early work investigating the impact of video games focused primarily on the spatial abilities of children and information processing abilities in the elderly. This body of work was consistent in demonstrating performance improvements as a function of video game experience. Specifically, various studies demonstrated that video game experience was associated with, and in some cases led to, enhanced spatial abilities (Dorval & Pepin, 1986; Gagnon, 1985, McClurg & Chaillé 1987; Okagaki & Frensch, 1994; Subrahmanyam & Greenfield, 1994; however, see Sims & Mayer, 2002 for a restricted view of this enhancement) and improved reaction time performance (Clark, Lanphear, & Riddick, 1987; Drew & Waters, 1986; Goldstein, et al., 1997; Orosy-Fildes & Allan, 1989; Yuji, 1996).

The past decade has seen an increase in this line of research, investigating the impact of video games that are now far more sophisticated than their technological predecessors. Much of this recent research has yielded findings consistent with earlier work, demonstrating that video game players outperform non-players on a host of tasks thought to engage independent domains of cognition. These findings have continued to fuel interest in the use of video games as a viable rehabilitative tool (Achtman, Green, & Bavelier, 2008; Anguera et al., 2013; Franceschini et al., 2013; Li, Ngo, Nguyen, & Levi, 2011). In addition, video games have also been considered as a potential training tool for surgeons and army personnel (Gopher, Well, & Bareket, 1994; Lintern & Kennedy, 1984; Lynch, Aughwane, & Hammond, 2010; Rosenberg, Ladsittel, & Averch, 2005; Rosser et al., 2007; Yule et al., 2011). Given the possible practical application of video game training, a greater emphasis has recently been placed not only on understanding both the circumstances that video game players differ from non-players, but the mechanism(s) underlying those differences.

1.2 The case of action video games

Much of the aforementioned work investigating the effect of video games on cognitive abilities did not emphasize the use of any particular genre of video game. Instead most studies chose games that were either popular at the time (e.g. Tetris, Donkey Kong), were similar to certain "real-world" contexts (e.g. Air Combat Maneuvering), or were created by the scientific community to address questions of skill acquisition (i.e. Space Fortress; Mane & Donchin, 1989). As evidence has emerged to indicate that not all games yield similar cognitive effects (Cohen, Green, & Bavelier, 2007; Oei & Patterson, 2013), recent research has become a bit more selective, focusing its efforts on the effects of one particular genre of video game – *action video games*. Action video games are referred to as such as a function of their specific features and many of these games fall under the sub-genre of first person shooter (FPS) games. Popular examples from this type of video game include *Call of Duty, Halo, Team Fortress 2, Counter-Strike, and Battlefield.* Action video games are characterized as being incredibly fast paced, requiring quick and accurate responses all while often simultaneously tracking multiple moving objects (e.g. friendly units, enemy units, items of interest, etc.), making split second decisions (e.g. engage enemy vs. look for cover) and requiring the efficient selection of goal-relevant information while avoiding distraction from irrelevant information. Players are also often required to divide attention across a number of screen locations that provide navigational information, goal-relevant cues, character relevant information, and possible enemy positions (Figure 1.1). In these gaming contexts, not only must players act and respond on a moment-to-moment basis, but they must also maintain some representation of the global goal of the game in memory and actively work toward achieving it.

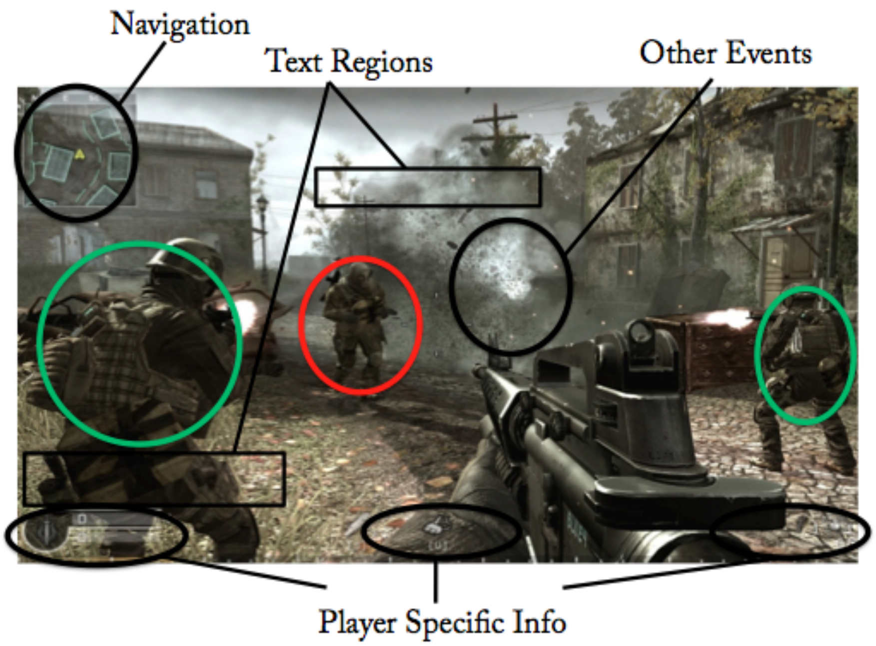

Figure 1.1 – Screenshot of an action video game (Call of Duty 4: Modern Warfare) to provide an example of all the information players must monitor. In addition to the noted sources of information, friendly units are circled green and the hostile unit is circled red.

In addition to the features associated with action video games that make them interesting from an empirical standpoint they are one of the most commonly played genres of video games. According to the Entertainment Software Association (2012), 37% of Canadian adult, and 59% of Canadian young adult video game players play action video games and, in the United States, FPS/action video games were the second highest selling genre of video games in 2011, making up 18.4% of 229.8 million video game units sold. Within many of these games exist online multiplayer modes, which provide players with a significant number of hours playing competitively and cooperatively online with other players around the world.

Thus, the prevalence and attentionally demanding nature of action video games have made them an interesting candidate to investigate the potential effects that such interactive experience can have on the cognitive system. Though this dissertation focuses on understanding the possible beneficial aspects of action video game experience, it is worth noting that not all research has provided positive outcomes associated with action video game experience. Like other forms of entertainment, such as television and gambling, video games have been targeted for their potential deleterious effects. Specifically, there is an ongoing debate as to whether exposure to the, sometimes extreme, violence presented in action video games has a negative effect on players. Though this body of work is based largely on correlational findings, a recent meta-analysis argued that a causal link exists between exposure to violent video games and increased aggressive behaviour, aggressive cognition, and a decrease in prosocial behaviour and empathy (Anderson et al., 2010; however, see Ferguson & Kilburn, 2010 for an alternative view). Moving forward, it may be important to weigh the list of positive outcomes associated with action video game use against the possible negative effects. However, in either case, for the field to move forward it is critical to gain a better understanding of the mechanism(s) underlying the changes observed in video game player behaviour. To provide a framework for the present dissertation, I will begin by presenting an overview of the literature investigating the effects associated with action video game experience.

1.3 Effects of action video game experience

The effects of action video game experience spread across a host of cognitive domains and experimental paradigms. These investigations primarily compare performance of those who meet some criteria to be considered an action video game player (AVGP) with those who meet the criteria to be considered either a non-video player (NVGP) or a non-action video game player (i.e., those who play video games but specifically little to no action video games). In order to provide an overview of these findings, I present sections for each of the specific effects that have been reported in the literature.

1.3.1 Improvements in basic vision

A number of studies have provided evidence that AVGPs outperform NVGPs on tasks that traditionally measure basic aspects of vision. For example, results revealed that, compared to NVGPs, AVGPs possess larger Goldmann visual fields (Buckley et al. 2010) reflecting enhanced visual sensitivity in the periphery, and greater contrast sensitivity (Li et al., 2009), indicating improved detection of low-contrast stimuli, than NVGPs. AVGPs have also been revealed to possess greater visual acuity, demonstrated as smaller costs associated with visual crowding, even in the visual periphery (Green & Bavelier, 2007). Research has even demonstrated that the visual acuity and contrast deficits associated with amblyopia (Asper, Crewther, & Crewther, 2000), a developmental abnormality that impairs vision in an affected eye, are reduced following action video game training (Li, et al., 2011).

1.3.2 Improved spatial cognitive skills

Earlier work investigating the influence of video games on cognition largely focused on their effect on spatial skills in younger samples (Dorval & Pepin, 1986; Gagnon, 1985, McClurg & Chaille, 1987; Okagaki & Frensch, 1994; Sims & Mayer, 2002; Subrahmanyam & Greenfield, 1994). Only a few more recent studies have assessed the impact specifically of action video game experience on spatial cognition (see Spence & Feng, 2010 for a review). For example, Feng et al. (2007) demonstrated that both self-reported AVGPs and participants who trained on an action video game demonstrated improved mental rotation performance (i.e., more correct responses) compared to self-reported NVGPs and those who trained on a control/non-action video game. Interestingly, greater improvements were observed in females compared to males. Also employing a mental rotation task, Cherney (2008) demonstrated a similar effect where, although video game training improved subsequent task performance, the greatest improvements were seen in females. These findings may have important implications for the differences in spatial skills typically demonstrated across genders (e.g. Voyer, Voyer, & Bryden, 1995). Boot et al. (2008) also provided a comparison of AVGP and NVGP performance in a mental rotation task. Although they demonstrated a strong trend for improved accuracy and reaction time, the results were not quite statistically significant. It has been suggested that Boot et al.'s (2008) failure to replicate the improvement in mental rotation, in addition to a number of other previously observed effects, may have been a result of a more liberal inclusion criteria for the AVGP group (Hubert-Wallander, Green, & Bavelier, 2010). Despite this potential conflicting finding, it appears that spatial skills are improved by action video game experience. The basis for such improvements could reflect the skills gained from having to spatially navigate relatively complex, and in many cases three-dimensional, virtual environments.

1.3.3 Enhanced allocation of spatial attention

Greenfield et al. (1994) provided the first instance of video game experience affecting spatial attention by assessing AVGP and NVGP performance on a divided attention task. Based on Posner, Snyder, and Davidson’s (1980) original stimulus detection paradigm, participants were required to detect the presence of a target either to the right, left of a central fixation point, or at both locations simultaneously. Greenfield and colleagues then manipulated the probability of a target appearing at one of the two locations. In a neutral condition, it was equally probable that the target would appear on the right or left of fixation (45%) and a 10% chance that the target would appear simultaneously at both locations. In the second condition, a high and low probability location was created by having the target appear at one location on 80% of trials and the other location on only 10% of trials. Again, on the remaining 10% of trials, the targets appeared at both locations. By comparing performance on the neutral condition to the high and low probability locations, this paradigm provides a measure of attentional benefit (faster reaction times) and cost (slower reaction times), respectively, associated with dividing attention across multiple spatial locations. Results revealed that both AVGPs and NVGPs experienced a similar performance benefit when a target appeared at the high probability location. However, whereas NVGPs showed the traditional cost effect when the target appeared the low probability location, AVGPs did not show this effect. The fact that AVGPs did not show a cost led Greenfield and colleagues to propose that AVGPs engage a strategic change in how they allocate attention.

Over the past decade, research has come to support the claim made by Greenfield et al. (1994). Specifically, evidence has emerged suggesting that AVGPs possess improved control over the distribution (Feng et al., 2007; Green & Bavelier, 2003, 2006a) and spatial allocation of attention (e.g. Chisholm et al., 2010; Clark, Fleck, & Mitroff, 2011; Hubert-Wallander, Green, Sugarman, & Bavelier, 2011). For example, a number of studies employed a Useful Field of View (UFOV) task to investigate whether AVGPs and NVGPs differ in how they spatially distribute attention. The task requires participants to indicate the location of a briefly presented target along a variety of peripheral eccentricities (Ball & Owsley, 1993). Results of these investigations were consistent in demonstrating an AVGP advantage for correctly localizing the target at distances as far as 30 degrees of visual angle away from a central fixation point (Feng, et al., 2007; Green & Bavelier, 2003, 2006a). In another study, Chisholm et al. (2010) aimed at assessing whether improved spatial allocation of attention could reduce distractor interference in an attentional capture task. Using an additional singleton paradigm (Theeuwes, 1991, 1992), participants searched and responded to information embedded within a unique shape target singleton. On half the trials a salient but task-irrelevant distractor, a colour singleton, appeared within the display. Traditionally, reaction times are slower on distractor present trials as it is thought that attention is first reflexively captured by the most salient item in a display prior to orienting to the target, independent of any concurrent top-down goals (Theeuwes, 1991, 1992, 2004; however, see Folk, Remington, & Johnson, 1992 and Bacon & Egeth, 1994 for competing accounts). Chisholm and colleagues revealed that, although both NVGP and AVGP performance was negatively influenced by the presence of a salient distractor, the magnitude of the capture effect was significantly smaller in AVGPs.

It is important to note that not all aspects of spatial attention appear to be affected equally. Traditionally, two guiding processes influence the allocation of spatial attention. Bottom-up or exogenous guidance can result in reflexive shifts of attention, independent of available attentional resources, as a result of stimulus-based properties (e.g. salience). In contrast, top-down guidance results in volitional shifts of attention, dependent on available resources, based on ones current goals (Posner, 1980). Whereas much evidence has been provided to suggest an effect of action video game experience on top-down attentional control (Hubert et al., 2010), there appears to be little to no effect on bottom-up/exogenous attention. For example, although Castel et al. (2005) demonstrated quicker reaction times in AVGPs in an inhibition of return (IOR) task, they did not demonstrate any differential attentional effect associated with the briefly presented exogenous cue that preceded the target. In addition, using the Attentional Network Task (Fan, McCandliss, Sommer, Raz, & Posner, 2002) Dye, Green, and Bavelier (2009a) revealed no differences in spatially orienting attention in response to an exogenous cue in both adult and younger samples of action and non-gamers. Hubert et al. (2011) further tested the impact of exogenous cues in AVGPs and non-gamers in a modified Posner cueing paradigm. Results revealed that orienting attention to the exogenous cue did not differ between groups; however, AVGPs did, once again, demonstrate overall faster manual reaction times. Interestingly, a recent study by Cain, Prinzmetal, Shimamura, and Landau (2014) has suggested that AVGPs may exhibit more flexible control over the influence of exogenous cues. Specifically, when performing a cuing task, AVGPs exhibited behaviour indicative of making use of exogenous cues when it benefited performance (i.e., valid cues) but were not influenced by the same cues when it was detrimental to do so (i.e., invalid cues). Collectively, the evidence points to action video games having an effect on the spatial allocation and distribution of attention, specifically on tasks that require some form of top-down control.

1.3.4 Improving temporal aspects of attention

In addition to the work on the spatial allocation of attention, research has provided evidence that action video game experience affects the temporal dynamics of attention. Such investigations have demonstrated improved temporal resolution of AVGPs' attention in tasks that require individuals to process sequential information presented close in time (Dye & Bavelier, 2010; Green & Bavelier, 2003; Li, Polat, Scalzo, & Bavelier, 2010). AVGPs' improvements also appear to extend beyond the visual modality, as they demonstrate an improvement in the ability to determine the temporal sequence of multimodal (visual and auditory) information (Donohue, Woldorff, & Mitroff, 2010; however, see West, Stevens, Pun, & Pratt, 2008 for conflicting temporal order judgment results in just the visual modality).

To investigate the possible effects of action video game experience on the temporal dynamics of attention, a handful of studies compared AVGP and NVGP performance on an attentional blink task. The attentional blink task is commonly used to investigate and demonstrate the attentional bottleneck that occurs when attempting to process information that is presented close together in time (see Dux & Marois, 2009 for a review). This task requires participants to identify an initial target letter (T1) presented in a rapid serial visual presentation (RSVP) stream followed by the detection of a second target (T2) presented shortly after in the same stream. The ability to accurately detect T2 as a function of the time between the presentation of T1 and T2, allows for the measurement of the attentional bottleneck. Traditionally, when T1 and T2 appear close together in time, T2 detection rates drop significantly. Although ultimately based on attentional processes, competing accounts have been provided for this deficit in T2 performance. Earlier accounts have argued that the attentional blink occurs as a result of attentional resources being allocated to the identification of T1, leaving fewer resources to properly detect the appearance of T2 (e.g. Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1998; Shapiro, Raymond, & Arnell, 1994). In contrast to such attentional depletion accounts, others have argued that the attentional blink instead reflects either a disruption or a temporary loss of control over the maintained attentional set (Di Lollo, Kawahara, Shahab Ghorashi, & Enns, 2005; Kawahara, Kumada, & Di Lollo, 2006) or a temporary tightening of attentional control after incorrectly processing a distractor appearing immediately following T1 (i.e. overcompensation; Olivers, van der Stigchel, & Hulleman, 2005). A comparison of AVGPs and NVGPs on this task revealed that, AVGPs exhibited a significantly smaller attentional blink than NVGPs (Dye & Bavelier, 2010; Green & Bavelier, 2003, Oei & Patterson, 2013). It is important to note that not all tests using attentional blink showed a difference (Boot et al., 2008; Cain et al., 2014; Murphy & Spence, 2009), however it has been suggested that this may be due more to limitations in the attentional blink tasks used than to the effect of video game playing (Cain et al., 2014).

An investigation by Li et al. (2010) also demonstrated effects of action video game experience on the temporal dynamics of attention. AVGP and NVGP performance was compared in a masking paradigm, which presented a visual mask shortly before (forward masking), simultaneous with, or after (backward masking) the time of target presentation. The presentation of a visual mask is known to disrupt an individual's ability to detect a given target (see Breitmeyer & Ogmen, 2006 for a review). Employing a lateral masking paradigm, Li and colleagues required participants to detect the presence of a central target Gabor patch, the contrast of which was adjusted in a stepwise fashion based on participant performance (e.g. response error resulted in an increase in target contrast). Flanking Gabor patches introduced a spatial (i.e. appears at a different location than the target) and temporal (i.e. appears at different times around target presentation) mask. AVGPs demonstrated a lower detection threshold for targets followed by a visual mask (i.e. less backward masking) compared to NVGPs. Interestingly, no differences were observed in forward or simultaneous masking. However, the effect seen on backward masking trials suggests that AVGPs are less affected by potentially distracting/interfering information presented shortly after the presentation of a target. Coupled with the attentional blink data, the evidence highlights an effect of action video game experience on temporal aspects of attentional processes.

1.3.5 Improved visual sensitivity

Recent work by Green, Pouget, and Bavelier (2010) has provided evidence for an improvement in sensory sensitivity in AVGPs. In their study, they questioned whether AVGPs and NVGPs differ in their ability to make probabilistic inferences. That is, whether AVGPs and NVGPs differ in their ability to extract and make use of task related information in order to generate a decision. The probability that a given decision is correct depends on the evidence accumulated up to the point a decision is made. When some decision-based boundary is reached, the system stops collecting evidence and signals a decision. Thus, Green and colleagues aimed to establish whether the critical boundary where a decision is made differs between AVGPs and NVGPs. Both groups were tested in visual (coherent dot motion discrimination task) and auditory (tone location discrimination task) perceptual decision tasks and compared the results to neural models of decision-making (e.g. Beck, et al., 2008; Ratcliff & McKoon, 2008). Results from this investigation revealed that AVGPs are able to make better use of sensory information than NVGPs. Specifically, AVGPs were revealed to possess a greater integration rate of sensory information, meaning that they were able to accumulate evidence more quickly over time. As a result of this enhanced sensitivity to sensory information, AVGPs were able to make perceptual decisions much faster than NVGPs, while maintaining an equivalent level of accuracy.

A number of other studies have provided evidence consistent with this finding of improved sensory sensitivity in AVGPs. West et al. (2008) found that AVGPs exhibit improved detection for a motion signal in a dynamic visual search task. Pohl et al. (2014) revealed an AVGP advantage in the speed of processing of briefly presented and masked information. And Wilms, Petersen, and Vangklide, (2013), provided evidence that action video game experience is associated with quicker encoding of visual information into short-term memory. Related to this finding, research has demonstrated an AVGP advantage in the quality of encoded memory representations

(Sungur & Boduroglu, 2012). In another study assessing memory performance demonstrated an AVGP advantage in a modified partial report paradigm. However, using a psychometric model of behaviour, Apelbaum, Cain, Darling, and Mitroff (2013) found no differences between groups in terms of the rate at which visual representations decayed over time. Instead, they found further evidence for increased sensitivity to visual information and argued that this effect could give rise to greater accessibility of information maintained in iconic memory, an effect that has been linked to volitional attention (Perush, Genzer, & Melara, 2012; Ruff, Kristjansson, & Driver, 2007).

These findings speak to earlier results that have been categorized as effects of action video game experience on object-based attention. Given the resource dependent nature of controlled attentional processes, there exists a limit to the number of objects that can be simultaneously attended or tracked. Evidence suggests that most people can attend to approximately 2-4 objects at a given time (Cowan, 2001; Luck & Vogel, 1997). Interestingly, experience with action video games appears to allow players to perform beyond this limitation imposed on object-based attention. Specifically, comparing AVGP and NVGP performance on enumeration and multiple object tracking (MOT) tasks has revealed that the number of items simultaneously attended (i.e., subitizing range) or tracked by AVGPs surpasses this traditional limit. Using an enumeration task, which presents participants with a display consisting of a varying number of objects (e.g. 1 to 12 items) for a very short duration (50ms), Green and Bavelier (2003, 2006b) revealed that AVGPs could concurrently apprehend more objects than NVGPs. Specifically, whereas NVGPs could apprehend 3 targets with high accuracy, AVGPs demonstrated comparable accuracy up to 5 targets. Interestingly, recent work has revealed that the subitizing range is an attention-dependent effect and influenced by available resources (Olivers & Watson, 2008; Railo, Koivisto, Revonsuo, & Hannula, 2008; Vetter, Butterworth, & Bahrami, 2008). Where the enumeration task provided a measure of AVGPs' ability to acquire information at a single moment in time, the multiple-object tracking assessed their ability to maintain the attendance of multiple objects over time. Performance again revealed an AVGP benefit, where AVGPs were more accurate in their ability to track 3-5 objects than non-gamers (Boot et al., 2008; Green & Bavelier, 2006b). Similar MOT effects have been observed in younger sample of action gamers (Dye & Bavelier, 2010, Trick, Jaspers-Fayer, & Sethi, 2005). Therefore, action video game experience appears to affect object-based attentional processes, which may operate via enhancements in access and sensitivity to task-relevant information.

1.3.6 Greater attentional resource capacity

Further assessing the impact of action video game experience on aspects of selective attention, Green and Bavelier (2003) used a modified version of the perceptual load task to assess whether attentional resource capacity differed between AVGPs and NVGPs. The perceptual load task has traditionally been used to demonstrate the resource-based processing limits of attention (e.g. Lavie, 1995; Lavie & Cox, 1997). The task typically requires participants to indicate which of two targets is present in a display at one of a number or predetermined locations. On some trials a distractor stimulus appears in the display at a novel location (i.e. not one of the predetermined locations).

The distractor is considered either compatible (i.e. the same object as the target) or incompatible (the target not present in the display) with the target. Participants are asked to perform this task at various levels of perceptual load. Specifically, the target can appear in isolation (i.e. low load) or with many more non-target objects (i.e. high load). During low load trials, the presence of a distractor yields a compatibility effect indicating that enough resources were available to process the distractor and have it influence participants' responses. Specifically, when the distractor is compatible, individuals make faster and more accurate responses compared to when presented with incompatible distractors. However, during high perceptual load trials, the compatibility effect typically disappears. The common account of this effect suggests that during high load conditions, all attentional resources are dedicated to the primary search/identification task, leaving no resources available to "spill over" and process the irrelevant distractor.

In Green and Bavelier's (2003) task, participants indicated whether a square or diamond target was present in the displays varying in perceptual load (i.e. 1 to 6 objects) and compatible and incompatible distractors were presented in the periphery. Both AVGPs and NVGPs demonstrated the standard compatibility effect during low load conditions; however, as the magnitude of the compatibility effect diminished in NVGPs as perceptual load increased, this pattern was not observed in AVGPs. Instead, AVGPs demonstrated a significant compatibility effect even at the highest perceptual load condition. This result led to the conclusion that while the attentional resources available to NVGPs were completely allocated to the primary task, AVGPs possessed additional available resources beyond the "standard" capacity, allowing them to process and be influenced by the distractor during high load trials.

The compatibility effect demonstrated by AVGPs even under high load conditions has also been replicated by a number of subsequent studies (however, see Irons, Remington, & McLean, 2011 for conflicting results). For example, a similar effect was observed regardless of whether the distractor items appeared either centrally or in the periphery (Green & Bavelier, 2006a). Evidence has also demonstrated that AVGPs, unlike NVGPs, process objects adjacent to targets during high load trials (Xuemin & Bin, 2010). Finally, the proposed increase in attentional resource capacity has also been observed in younger samples of AVGPs (Dye et al., 2009a). Interestingly, these studies appear to present an anomalous finding when considering the consistent improvements in performance demonstrated by AVGPs. Specifically, these results provide an example where action video game experience could yield a relative deficit in performance. That is, these results suggest that, under high load conditions, AVGPs may be more susceptible to distracting information[1]. Despite this possibility, as many tasks involve resource-dependent attentional processes, having a deeper pool of available resources to draw from would likely be considered a beneficial outcome associated with action video game experience. For example, an increased resource capacity could provide AVGPs with essentially a boost to various top-down processes (e.g. allocation of spatial attention, attention in time, attending to multiple objects, enhanced visual sensitivity to task-relevant information).

[1] An alternative account of these data suggests that compatibility effects may persist because of the aforementioned sensitivity to task-relevant information, even under a high load. For example, despite appearing in the periphery, the "distracting" items were still target shapes. Much of the evidence reviewed supports the notion of improved target sensitivity in AVGPs.

1.3.7 Improvements in executive function

Another area that has received much research is the effect of action video game experience on performance in task switching paradigms. Task switching paradigms require participants to change cognitive/attentional task settings in order to perform interchanging tasks. Switching from one task set to another tends to negatively affect reaction time and accuracy on the switched task. This general effect of performance is referred to as task-switching costs (Allport, Styles, & Hsieh, 1994). Given the perceptual and attentional effects demonstrated in AVGPs, it became of interest whether action video game experience could impact higher-level executive functions as measured by the cost associated with having to dynamically switch between cognitive/attentional sets. One of the first assessments of the effect of action video game experience had AVGPs and NVGPs switch between responding to local or global stimulus features (Colzato et al., 2010). On each trial participants were cued to whether they were to make a manual response based on a global or local target features. Performance was compared across repeat trials (i.e. no set shift required) and switch trials (i.e. requiring a set shift). On switch trials, both AVGPs and NVGPs demonstrated a switching cost; however, the AVGPs' cost was significantly less than the NVGPs. These results led to the conclusion that AVGPs may possess greater cognitive flexibility, which can allow for more efficient shifts between various cognitive/attentional sets. Greater flexibility could give rise to more effective strategies when completing cognitive tasks. For example, AVGPs demonstrated broader search patterns when searching for changes in a change detection task (Clark et al., 2011; however, see Durlach, Kring, & Bowens, 2009 for conflicting results). Additional support for reduced switching costs in AVGPs have come from a number of other sources that have employed either task-switching paradigms (Boot et al., 2008; Cain, Landau, & Shimamura, 2012; Karle, Watter, & Shedden, 2010) or dual-task paradigms (Chiappe, Conger, Liao, Caldwell, & Vu, 2013; Strobach, Frensch, & Schubert, 2012; however see Donohue, James, Eslick, & Mitroff, 2012), providing further evidence that action video game experience has an impact on aspects of executive function.

1.3.8 Neurophysiological evidence

Only more recently has research begun to investigate the potential neurophysiological differences between AVGPs and NVGPs. A study by Mishra, Zinni, Bavelier, and Hillyard (2011) presented AVGPs and NVGPs with three separate streams of rapid serial visual presentation (RSVP), i.e., left, right, and above central fixation. Participants were directed to covertly attend to a particular RSVP stream based on a directional cue and were required to detect the appearance of a target within the attended stream. The behavioural data revealed that AVGPs were quicker and more accurate than NVGPs in detecting a target presented in the cued RSVP stream. Critically, while performing this task, steady-state visually evoked potentials (SSVEP) were also recorded. The amplitude of SSVEPs is thought to provide a measure of attentional resources allocated to a given stimulus (Di Russo, Teder-Sälejärvi, & Hillyard, 2002; Toffanin, de Jong, Johnson, & Martens, 2009). The electrophysiological results failed to demonstrate a difference in SSVEPs amplitudes between AVGPs and NVGPs for an attended stream; however, significantly greater suppression of SSVEP amplitudes was observed in AVGPs for the unattended streams. This result suggests that AVGPs demonstrate more effective distractor suppression than NVGPs. Additional support for this claim comes from another study that also recorded SSVEP while participants completed a search task and again demonstrated improved distractor suppression in AVGPs (Krishnan, Kang, Sperling, & Srinivasan, 2012).

Another recent study has demonstrated changes in event-related potential (ERP) components following action video game training. Wu et al. (2012) recorded behavioural and ERP measures while participants completed the Useful-Field of View task pre- and post-training. Behavioural results revealed similar findings to previous work (Dye & Bavelier, 2010; Feng et al., 2007; Green & Bavelier, 2003, 2006a), with the action video game training group showing significantly greater improvements in task performance at varying eccentricities compared to participants in the non-action video game training group. Critically, Wu and colleagues demonstrated changes in the amplitude of a number of ERP components. The amplitude of both P2 and P3 components, thought to reflect aspects of attentional control (e.g. Fritzsche, Stahl, & Gibbons, 2011; Potts, Patel, & Azzam, 2004) and the amount of attention allocated to a stimulus (Johnson, 1988; Mangun & Hillyard, 1990), respectively, increased following action video game training. It is important to note that no changes were observed in the amplitude of the P1 component following training. The P1 component is thought to reflect the deployment of attention at an early stage or bottom-up/exogenous processing (i.e. amplitude affected by whether a stimulus is attended or not; Mangun, 1995), and thus provides evidence that not all components of attention are affected by action video game experience, much like the lack of effect seen on exogenous orienting (Castel et al. 2005; Hubert-Wallander et al., 2011).

In addition to electrophysiological investigations, a handful of fMRI investigations involving video game players have also emerged recently. Bavelier, Achtman, Mani, and Focker (2012) conducted an fMRI study focused on investigating the neural activity associated with enhancements in selective attention demonstrated by AVGPs. Of interest was a comparison of neural networks thought to underlie attentional processes associated with distractor processing in AVGPs and NVGPs under increasing levels of task difficulty. Participants completed a modified perceptual load task while distracting patches of moving or static dots were presented either centrally or in the periphery. The imaging data revealed differential recruitment of the dorsal fronto-parietal network, believed to control and regulate selective attention (Corbetta & Shulman, 2002). Whereas activity in this network increased in NVGPs as task load increased, AVGPs demonstrated significantly less activity in this network, even under high load conditions. Despite less activity in the fronto-parietal network, AVGPs still outperformed NVGPs on the perceptual load task, producing faster reaction times for detecting targets. Collectively, early neurophysiological effects seen in AVGPs suggest that action video game experience is associated with changes in the neural processes that subserve aspects of selective attention.

1.4 Causal or correlational?

It is important to note that much of the data presented in the action video game literature is cross-sectional in nature. That is, individuals are often recruited as a result of meeting some criteria that defines them as an AVGP or NVGP. The concern with this kind of quasi-experimental design is that there lacks a definitive ability to assign causal relationships between action video game experience and performance demonstrated on tasks by AVGPs. This issue is particularly important given recent criticisms of the field (Boot, Blakely, & Simons, 2011; Kristjansson, 2013), for example, suggesting that action video game effects could instead result from demand characteristics (e.g., priming motivational states). Specifically, if AVGPs become aware that a given study is about the effect of action video games, they may become more motivated to perform well. Another more common concern is the possibility that action video games do not positively affect players' cognitive processes, but rather, individuals who already possess some form of inherent cognitive enhancement are drawn toward action video games.

Importantly, and already alluded to above, evidence from a number of training studies has indicated that there is little cause for concern regarding the causal relationship between action video game experience and associated improvements in task performance. Training studies have typically involved recruiting individuals with little to no action video game experience and assigning them to one of two groups. One group is assigned to train with an action video game (e.g. *Medal of Honor, Unreal Tournament*) for some predetermined amount of time over several weeks (typically ranging from 10 – 50 hours). Those in a second group experience a similar procedure, however, they are required to train on a non-action video game (e.g. *Tetris, The Sims*). In-game performance is often measured to ensure that participants improve on the trained game and, critically, performance on a given cognitive task is compared across groups pre- and post training. Evidence has revealed that training on an action video game affects performance on many of the tasks that also demonstrate cross-sectional effects as reviewed previously (e.g. Feng et al., 2007; Green & Bavelier, 2003, 2006a, 2006b, 2007; Green et al., 2010; Greenfield et al., 1994; R. Li et al., 2009, 2010; W.L. Li et al., 2011; Wu et al., 2012 – Boot et al., 2008 and Murphy & Spencer, 2009 provide some exceptions but see Hubert-Wallander et al., 2010 for a criticism of their null effects).

1.5 Accounting for AVGP performance benefits

In order to succeed at playing action video games, players must be able to engage a variety of attention-based processes. For example, players must shift between distributed and focused attentional states when attempting to detect and respond to, respectively, potentially threatening information. Moreover, target information must be emphasized while inhibiting distracting information. Accordingly, much of the research has focused on the possible effects of action video game experience on the allocation of human attention. From the evidence reviewed, action video game experience appears to have an effect on top-down/control-based attention but little effect on exogenous/bottom-up orienting. As a result, the prevailing view is that action video game experience gives rise to greater endogenous attentional control. For example, the behavioural evidence reviewed indicates that AVGPs possess greater control over the allocation of spatial attention. That is, AVGPs have demonstrated faster reaction times when searching for a target (e.g. Dye et al., 2009a, Hubert-Wallander, et al., 2011), more efficient detection of briefly presented targets at peripheral locations (e.g. Feng et al., 2007; Green & Bavelier, 2003, 2006a), as well as greater resistance to distraction (Chisholm et al., 2010; Mishra et al., 2011). Additional evidence has also suggested that differences in task-switching performance can be accounted for by selective benefits in attentional control (Karle et al., 2010).

Although other accounts have been provided, namely improvements in perceptual processing speed (Dye, Green, & Bavelier, 2009b) and the recently proposed learning to learn account (Bavelier, Green, Pouget, & Schrater, 2013; Green & Bavelier, 2012) which is discussed in detail in Chapter 7, the collective evidence appears to favour an attention-based mechanism, specifically one that involves enhanced attentional control, to account for the performance benefits displayed by AVGPs. In line with this notion, a recent proposal has been advanced that AVGPs may demonstrate greater control via an enhanced ability to flexibly allocate attentional resources (Hubert-Wallander et al., 2010). This account suggests that action video game experience provides AVGPs with a generalized ability to direct attentional resources more effectively to meet task demands on a task-by-task basis. This notion provides an account for any task that requires the engagement of controlled attentional processes, but also accounts for the lack of effects seen in exogenous attention tasks (i.e. where attention is engaged in an automatic, non-resource dependent fashion). For example, whether a task requires quick deployment of spatial attention to locate and process a target stimulus (e.g. Feng et al., 2007; Green & Bavelier, 2003, 2006a) or the simultaneous tracking of multiple objects (e.g. Boot et al., 2008; Dye & Bavelier, 2010; Green & Bavelier, 2006b), AVGPs are better able to allocate resources to the processes necessary to enhance task performance. However, although AVGPs demonstrate improved performance, it is worth noting that it seems unlikely that they engage attentional processes in a manner that is distinct from NVGPs. For example, every individual who participates in a visual search task will engage processes to detect a target and inhibit distractors. Therefore, the question becomes – what allows AVGPs to flexibly engage attentional processes more efficiently than NVGPs?

As attentional control is affected by the availability of resources, the evidence that AVGPs possess an increase in their attentional resource capacity (Dye et al., 2009a; Green & Bavelier, 2003, 2006a), could provide a basis for such an improvement in attentional control. For example, being better able to draw upon and effectively allocate greater attentional resources could perhaps give rise to improvements in target detection accuracy and speed (e.g. Castel et al., 2005; Feng et al., 2007; Green & Bavelier, 2003, 2006a; West et al., 2008; i.e., increasing target sensitivity) or help reduce interference from distracting information (e.g. Chisholm et al., 2010; Green & Bavelier, 2003; Li et al., 2010; i.e. greater distractor inhibition). However, while this type of argument might account for the differences in AVGP and NVGP performance, it does beg the question of how AVGPs could come to possess greater attentional resources (and have greater control) than NVGPs. Claiming that there is a difference in attentional resources seems to simply offload the issue to another yet to be understood level of explanation. Although the field has speculated on the specifics of the differences between AVGPs and NVGPs, the current state of behavioural evidence has not been able to produce a direct demonstration of how "improved attentional control" is manifested in AVGPs to outperform NVGPs.

1.6 Oculomotor control

High visual acuity is present at the central foveal region of the retina, with acuity becoming increasingly degraded as incoming information lands on more peripheral retinal locations. As a result, eye movements, referred to as saccades, are necessary to bring potentially relevant information to the fovea in order to be seen clearly. Despite the ubiquity of eye movements in our moment-to-moment behaviour, our current understanding of attention has largely emerged from the field's reliance on covert attentional paradigms, where eye movements are restricted. Although incredibly informative, such paradigms have often been required to infer attentional effects based on less direct measures of attention (e.g., reaction time and accuracy of manual responses). Thus, research has begun to place a greater emphasis on the use of eye movement behaviour to provide a more direct measure to further our understanding of the processes underlying attention.

It is clear that attention can be spatially allocated within one's visual field without an associated saccade (Posner, 1980) and evidence has been provided to indicate overt and covert attentional systems can operate independently of one another when fixation is maintained (Hunt & Kingstone, 2003a, 2003b; Klein, 1980). However, despite this dissociation, it is unlikely that shifts of attention and saccades are generated in parallel to disparate spatial locations. That is, although the two can be separated during fixation, the two are linked when saccades are made. Specifically, much research has demonstrated that covert attention tends to precede a saccade to a given location (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler, Anderson, Dosher, & Blaser, 1995; Moore & Fallah, 2001; Rayner, McConkie, & Ehrlich, 1978;

Shepard, Findlay, & Hockey, 1986; Van der Stigchel & Theeuwes, 2007). Thus, it is generally agreed that when saccades are made, they provide an overt measure of the covert allocation of spatial attention.

Spatial attention can be guided in a reflexive, bottom-up manner, based on stimulus properties, independent of available attentional resources. In contrast, spatial attention can also be guided in a more volitional, top-down manner, based on one's goals, though such a process is resource dependent (Posner, 1980). In light of the link between overt and covert attentional systems, it is generally agreed that overt attention is also guided by similar orienting mechanisms. Research investigating the cognitive effects of action video games has also almost exclusively employed covert attentional paradigms. Thus, the majority of the effects summarized above have been based on indirect measures of attention. Aside from the work discussed in the present dissertation, only one study, to the best of my knowledge, compared AVGP and NVGP oculomotor behaviour. In a task comparing AVGP and NVGP saccade trajectories, West, Al-Aidroos, and Pratt (2013) provided evidence that experience with action video games can influence the interplay between bottom-up and top-down signals when generating oculomotor behaviour. As this is the only study that directly assessed oculomotor control in AVGPs, this area is still ripe for further investigation and has the potential to contribute to the field in a number of ways. First, although West et al. (2013) provide evidence that oculomotor behaviour is affected by action video game experience, one study is certainly not conclusive in suggesting that this is a general effect that will emerge across other contexts. Thus, comparing oculomotor behaviour in other paradigms will be important to acquire a better sense of the extent to which the described covert effects can be observed in overt paradigms. Second, in the case that differences are observed between AVGPs and NVGPs in overt attention paradigms, these differences may provide a more direct measure of the allocation of spatial attention, and thus enable the field to address questions that would be more difficult to resolve with covert paradigms. Ultimately, measuring oculomotor control can provide significant insight into our understanding of the attentional basis for performance differences between AVGPs and NVGPs.

1.7 Oculomotor capture

Oculomotor capture refers to the situation where one reflexively saccades toward a highly salient visual stimulus despite it being entirely irrelevant to one's goals (e.g., Boot, Kramer, & Peterson, 2005; Irwin, Colcombe, Kramer, & Hahn, 2000; Theeuwes, Kramer, Hahn, & Irwin, 1998). Oculomotor capture presents an overt representation of the more traditionally studied attentional capture effect. Generally, capture tasks have participants search for a target, unique in some particular feature (e.g., colour, shape, abrupt onset), among a number of non-target items. On a portion of trials a highly salient, though task-irrelevant, item is added to the display simultaneously with the appearance of the target. This task thus places top-down attentional processes in direct competition with the bottom-up signal generated by the salient item. In traditional capture tasks, manual reaction times are slower when a singleton distractor is added to the display (e.g., Remington, Johnston, & Yantis, 1992; Theeuwes, 1991, 1992, 1994, Theeuwes, Atchley, & Kramer, 2000). This is taken as evidence that attention was spatially allocated to the distractor (i.e., captured) prior to attending to the target stimulus (Hickey, Mcdonald, & Theeuwes, 2006; Theeuwes & Burger, 1998). In the case of oculomotor capture, saccades toward the distractor prior to correctly shifting their eyes toward the target, provides an overt representation of this effect.

The basis for attentional capture has been a topic of debate spanning the last several decades. Some have argued that attention is always captured in a bottom-up fashion (Theeuwes, 1991, 1992, 2004). Specifically, attention is oriented to the most salient item in a display regardless of one's current goals. In contrast, others have argued that capture is modulated by top-down attentional control settings and search strategies (Bacon & Egeth, 1994; Folk, Remington, & Johnston, 1992, Leber & Egeth, 2006). In the case of oculomotor control, the evidence is clear that capture does not occur on 100% of trials – the normative range appears to indicate that capture occurs, on average, anywhere from 10-50% of trials. Rather than weighing in on the aforementioned debate, the present work instead focuses on the fact that results from oculomotor capture paradigms speak to the notion that the degree of capture is not necessarily governed solely by either bottom-up or top-down factors, but rather is based on an interaction of both processes. It has been proposed that whether oculomotor capture occurs is similar to that of a horse race model. That is, the oculomotor system generates two saccade plans in parallel, one based on one's current goals and the other based on the properties of the presented visual information. Whichever of the two saccade plans "reaches the finish" first is then executed.

The oculomotor capture paradigm thus presents an ideal task to compare AVGP and NVGP. First, given the claim that AVGPs demonstrate improved control over the allocation of spatial attention, this paradigm can provide a direct test of this claim. That is, it provides an overt measure of where attention is spatially allocated during visual search. Second, as capture tasks place top-down and bottom-up processes in competition with each other, the paradigm allows for further assessment of whether AVGPs can engage the proposed improved attentional control to avoid distraction. Moreover, my previous work has demonstrated that AVGPs outperform NVGPs on a traditional covert attentional capture task (Chisholm et al., 2010). A conceptual replication of the covert attentional capture task (i.e., with an oculomotor capture task) allows for the assessment of whether the effect in the covert task generalizes to an overt paradigm and, as described below, provides a crucible with which to answer several foundational questions.

1.8 Thesis overview

The general focus of the present dissertation is to compare oculomotor control between AVGPs and NVGPs to provide insight into how improved attentional control, proposed as the basis of AVGPs performance benefits, is manifested in a visual search task. To achieve this, a series of studies are presented where eye movements are recorded while participants complete an oculomotor capture paradigm. The present work focused on answering the following questions:

1. Do the beneficial effects demonstrated by action video game players in covert attention tasks extend to overt attention tasks (i.e. do AVGPs and NVGPs differ in oculomotor control)?
2. What is the basis for the reduced distraction demonstrated by AVGPs in an oculomotor capture paradigm?

3. Does an AVGP benefit persist when using more biologically relevant stimuli (e.g. faces and emotion)?
4. Does an attention-based explanation provide a satisfactory account of the extant literature?

Chapter 2 presents a direct follow-up to Chisholm et al. (2010), which formed the basis for my MA. Chisholm et al. (2010) demonstrated that AVGPs experience less covert attentional capture than NVGPs. Two competing theories were provided to account for this effect. AVGPs could have outperformed NVGPs by either showing greater resistance to capture (i.e., fewer spatial shifts of attention to the salient distractor) or by being quicker to recover once captured (i.e., shorter time attending distractor prior to reorienting to target). By recording oculomotor behaviour, a direct measure of attentional allocation was acquired to address this question and to examine whether the AVGP advantage demonstrated in a covert attention task extends to overt attention. This work provides evidence that the beneficial effects seen in covert paradigms do generalize to an overt task, and points to the basis for the reduced capture demonstrated by AVGPs. Chapter 3 presents a study that aimed to further our understanding of the processes affected by action video game experience. Specifically, the oculomotor capture paradigm used in Chapter 2 was modified to require a manual response once participants fixated the target. This created a compound search task, requiring participants to select a target based on a given feature (i.e., colour) and generate a subsequent manual response based on independent information (i.e., left/right discrimination task). This study addresses whether AVGPs enhanced performance is based on improvements in selection, response, or both types of processes.

Previous work has provided conflicting evidence regarding the influence of distractor awareness on visual search performance. As will be discussed, some evidence demonstrates that distractor awareness can benefit performance while others report that awareness can hinder performance. Data from Chapters 2 and 3 were suggestive of a possible influence of distractor awareness on AVGP and NVGP performance. Therefore, Chapter 4 presents a study aimed at resolving the conflict in the literature prior to looking into the possible influence on AVGP and NVGP performance. Independent of video game experience as a factor, Chapter 4 provides a direct test of whether distractor awareness benefits or interferes with visual search performance. The knowledge acquired from Chapter 4 was then applied in two studies reported in Chapter 5. Specifically, all participants were made aware of the potential appearance of the distracting information in order to examine the influence of distractor awareness on AVGP and NVGP performance.

Given the breadth of effects associated with action video game experience, there has been a growing interest in using video games as a rehabilitative tool. However, despite this interest, it remains relatively unclear whether the effects seen in lab-based contexts with basic stimuli will scale up to more natural contexts. Chapter 6 presents a study comparing AVGP and NVGP oculomotor control when using more biologically relevant stimuli. This study employs the same oculomotor capture paradigm used in Chapters 2-5; however, it replaces the previously used basic stimuli with schematic faces. In addition, whereas the target and non-target stimuli depicted a neutral face, the abrupt onset could depict either a neutral, happy, or inverted happy. This allowed for the investigation of whether AVGPs and NVGPs differ in their sensitivity to different emotional content.

As reviewed, the literature to date suggests that improvements in attentional control accounts for the differences between AVGPs and NVGPs. However, an alternative explanation, referred to as the learning to learn account, has recently been proposed (Bavelier et al., 2012; Green & Bavelier, 2012). Chapter 7 presents a test of the learning to learn account by conducting time-course analyses on the combined data in the previous chapters, i.e., those that enabled a comparison between AVGP and NVGP performance.

A general discussion of the findings in this dissertation is presented in Chapter 8. This discussion revisits and provides answers to the questions highlighted above. In addition to highlighting the implications of the presented findings, I conclude this chapter by providing a discussion of some of the limitations associated with the present work as well as recommend avenues for future research.

2 Improved top-down control reduces oculomotor capture: The case of AVGPs

2.1 Introduction

The last decade has seen an increase in research dedicated to understanding the cognitive effects associated with extensive video game use, highlighting the differences between video game players and non-video game players (NVGPs). This growing body of work has largely employed paradigms that require the engagement of selective visual attention and has been consistent in demonstrating benefits in task performance associated with video game experience (e.g., Dye, Green, & Bavelier, 2009a, 2009b; Castel, Pratt, & Drummond, 2005; Chisholm, Hickey, Theeuwes, & Kingstone, 2010; Clark, Fleck, & Mitroff, 2011; Feng, Spence, & Pratt, 2007; Green & Bavelier, 2003, 2006a, 2006b, 2007; Greenfield et al., 1994; Mishra, Zinni, Bavelier, & Hillyard, 2011; West, Stevens, Pun, & Pratt, 2008). The beneficial effects of video game experience observed in these attention-based paradigms has been routinely observed in, if not in some cases restricted to, action video game players (AVGPs). This literature has not only highlighted that AVGPs outperform NVGPs across a variety of attention-based tasks, but training studies have demonstrated that NVGPs can exhibit similar performance benefits after relatively short periods of training with action video games compared to training with control non-action video games (Feng et al., 2007; Green & Bavelier, 2003, 2006a, 2006b, 2007; Green, Pouget, & Bavelier, 2010; Greenfield et al. 1994; but see Boot, Kramer, Simons, Fabiani, & Gratton, 2008 for a notable exception). These findings strongly suggest that there exists a causal relationship between action video game experience and improvements in task performance.

In terms of accounting for the advantage demonstrated by AVGPs, specifically in visual attention-based paradigms, the literature has collectively pointed to an endogenous mechanism. Indeed, the evidence to date converges on the conclusion that AVGPs' improved performance in attention-based paradigms (i.e. tasks that require the deployment of visuospatial attention) reflects enhanced top-down control over the allocation of selective visual attention (e.g., Chisholm et al., 2010; Clark, et al., 2011; Colzato, van Leeuwen, van den Wildenberg, & Hommel, 2010; Feng et al., 2007; Green & Bavelier, 2003, 2006a; Karle, Watter, & Shedden, 2010; Mishra et al., 2010; see Hubert-Wallander, Green, Bavelier, 2010 for a review). Of course, this does not mean that other cognitive mechanisms cannot be positively (or negatively) affected by action video game playing, nor does this mean that the only interpretation of AVGPs improved performance on attention tasks is that it reflects enhanced endogenous control (e.g. see Castel et al., 2005; Green, Pouget, & Bavelier, 2010). However, both behavioural and neurophysiological evidence has provided support for the top-down control account of AVGPs performance advantages in visual attention-based paradigms. For example, AVGPs are quicker to locate and respond to targets presented amongst distractors (e.g., Chisholm et al., 2010; Feng et al., 2007; Green & Bavelier, 2003, 2006a). Neurophysiological evidence has also demonstrated that AVGPs are better able to suppress (Mishra et al., 2011) or filter (Bavelier, Achtman, Mani, & Focker, 2012) task-irrelevant information. The fact that AVGPs and NVGPs are equally affected by exogenous cues (Castel et al., 2005; Dye, et al., 2009a; Hubert-Wallander, Green, Sugarman, & Bavelier, 2011; however, see West et al., 2008) lends further support that the AVGP advantage is specific to an endogenous mechanism. Together, these findings suggest that AVGPs can be viewed as a group that possess enhanced top-down control over the allocation of visuospatial attention and thus make a noteworthy population to sample from as a means of informing key models of attention.

One notable paradigm that brings together competing theories of attention is the attentional/oculomotor capture task (e.g. Bacon & Egeth, 1994; Folk, Remington, & Johnston, 1992; Theeuwes, 1991, 1992; Yantis, 1993; Yantis & Jonides, 1990). In a recent paper, Chisholm et al. (2010) reported that the interfering effect of a salient visual distractor was less pronounced for AVGPs than NVGPs. Working from the theoretical perspective that top-down control in this task is not possible until *after* a salient distractor has captured attention (Theeuwes 1991, 1992, 2004; Theeuwes & Godijn, 2001), Chisholm et al. suggested that AVGPs were better able than NVGPs to apply top-down attentional control to disengage their attention from the distractor stimulus. However, this interpretation effectively dismissed an alternative, and equally viable interpretation: that AVGPs enhanced top-down control was applied *before* visuospatial attention was ever captured by the distractor (Bacon & Egeth, 1994; Folk, et al., 1992). In other words, top-down control accentuated the target stimulus or inhibited the distractor stimulus, thereby dampening the ability of a salient distractor to capture attention.

The aim of the present investigation is to distinguish between these two theories, i.e. whether top-down control is applied before or after a distracting stimulus captures attention. To this end we compared AVGP and NVGP performance in an oculomotor capture task. This paradigm is a conceptual equivalent of the attentional capture paradigm (Hunt, von Muhlenen, & Kingstone, 2007) but now, critically, eye movements (saccades) are recorded while participants search the visual display. In tracking participants' eye movements, one can acquire an overt measure of where attention is allocated.

In our task, participants searched for a unique colour target and, on half the trials, an additional non-target item appeared in the display as an abrupt onset. Traditionally, individuals will make reflexive saccades towards the abrupt onset even when it is known to be task-irrelevant (e.g., Boot, Kramer, & Peterson, 2005; Irwin, Colcombe, Kramer, & Hahn, 2000; Theeuwes, Kramer, Hahn, & Irwin, 1998). The proportion of initial saccades that orient toward the abrupt onset provides a measure of oculomotor capture. Based on previous work, we predicted that AVGPs performance would be negatively affected by the presence of an abrupt onset to a lesser degree than NVGPs. The key question was whether this AVGP top-down advantage would be achieved *after* attention was captured by the distractor stimulus, i.e., by faster disengagement from the distractor; or *before* attention was captured by the distractor stimulus, i.e., reduced capture by the distractor stimulus.

It is worth noting that previous studies demonstrating a difference between AVGP and NVGP have employed covert attention paradigms (i.e. restricted eye movements) or, when eye movements were allowed, they were not recorded. It is thus possible that the benefits seen in covert orienting tasks will not extend to an overt orienting task as covert and overt attentional systems may be separable when eye movements are withheld and attention is allocated covertly (Hunt & Kingstone, 2003a, 2003b; Klein, 1980;). That said, the general consensus is that when eye movements are executed, covert and overt shifts of attention are tightly linked, such that covert shifts precede overt shifts of attention (Hoffman & Subramaniam, 1995; Moore & Fallah, 2000; Van der Stigchel & Theeuwes, 2007). Therefore, it is reasonable to expect that the AVGP covert attention advantage will extend to the overt attentional orienting.

2.2 Methods

Participants

Data is reported from 43 UBC undergraduate males (17-39 years old, mean: 21.4) who received course credit or monetary compensation for their participation. Recruitment involved explicitly asking for AVGPs and NVGPs to participate. Those who reported playing a minimum of 3 hours per week of action video games over the last six months were defined as AVGPs. The majority of AVGPs reported playing a similar collection of games (e.g. *Counter-Strike, Call of Duty, Halo, Battlefield*). NVGPs were defined as those who reported little to no action video game playing over the past six months. Of the 43 participants, 23 were AVGPs and, as a group, reported playing an average of approximately 10 hours of action video games per week. The 20 NVGPs did not report any action video game playing, and as a group reported playing an average of only 1 hour of non-action video game per week. All participants provided written informed consent and reported normal or corrected-to-normal vision.

Apparatus and Stimuli

Visual stimuli were gray and blue circles on a black background, viewed from a chinrest positioned 65cm before a 17-inch LCD monitor. An Eyelink 1000 (SR Research) tracked and recorded eye-movements at 1000 Hz. The display consisted of six circles evenly spaced around the circumference of a 14.7° imaginary circle. Each circle was 2.35° and consisted of an inner black square (0.3°). An abrupt onset appeared on the imaginary circle at an angle of 90° or 150° from the target. The onset was identical to the other non-target items in the display.

Procedure

Participants first answered a questionnaire to assess video game playing experience. Before beginning the computer task an oral and written (via the computer monitor) description of the task was provided. Participants were told that each display consisted of one target (gray circle) among five non-targets (blue circles) and that they were to make an eye movement to the location of the target circle. Participants were encouraged to respond as quickly and accurately as possible. They were not informed of any possible additional distractor items (i.e., abrupt onsets).

Each trial began with a central fixation point (0.7°) presented for 150ms followed by six gray circles. After 2500ms, all but one gray circle changed to blue. The target appeared at each of the possible six positions equally often. On half of the trials an additional blue circle (abrupt onset) was added to the display at the time the other circles turned blue. After making a response (or after 2000ms, whichever came first) the screen went blank for 500ms signaling the trial's end (Figure 2.1).

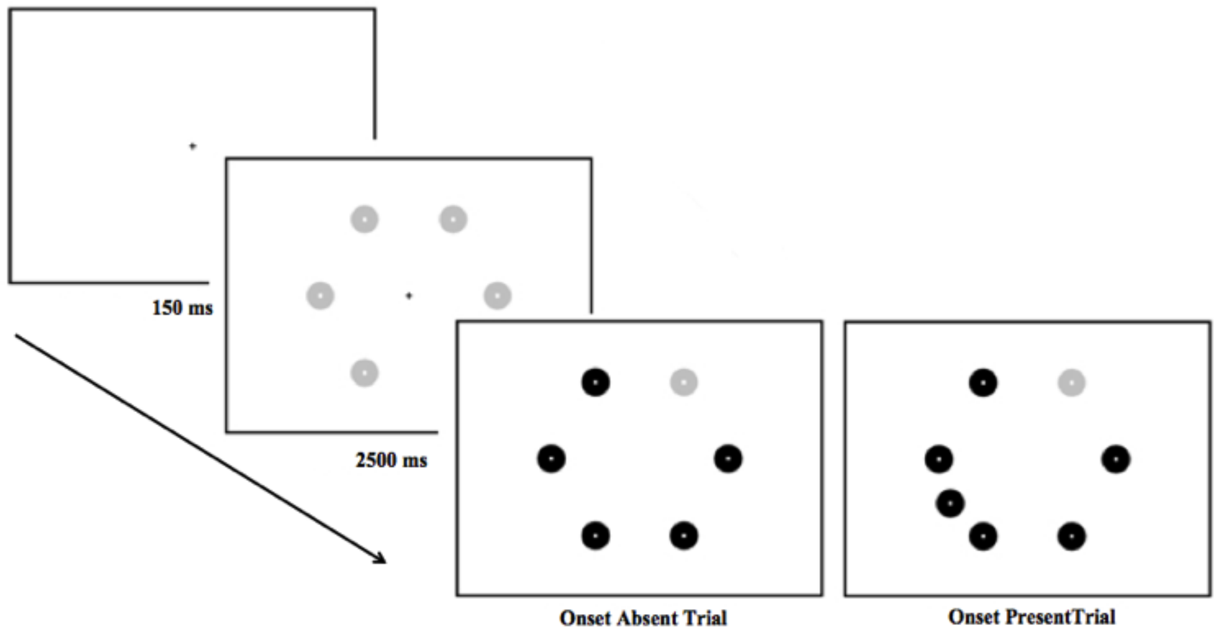

Figure 2.1 – Example of the sequence of events for each trial. Black circles appeared as blue in actual display.

Participants received a practice session of 12 trials, and were then questioned to confirm that they could identify the target amongst the non-targets. Participants then completed four blocks of 48 trials (192 test trials). Before each block a nine-point eye calibration was performed. The target appeared at each of the possible six positions equally often and the abrupt onset appeared an equal number of times at either 90^{o} or 150^{o} from the target. Initial saccades that landed within a 70° window centered on the target (i.e. 35° either side) were recorded as correct; similarly initial responses landing within 70° of the onset were capture trials. Other eye movements (excluding blinks) were scored as errors. At the end of each block, participants were presented with their average search time for that block. Participants were asked to read back these times to the experimenter.

2.3 Results

The following trials were excluded from analysis: Trials where participants initiated a saccade faster than 100ms or slower than 500ms, trials where participants failed to maintain initial fixation within 2^{o} of central fixation prior to target presentation, trials with initial saccade amplitudes less than 2^{o} or saccade velocity slower than 30^{o}/sec. This resulted in a loss of 9.9% of trials (10.5% from AVGPs and 9.2% from NVGPs, $p>0.05$).

Prior to addressing whether AVGPs' advantage occurs before or after capture, it was first necessary to establish that AVGPs and NVGPs' performance did in fact differ in the task. A 2 x 2 repeated measures analysis of variance (ANOVA) with video game experience (AVGP vs. NVGP) and onset presence (absent vs. present) as factors was used to compare search time (i.e. the time taken for the eyes to arrive at the target) across groups [2]. This analysis revealed a main effect of onset presence ($F_{(1,41)}=86.14, p<0.001$) and a marginal effect of video game experience ($F_{(1,41)}=3.30, p<0.08$), indicating that both groups took longer to reach the target when an abrupt onset appeared in the display; however, a trend was observed that AVGPs were able to reach the target faster than NVGPs. A significant interaction between both video game experience and onset presence was found ($F_{(1,41)}=5.94, p<0.05$), indicating that AVGPs' search time was less affected by the presence of the abrupt onset (Figure 2.2). This finding allows for further analysis to isolate the source of this search time effect.

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[2] Participants were aware that fixating the target offset the display, which led to the start of the next trial. Occasionally (5%) participants made a saccade and incorrectly thought they had fixated the target. When they discovered the display had not offset they made a "re-fixation" to the target. A conservative cutoff of 800ms was used to exclude these trials from the analysis.

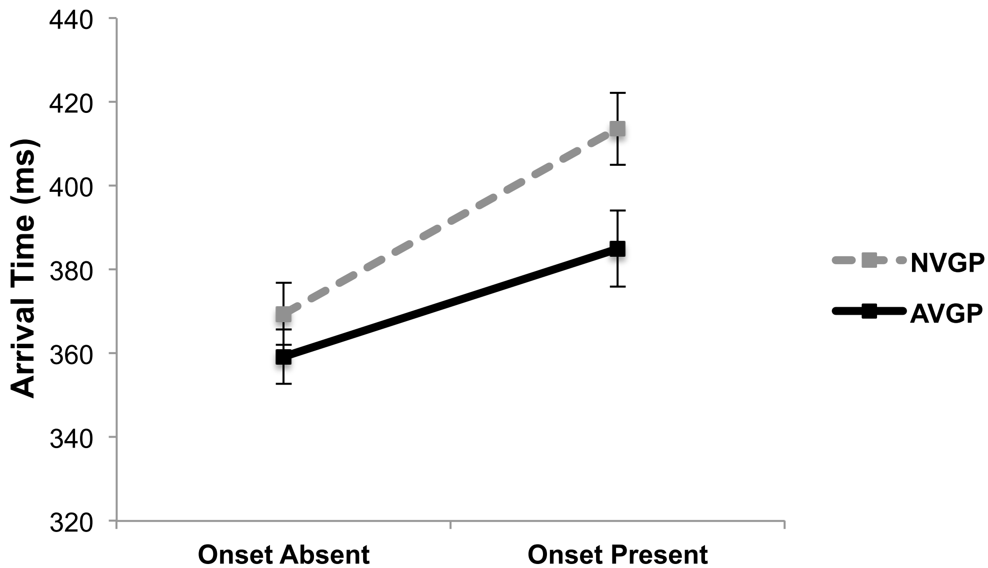

Figure 2.2 – Average time AVGPs and NVGPs took to reach the target in onset absent and present trials. AVGPs' experienced less interference from the presence of the abrupt onset compared to NVGPs (p<0.05). Error bars represent the standard error of the mean.

Quicker to orient attention?

As AVGPs tend to make faster responses relative to NVGPs (Dye, et al., 2009b), we assessed whether AVGPs and NVGPs differed in the time taken to initiate a saccade (i.e. saccade latency). A 2 x 3 repeated measures ANOVA was conducted on mean saccade latencies with video game experience (AVGP vs. NVGP) and trial type (no onset present, onset was present but the eyes went correctly to the target, and onset was present and the eyes were captured). Analysis revealed a violation of sphericity ($p<0.05$); therefore, a Greenhouse-Geisser correction was applied to the results. The analysis revealed a main effect of trial type ($F_{(1.3,82)}=76.43, p<0.001$) but no main effect of video game experience ($F_{(2,82)}=1.39, p>0.05$) and no trial type X video game experience interaction ($F_{(1.3,82)}=2.19$, $p>0.05$). Bonferonni corrected multiple comparisons revealed that both groups produced shorter saccade latencies on capture trials than either accurate trial types ($p<0.001$); however, accurate trial types did not differ ($p>0.05$). Together these data and analyses indicate that AVGPs and NVGPs did not differ in time taken to initiate a saccade (Figure 2.3).

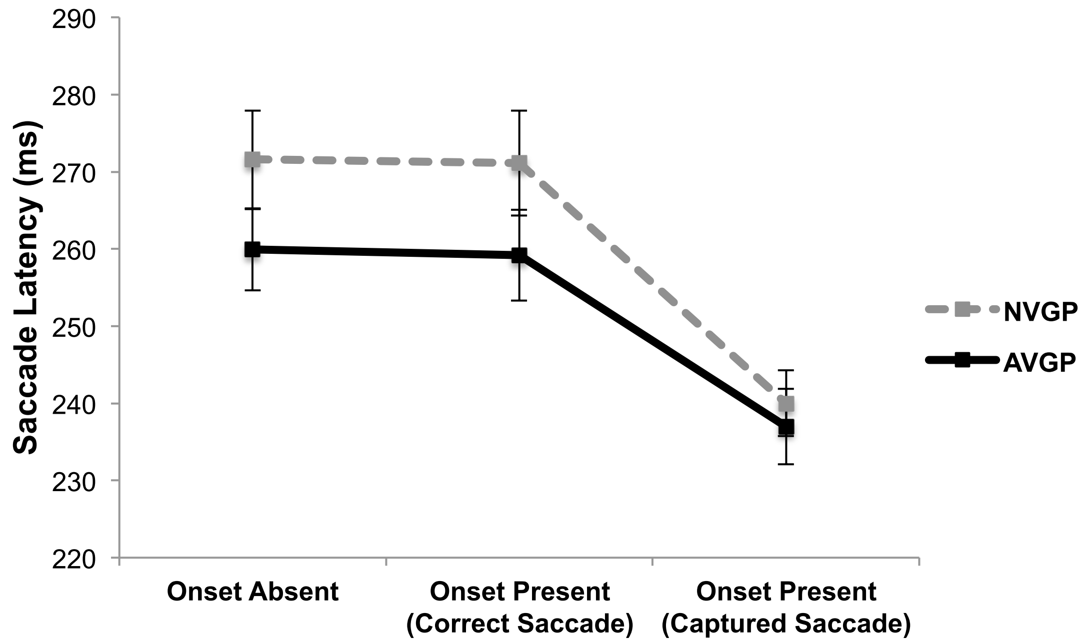

Figure 2.3 – Average AVGP and NVGP saccade latencies across trial types. Although a slight AVGP advantage was observed, this effect was not reliable ($p>0.05$). Error bars represent the standard error of the mean.

Quicker to disengage?

To assess whether AVGPs and NVGPs differed in the time needed to reorient to the target following capture, the mean duration of the fixations immediately following a saccade oriented toward the distractor was compared across groups. This analysis revealed no difference between groups ($t_{(41)}=0.10$, $p>0.05$). Both AVGPs and NVGPs, once captured, took the same amount of time to correct the captured saccade (87.6ms and 88.3ms, respectively) prior to reorienting to the target.

Less capture?

Finally, to assess whether the observed performance difference was a result of AVGPs producing fewer saccades to the abrupt onset, a 2 x 2 repeated measure analysis was conducted on first saccade accuracy with onset presence (absent vs. present) and video game experience (AVGPs vs. NVGPs) as factors. This analysis revealed that accuracy was significantly higher for both groups in onset absent trials than when an abrupt onset appeared in the display ($F_{(1,41)}$=103.79,p<0.001). No main effect of video game experience was observed ($F_{(1,41)}$=2.43,p>0.05); however, the onset presence X video game experience interaction was significant indicating that the appearance of the abrupt onset negatively affected the saccade accuracy of NVGPs to a greater degree than AVGPs' accuracy ($F_{(1,41)}$=5.50,p<0.05, Figure 2.4). A subsequent analysis revealed that NVGPs produced more initial saccades to the abrupt onset (31.0%) compared to AVGPs (21.3%; $t_{(30)}$=2.22,p<0.05).

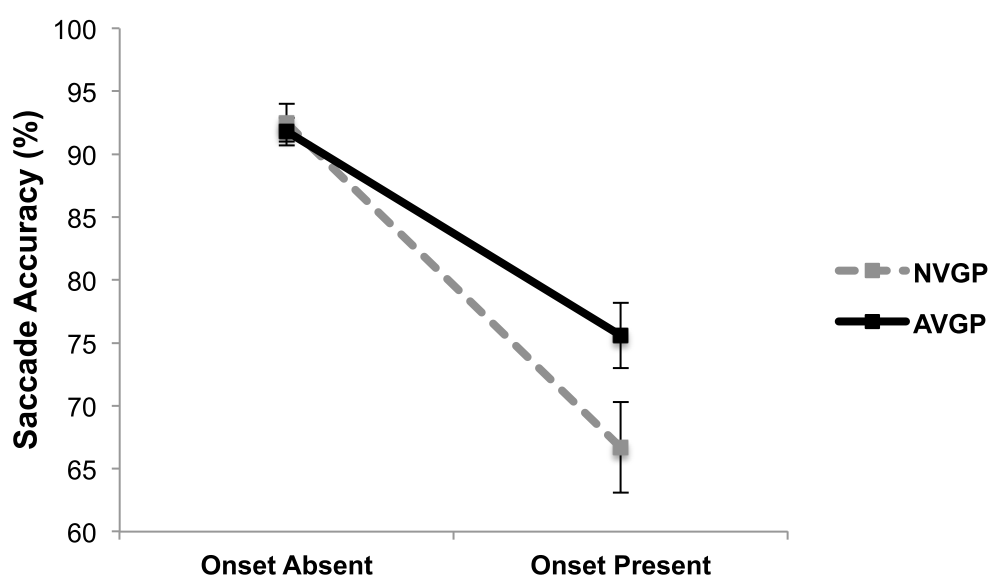

Figure 2.4 – Average saccade accuracy for trials where an abrupt onset was either absent or present. Both groups were equally accurate on the onset absent trials; however, AVGPs produced more accurate saccades than NVGPs when an abrupt onset was present in the display (p<0.05). Error bars represent the standard error of the mean.

2.4 Discussion

The demonstration that AVGPs were faster than NVGPs to attend to a target colour singleton when a task-irrelevant abrupt onset appeared in the display highlights that the effects of action video game experience observed in covert tasks can extend to an overt attentional task. In addition, the present results are consistent with the notion that AVGPs outperform NVGPs in attention-based tasks as a result of engaging enhanced top-down control over the allocation of visuospatial attention (Chisholm et al., 2010; Clark et al. 2011; Green & Bavelier, 2003; Hubert-Wallander et al. 2010; Karle et al., 2010). To the best of our knowledge, the present study is one of the first to record and compare AVGP and NVGP eye movement behaviour (but see West et al. 2013). This allowed for a more direct measure of the allocation of attention to provide insight into the longstanding debate of whether the capture of attention occurs in a purely bottom-up fashion (Theeuwes, 1991, 1992, 2004) or whether it can be modulated by top-down factors (Bacon & Egeth, 1994; Folk et al., 1992). In opposition to the prediction offered by a recent bottom-up account of capture (Chisholm et al., 2010), AVGPs and NVGPs did not differ in the time taken to disengage from the abrupt onset or correct captured saccades but instead differed *prior* to capture. That is, our results show unequivocally that those believed to possess greater top-down control over the allocation of visuospatial attention produce fewer shifts of attention to a task-irrelevant abrupt onset. The theoretical implication of our finding for AVGPs is that it reflects a general principle of human cognition: top-down modulation of covert and overt attentional capture can be realized before, not after, attention is drawn to a irrelevant singleton.

One possible mechanism to account for the reduction in oculomotor capture is that top-down control can be engaged to better prioritize targets. Participants were instructed to search for a gray target circle and were not informed of the presence of abrupt onsets; therefore, it is possible that both AVGPs and NVGPs adopted an attentional set (Folk et al., 1992) for the colour target rather than a set against the distractor. The observed reduction in oculomotor capture could then reflect an increase in one's sensitivity to known target features. Indeed, some recent evidence provides support for this view, highlighting that AVGPs demonstrate greater sensitivity to target stimuli (Green, et al., 2010; West et al., 2008). An alternative account is that top-down control can be engaged to improve distractor inhibition. This notion is consistent with recent neurophysiological evidence indicating that AVGPs are better able to suppress (Mishra et al., 2010) or filter (Bavelier, et al., 2012) distracting or irrelevant information. Clearly whether improved top-down control is enabled via target prioritization or distractor inhibition remains an important issue for further investigation.

It is worth noting that by taking the novel approach of using AVGPs as an individual-difference variable that enabled one to test the role of top-down attentional control in the allocation of visuospatial attention, one could reasonably argue that we cannot claim with complete certainty that AVGPs outperform NVGPs because of their prior experience with action video games. Indeed, due to the cross-sectional nature of the present investigation, some other factor correlated with action video game playing could have mediated our observed effects (Boot, Blakely, & Simons, 2011). For example, AVGPs may be naturally more motivated to perform well in computerized tasks. However, it is unlikely that such an account would specifically predict fewer saccades to an abrupt onset over other equally viable alternatives for AVGPs to outperform NVGPs (e.g. shorter saccade latencies, quicker disengagement). Although we acknowledge the limitations of cross-sectional designs, we feel they do not undermine the empirical or theoretical contributions of the present study. Moreover, previous work has provided ample evidence in support of a causal link between action video game experience and subsequent performance improvements on a number of different visuospatial tasks (Feng et al., 2007; Green & Bavelier, 2003, 2006a, 2006b, 2007; Green, et al., 2010; Greenfield et al. 1994; but, see Boot et al., 2008). Therefore, the evidence to date suggests that video game playing could provide a quick and reliable individual difference measure for isolating individuals with enhanced top-down control.

Conclusion

In AVGPs, research has identified a population that demonstrates greater resistance to the interfering effects of distraction. While by no means the only factor, engaging top-down control is a key factor for this performance benefit. The findings in the literature converge on the notion that the AVGP advantage in attention-based paradigms can be accounted for via enhanced top-down control over the allocation of visuospatial attention. Therefore, the use of AVGPs allows for an investigation into competing bottom-up and top-down models of attention. Rather than both groups differing only after capture had occurred, as predicted by a bottom-up account of capture, AVGPs made fewer saccades toward task-irrelevant abrupt onsets than NVGPs. Thus, our study suggests unequivocally that improved top-down control processes can be engaged to prevent the capture of attention rather than enhancing the ability to deal with capture after it has occurred. In sum, the present results provide support for the notion that top-down factors can modulate the involuntary capture of attention.

3 Disassociating selection and response-based processes in AVGPs

3.1 Introduction

Over the past decade, research has taken an interest in the impact experience with action video games has on cognition. As action video games are typically fast-paced and require players to accurately select relevant information and make split second decisions in contexts that are visually complex and attentionally demanding, these games have been targeted as a potential ideal candidate to assess the malleability of cognitive processes via experience. Research has revealed ample evidence that experience with action video games does have an impact on cognition, demonstrating an impressive generalization of improvements across a host of cognitive paradigms. Although experience with action video games has been linked to a variety of visual and cognitive benefits (Bavelier, Green, Pouget, & Schrater, 2012; Hubert-Wallander, Green, Pouget, & Bavelier, 2010; Spence & Feng, 2010), much of this work has emphasized improvements in tasks that engage selective attention processes. For example, relative to non-video game players (NVGPs), action video game players (AVGPs) have demonstrated improvements in the spatial distribution of attention (Dye & Bavelier, 2010; Feng, Spence, & Pratt, 2007; Green & Bavelier, 2003, 2006a), visual search performance (Castel, Pratt, & Drummond, 2005; Hubert-Wallander, Green, Sugarman, & Bavelier, 2011), reduced crowding (Green & Bavelier, 2007), and reduced distraction (Chisholm, Hickey, Theeuwes, & Kingstone, 2010; Mishra, Zinni, Bavelier, & Hillyard, 2011). Many of these effects have also been demonstrated in NVGPs following training with action video games, providing evidence that a causal relationship exists between action video game experience and improved performance (e.g., Green &

Bavelier, 2003, 2006a, 2006b, 2007; Feng et al., 2007, Li, Polat, Makous, & Bavelier, 2009; however, see Boot, Blakely, & Simons, 2011 and Kristjansson, 2013 for criticisms and Boot, Kramer, Simons, Fabiani, & Gratton, 2008 for failing to show training effects).

Recently the field has shifted its focus, placing greater emphasis on understanding the mechanisms underlying the improvements demonstrated by AVGPs, rather than simply continuing to identify situations where AVGPs outperform NVGPs. A prominent account for the performance differences observed between AVGPs and NVGPs has been attributed to improvements in the controlled allocation of attentional resources (Hubert-Wallander et al., 2010; however, see Bavelier, et al., 2013 and Green & Bavelier, 2012 for a discussion of a recently proposed learning to learn account). The performance benefits observed in tasks that require participants to engage visuospatial attention has provided much of the evidence in support of this view. However, despite this account being well supported, it remains unclear how exactly improved control is manifested in these tasks. For example, we recently demonstrated that AVGPs were better able to resist distraction by task-irrelevant singletons (Chisholm et al., 2010). Although this finding was consistent with the attention-based account of AVGPs performance improvements, due to the covert nature of the task, it was unclear how AVGPs were reducing the measured capture effect. It was possible that AVGPs were better able to avoid making spatial shifts of attention toward the distractor or perhaps instead were quicker to correct incorrect shifts of spatial attention toward the distractor following capture. In conducting a follow-up study using an oculomotor capture paradigm, which allowed for an overt measure of attentional allocation, Chapter 2 provides evidence that AVGPs reduced distraction is due to committing fewer incorrect shifts of attention toward the salient distractor. Further understanding what changes in AVGP behaviour will be important in isolating the specific processes affected by action video game experience.

Motivated by this goal to better understand the specifics of how improved attentional control is manifested in AVGPs, the present investigation again compared AVGP and NVGP performance in a visual search task. In visual search tasks used to compare AVGP and NVGP performance, participants are often required to locate and respond to target stimuli; therefore, there is typically a selection feature that indicates what or where the target is in the display, followed by the need to respond to a response feature (e.g., tilt of a line, letter identity, target location, position of an indent/hole in a stimulus). Although AVGPs outperform NVGPs on these visual search tasks, past studies have been more interested in whether AVGPs demonstrate a benefit in search, rather than the specific mechanisms that yield such a performance benefit. As a result, it is currently unclear whether AVGPs perform better on visual search tasks because of improvements in selection or response-based processes.

The present study aimed to investigate whether AVGPs and NVGPs differ in selection vs. response-based processes. Despite acquiring an overt measure of attention in Chapter 2, we were unable to weigh in on this issue as the selection and response features were effectively the same (i.e., participants selected and responded to a colour singleton). Therefore, to answer this question in the present investigation the oculomotor capture task used in Chapter 2 was modified to make it a compound search task (Duncan, 1985). Specifically, participants were asked to search for one particular feature (i.e., select a target according to its colour) and respond to another feature (i.e., respond to an indent location within the target). Such a modification allows for an important distinction between selection and response-based processes. That is, saccade latency and accuracy can provide a measure into selection processes (e.g., whether selection is more efficient in AVGPs) and comparing manual response times, controlling for when participants fixate the target, can provide a measure of response efficiency. Thus, by comparing AVGP and NVGP performance on these two measures, we can tease apart whether AVGP visual search performance is associated with improvements in selection based processes, response based processes, or both. If only selection processes are improved, we would predict more efficient saccades to target stimuli with equivalent manual response times once the target is reached. The reverse is predicted if response processes are instead prioritized. More efficient saccades and manual response times are expected if improvements are experienced in both selection and response-based processes.

3.2 Methods

Participants

Data from 57 undergraduate male participants (17-30 years old, mean: 20.5), recruited from the University of British Columbia, are reported. The same approach as that used in Chapter 2 was employed to recruit participants. That is, the recruitment advertisement explicitly stated that the study was interested in recruiting AVGPs and NVGPs. Participants were separated into AVGP and NVGP groups based on the same criteria used in Chapter 2. As a group, AVGPs (n = 28) reported playing an average of approximately 8 hours of action games per week (e.g. *Counter-Strike, Left 4 Dead, Call* *of Duty, Gears of War, Halo*). As a group, NVGPs (n = 29) reported playing no action video games and an average of approximately 1 hour of non-action games per week. All participants provided written informed consent, reported normal or corrected-to-normal vision, and received course credit or monetary compensation for their participation.

Apparatus and stimuli

The experimental setup and design of the task was identical to that reported in Chapter 2 except for the following changes. Once participants initiated an eye movement, a small indent (4 pixels) was made on either the right or left side of the black square at the center of the target circle. Pilot testing indicated that the indent was only visible if fixated. A standard computer mouse was used to indicate whether the indent appeared on the left or right side of the square (Figure 3.1).

Figure 3.1 – Example of a target with an indent on the left side. Participants confirmed that they could respond to the location of the indent only if they were fixating the target.

Procedure

The procedure was identical to that used in Chapter 2 except for the following changes. Following target selection (i.e., once fixating the target), participants were required to provide a manual response, indicating the location of an indent made in a square within the target. Participants used the left and right mouse buttons to indicate whether the indent was on the left or right side of the square, respectively. Participants were encouraged to respond as quickly and accurately as possible, both in terms of their eye movements and manual responses and were again not informed that an abrupt onset distractor could appear.

Each participant began by completing a brief practice session of 12 trials and, in addition to being asked to confirm that they could identify the target circle amongst the non-targets, participants were asked to confirm that they could discriminate the location of the indent. Following the practice block, participants completed four experimental blocks, each consisting of 48 trials, for a total of 192 test trials. At the end of each block, participants were again provided with feedback regarding their performance; however, average manual response time (RT) was provided instead of average saccade RT (provided in Chapter 2). Participants were again asked to read their feedback aloud to the experimenter to keep participants motivated to respond quickly and accurately.

3.3 Results

The same criteria as that used in Chapter 2 was applied to exclude certain trials from any analyses. This resulted in a loss of 13.7% of trials (15.1% AVGPs and 12.5% from NVGPs, $p > 0.05$). An analysis of search time was provided in Chapter 2 to demonstrate that AVGPs reach the target faster than NVGPs on onset present trials. As this analysis simply reflected the effect oculomotor capture has on arrival time (i.e., slower to reach target when captured), it was not conducted in the present and subsequent chapters. Instead, an analysis of saccade latency is considered to provide a more meaningful assessment of selection performance.

Selection analysis

To assess whether AVGPs and NVGPs differ in their ability to efficiently select a relevant feature, we first conducted a 2 x 2 repeated measures analysis of variance (ANOVA) on saccade accuracy with onset presence (present vs. absent) and video game experience (AVGP vs. NVGP) as factors. Analysis of saccade accuracy revealed a main effect of onset presence ($F_{(1,55)}$= 300.70, p<0.001) and a marginal effect of video game experience ($F_{(1,55)}$= 3.64, p<0.07). Importantly, a significant interaction was observed ($F_{(1,55)}$= 5.72, p<0.05). Whereas AVGPs and NVGPs demonstrated comparable accuracy when no distractor appeared in the display, NVGPs demonstrated a greater detriment in saccade accuracy compared to AVGPs when a distractor was present (Figure 3.2). A follow-up analysis revealed that this difference was in fact due to a difference in oculomotor capture experienced by both groups ($t_{(55)}$= 2.34, p<0.05). AVGPs produced fewer incorrect saccades toward the abrupt onset (37.7%) compared to NVGPs (47.5%).

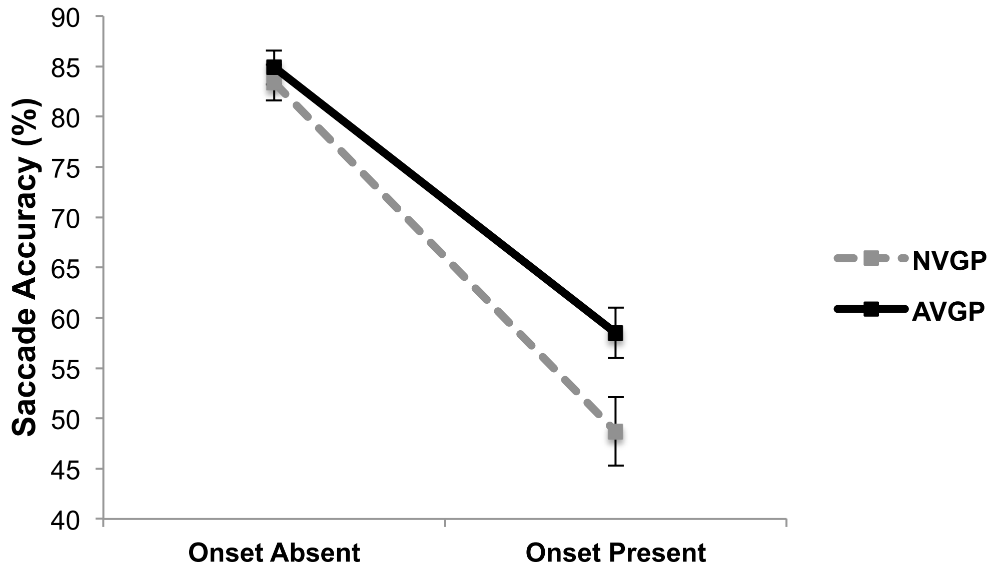

Figure 3.2 – Average saccade accuracy for trials where an abrupt onset was either absent of present. AVGPs produced more accurate saccades than NVGPs when an abrupt onset was present in the display ($p<0.05$). Error bars represent the standard error of the mean.

To further probe for differences in selection efficiency between groups, another 2 x 2 repeated measures ANOVA on saccade latency with onset presence (present vs. absent) and video game experience (AVGP vs. NVGP) as factors was conducted. For this analysis, only the trials where participants were not captured by the abrupt onset were included in the distractor present factor. Saccade latency when captured did not differ between groups ($p>0.05$), but as capture latencies are shorter, they create an imbalance when comparing latencies across groups that differ in the amount of capture experienced. Results revealed no main effect of onset presence ($F_{(1,55)}= 2.03$, $p>0.05$), a marginal main effect of video game experience ($F_{(1,55)}= 3.01$, $p<0.09$), and no significant interaction ($F_{(1,55)} < 1$, Figure 3.3). These results indicate that AVGPs and NVGPs did not differ in the time taken to initiate a saccade despite the differences observed in saccade accuracy. Thus, the results are not accounted for by a speed-accuracy tradeoff. If anything, AVGPs' saccades were both faster and more accurate[3].

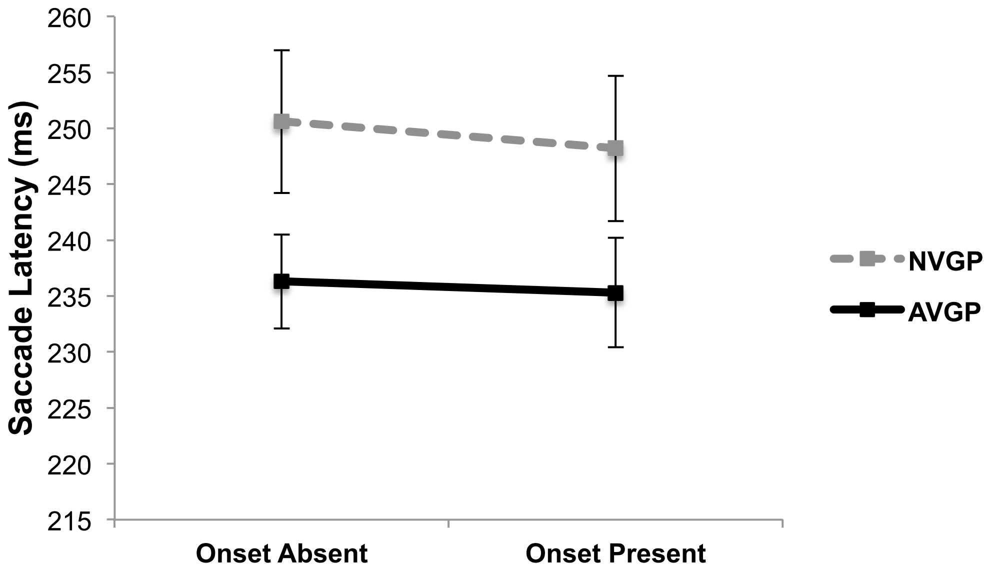

Figure 3.3 – Average saccade latency for trials where an abrupt onset was either absent or present. Latency was not affected by onset presence; however, a marginal advantage for AVGPs was observed (p<0.09). Error bars represent the standard error of the mean.

Response analysis

Trials where participants made saccade errors (i.e., not toward either target or abrupt onset) were not included in the analysis of manual RT. In addition, trials were excluded from any analyses if participants made an incorrect manual response or where RTs were 2.5 standard deviations from within-subject means (loss of 5.0% of trials). To acquire a measure of response selection without the contamination of all the stages that preceded the response, responses were standardized to the time of arrival at the target.

[3] Although not critical to the primary question of Chapter 3, readers may be interested in an analysis of the time needed to correct a captured saccade. Replicating the result seen in Chapter 2, AVGPs and NVGPs did not differ in the average time it took to correct a captured saccade (80.1ms vs. 88.5ms, respectively, $p>0.05$).

Thus, RT refers to the time taken to respond to the location of the indent from the moment the target was fixated.

To compare response selection efficiency across AVGPs and NVGPs, 2 x 2 repeated measures ANOVAs were conducted on both manual RT and manual response errors with onset presence (present vs. absent) and video game experience (AVGP vs. NVGP) as factors. Analysis of manual RTs revealed a main effect of distractor presence ($F_{(1,55)}$= 5.84, p<0.05) and video game experience ($F_{(1,55)}$= 12.79, p<0.01), but no significant interaction ($F_{(1,55)}$=1.60, p>0.05, Figure 3.4). Analysis of errors revealed no main effect of distractor presence ($F_{(1,55)}$= 2.64, p>0.05) or video game experience ($F_{(1,55)}$=1.62, p>0.05) and no significant interaction ($F_{(1,55)}$<1). AVGPs made errors on the same percentage of trials as NVGPs (3.4% vs. 2.7%, respectively). These results indicate that AVGPs produced, overall, faster manual responses than NVGPs without any significant additional cost to accuracy.

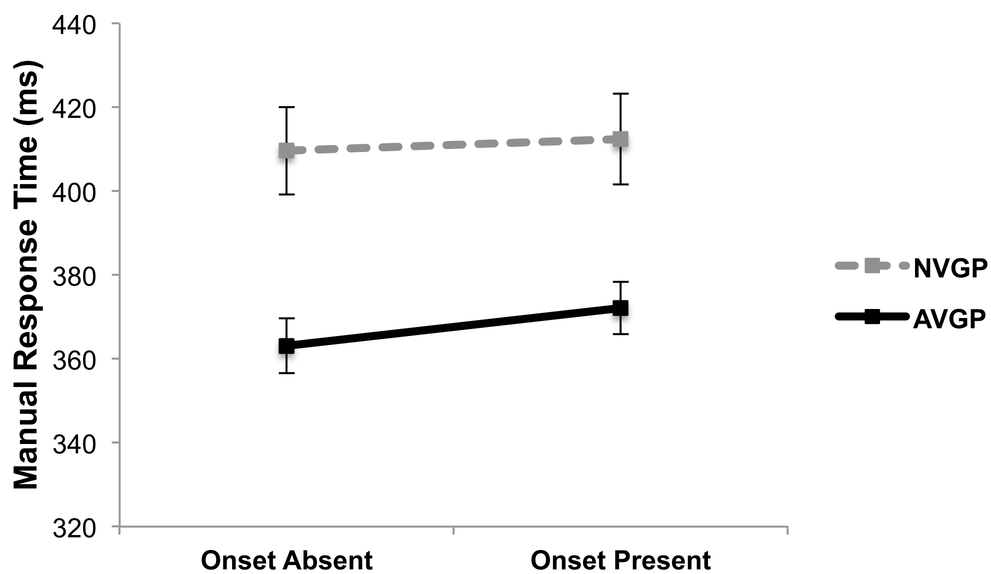

Figure 3.4 – Average manual reaction time for trials where an abrupt onset was either absent or present. Overall, AVGPs produced faster responses than NVGPs (p<0.01). Error bars represent the standard error of the mean.

3.4 Discussion

The present investigation aimed to further understand the specific manifestations of how AVGPs outperform NVGPs in a visual search task involving distraction. Critically, we employed a task that allowed us to dissociate behaviour associated with selection and response-based processes. To the best of our knowledge, this is the first investigation to distinguish between these two components of visual search when comparing AVGP and NVGP performance. Our results demonstrate that AVGPs are more efficient in selecting a target – as indexed by marginally faster saccades latencies and, critically, less oculomotor capture. This latter finding replicates the primary finding of Chapter 2 and is consistent with the notion of greater saccade control in AVGPs (West, Al-Aidroos, & Pratt, 2013) providing evidence for the reliability of improved oculomotor control in AVGPs. In addition, the results indicate that AVGPs are better at making quick and accurate manual responses – indexed by quicker button presses once fixating the target. Thus, our results demonstrate that action video game experience is associated with improvements in both selection and response-based processes.

As the likelihood of producing a reflexive saccade is associated with the effective maintenance of goal-related behaviour and availability of cognitive resources (Gaymard, Ploner, Rivaud, Vermersch, & Pierrot-Deseilligny, 1998; Guitton, Buchtel, & Douglas, 1985; Olk, Change, Kingstone, & Ro, 2006; Roberts, Hagar, & Heron, 1994), the fact that AVGPs are better able to resist oculomotor capture lends further support for the notion that action video game experience is associated with greater attentional control (Hubert-Wallader et al., 2010). The basis for improved response selection is, however, equivocal. Some have argued that faster manual responses may be due to improvements in the execution of motor responses (Castel et al., 2005). This makes intuitive sense given that AVGPs are effectively trained to be fast button pressers. One could argue that the present demonstration of faster manual responses exhibited by AVGPs could be interpreted to support this claim. However, recent work has provided evidence against this post-decisional motor account as an explanatory basis for a range of AVGP advantages (Dye & Bavelier, 2009b; Green et al., 2010, Hubert-Wallander, et al., 2012). Instead, evidence suggests that more efficient responding may result from improved perceptual decision-making processes (Green et al., 2010). The fact that AVGPs demonstrate enhanced visual acuity (Green & Bavelier, 2007) and acquire sensory information more quickly (Appelbaum, Cain, Darling, & Mitroff, 2013; Pohl, et al., 2014; Wilms, Petersen, & Vangkilde, 2013) could also provide a basis for more efficient response selection.

Interestingly, comparing the results of the present investigation to those of Chapter 2 revealed differences in a number of reported measures. Specifically, participants in the present investigation experienced significantly more capture than those who participated in the study reported in Chapter 2 (42% vs. 26%, respectively, $p<0.001$). In addition, participants produced faster saccades than those in Chapter 2 (243ms vs. 266ms, respectively, $p<0.001$). The only difference between these two tasks was the addition of a manual response following target selection and feedback given on this manual response measure rather than on the oculomotor selection measure. The observed differences in capture and latency did not interact with video game experience ($ps>0.05$), indicating that both groups were equally affected by the inclusion of a manual response. As previously mentioned, research has demonstrated that the likelihood of producing reflexive saccades is associated with the availability of cognitive resources (e.g., Roberts, et al., 1994). Research has also demonstrated that faster responding increases the likelihood of capture (van Zoest, Donk, & Theeuwes, 2004). As the task provided feedback on the speed of manual responses, this could have encouraged participants to prioritize the manual response at the cost of saccade accuracy. For example, in producing faster saccades, this would have made inhibiting the distractor more difficult. Hence the increase in capture observed in the present investigation may have been a result of less efficient inhibition of the distracting information, as resources were divided and perhaps differentially prioritized between two tasks (i.e., selection and manual response) compared to just one task (i.e. selection).

Two caveats regarding this work need to be addressed. First, given the cross-sectional nature of the present investigation, a degree of caution should be taken when considering the causal relationship between action video game experience and the observed effects. However, to date, many training studies have provided compelling evidence in favour of a causal link between action video game experience and performance improvements (e.g., Green & Bavelier, 2003, 2006a, 2006b, 2007; Feng et al., 2007, Li, et al., 2009; however see Boot, et al., 2008). Second, a recent criticism of the field has argued that active recruitment of AVGPs could influence or even cause the observed effects (Boot, et al., 2011; Kristjansson, 2013). That is, if AVGPs know that they are being recruited specifically for their expertise, they may be particularly motivated to perform better on the task. Although this raises a potentially critical concern for the reliability of the benefits demonstrated by AVGPs, it is important to note that some previous work has demonstrated AVGP advantages even when using covert recruitment strategy (Clark, Fleck, & Mitroff, 2011; Donohue, Woldoff, & Mitroff, 2010; also see Chapters 5 and 6). Therefore, although more work is needed to assess the relative influence of demand characteristics on AVGP and NVGP performance, current evidence suggests that this may not be a significant concern.

Conclusion

The present investigation aimed to further our understanding of how AVGPs outperform NVGPs on a visual search task. As previous work has confounded selection and response-based processes, an oculomotor capture paradigm was employed that allowed for the dissociation of these two processes. Results revealed that action video game experience is associated with improvements in both selection and response-based processes. Specifically, replicating the results of Chapter 2, AVGPs demonstrated reduced distraction to salient task-irrelevant stimuli. In addition, AVGPs produced more efficient manual responses. These results are consistent with the proposal that AVGPs possess greater attentional control compared to NVGPs. One particularly noteworthy aspect of the present work is that it provides insight into how this improved control is achieved. Furthermore, given the recent interest in using video games as a rehabilitative tool, the utility of such an endeavor will be based on our understanding of the specific processes affected by video game experience. In the present investigation, we provide evidence that suggests action video games could benefit those with deficits in either selection or response-based processes.

4 The influence of distractor awareness on oculomotor control

4.1 Introduction

At any given moment, the visual system is presented with far more information than it can possibly hope to handle. As a result, attentional mechanisms enable the selection of a portion of that incoming information for further processing. What receives attentional priority is governed by interactions between goal-driven and stimulus-based factors (Posner, 1980). That is, the selection of visual objects can be controlled by the volitional use of goal-related information (e.g. symbolic cues, attentional sets) or controlled by an object's salience relative to surrounding objects. The abrupt appearance of a new object represents one such visually salient event the attentional system is particularly sensitive to. When a target appears as an abrupt onset, search for that item is highly efficient; however, the abrupt appearance of a task-irrelevant object is quite effective at disrupting search performance. This capture of attention by abrupt onsets has been demonstrated in both covert (Jonides & Yantis, 1988; Remington, Johnston, & Yantis, 1992; Yantis & Jonides, 1984, 1990,) and overt attention paradigms (Boot, Kramer, & Peterson, 2005; Chisholm & Kingstone, 2012, Hunt, von Mühlenen, & Kingstone, 2007; Irwin, Colcombe, Kramer, & Hahn, 2000; Kramer, Hahn, Irwin, & Theeuwes, 2000; Theeuwes, Kramer, Hahn, & Irwin, 1998).

The attentional effect of making reflexive eye movements to task-irrelevant abrupt onsets is often measured in an oculomotor capture paradigm. While participants search for a target, typically a colour singleton, the sudden appearance of a new non-target object will capture the eyes on a significant number of trials. Despite attending to the abrupt onset, participants may report being unaware of having made erroneous eye movements, as well as being generally unaware of the fact that an extra item was added to the display at all (Kramer et al., 2000; Theeuwes, et al., 1999). This observation is quite interesting as it demonstrates significant interference on task performance with no conscious awareness on the part of the participant. Being aware of which information to attend to and which to suppress presents itself as the quintessential top-down situation for engaging effective attentional control. However, the fact that individuals exhibit oculomotor capture without being aware of their own behaviour raises the question of the importance of distractor awareness and its relative influence on search performance.

Behavioural and electrophysiological evidence has demonstrated that being aware of the spatial location of an upcoming distractor can give rise to anticipatory inhibition of that specific region in space (e.g., Chao, 2010; Munneke, Van der Stigchel, & Theeuwes, 2008; Ruff & Driver, 2006; Serences, Yantis, Culberson, & Awh, 2004; Van der Stigchel, Heslenfeld, & Theeuwes, 2006; Van der Stigchel & Theeuwes, 2006). Under these circumstances, performance is less affected by the presence of a distractor as processes can be engaged successfully to suppress their influence. Consistent with this, a study by Kramer et al. (2000) revealed that being aware of the presence of abrupt onsets in an oculomotor capture task could benefit performance. Awareness was manipulated by altering the relative saliency of the abrupt onset distractor across two testing blocks. The abrupt onset was either equiluminant or more salient compared to the other display items, establishing *unaware* and *aware* conditions, respectively. Results revealed that being aware of the distractor led to a decrease in oculomotor capture in young adults. For older adults, the pattern of results was reversed, with capture increasing with awareness. The authors suggested that being aware of the distractor allowed one to engage conscious working memory processes to actively inhibit the task-irrelevant information. Furthermore, noting that working memory processes decline with increasing age (e.g., Craik & Jacoby, 1996), the overall data pattern was explained. The broader implication of Kramer et al.'s (2000) explanation is that, without awareness, the attentional system is more susceptible to distraction because conscious inhibitory processes are not engaged to actively suppress the distracting information.

In the studies reported in Chapters 2 and 3, participants were not informed that a distractor could appear in the display. However, since it is not uncommon for participants to report being completely unaware of the appearance of abrupt onsets (Kramer et al., 2000; Theeuwes, et al., 1999), participants' awareness was queried to begin to get a feel for the frequency that participants report being aware or unaware of the distractor, with an eye towards possibly investigating in the future the role of awareness in oculomotor capture. For example, if being aware of distracting information improves oculomotor control (Kramer et al. 2000), then a possible account for the reduced capture demonstrated by AVGPs is that AVGPs are more aware of a distracting stimulus than NVGPs (e.g., overall as a group and/or more frequently in the oculomotor capture task). This possibility dovetails with the general nature of action video games, in that players must be ready to react at any given moment to potential threats. Such experience may make AVGPs more sensitive to becoming aware of the abrupt appearance of visual stimuli, and indeed there is some recent work suggesting that AVGPs are better able to detect the appearance of unexpected stimuli (Vallett, Lamb, & Annetta, 2013).

However, it is also noteworthy that research has revealed that inhibiting known distractors may not be efficient in all circumstances. Although Kramer et al.'s (2000) conclusion that working memory processes are engaged to inhibit distraction, subsequent work has demonstrated that performance is often negatively affected when the contents of working memory match the distractor information (e.g., Downing, 2000; Han & Kim, 2009; Olivers, Meijer, & Theeuwes, 2006; Olivers, 2009; Soto, Heinke, & Humphreys, 2005; however, see Downing & Dodds, 2004; Houtkamp & Roelfsema, 2006; and Woodman & Luck, 2007). Moreover two recent studies have also demonstrated that participants consistently attend to known to-be-ignored distractor locations, an observation that has been referred to as the "attentional white bear phenomenon" (Lahav, Makovski, & Tasl, 2012; Tsal & Makovski, 2006).

Convergent with these recent studies, evidence has been provided to suggest that known-to-be ignored distracting information must first be attended prior to being suppressed. For example, evidence for the time-course of distractor suppression comes from the use of a visual marking paradigm (Watson & Humphreys, 1997). In this task, a preview display is presented to indicate locations that will not contain a target. As revealed by performance in a probe detection task, attention is often first committed to the previewed non-target locations. Probe detection was thus facilitated at distractor locations when they appeared earlier in time (200ms following preview), but this facilitation was eliminated later in time (Humprhreys, Stalman, & Oliver, 2004). A similar pattern of results was demonstrated by Moher and Egeth (2012) when cueing to-be-ignored distractor features. They revealed that locations containing the to-be-ignored features were first attended, early in time, but then later suppressed. Moher and Egeth (2012) thus proposed a "search and destroy" model for distractor suppression, noting that such a strategy may be useful for prolonged search, when to-be-ignored information appears prior to a search display, but is likely inefficient when known distractor information appears simultaneously with a target.

In summary, considered collectively there is a conflict in the literature regarding the relative influence of distractor awareness on the efficiency of visual search. Kramer et al. (2000) demonstrate a benefit in search performance when participants become aware of the to-be-ignored information; however, a collection of more recent studies suggests that distractor awareness can, at least early in time, negatively affect performance.

Some glimpse on the potential importance of these issues with respect to AVGP and NVGP performance is gained by revisiting the data from Chapters 2 and 3, where a portion of both AVGP (33.3%) and NVGP (32.7%) groups reported being unaware of the abrupt onsets. Combining the data from Chapters 2 and 3 and including awareness as a factor revealed, in addition to a main effect of video game experience ($p<0.01$) a trend for a benefit for those who reported becoming aware of the distractor (33.4% capture) relative to those who reported being unaware (39.1% capture). This observation is in line with Kramer et al.'s (2000) study. However, the effect of awareness was not reliable ($p<0.11$) and it did not interact with gaming status ($p>0.05$, Figure 4.1).

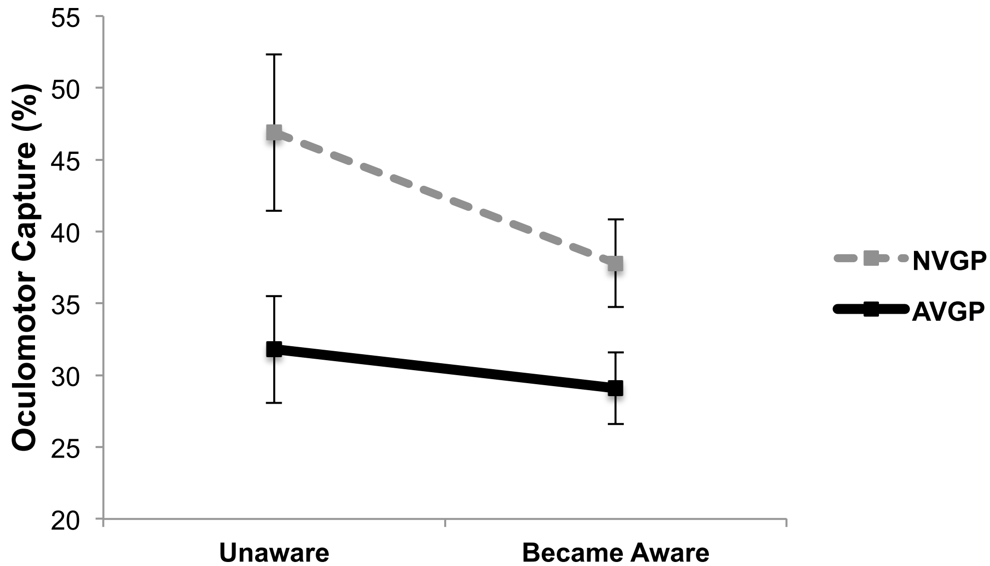

Figure 4.1 – Average AVGP and NVGP oculomotor capture as a function of whether participants reported being aware of the abrupt onset or not (data from Chapters 2 and 3). Error bars represent standard error of the mean.

This lack of a statistical effect must be treated with caution, however, as distractor awareness was only assessed post hoc with participants reporting at the end of the study whether or not they were aware of the distractor. A potential limitation of this methodology is that for participants who report being aware of the distractor it is unclear *when* awareness of the distractor occurred. Participants could have become aware at the beginning of the first block of trials or at the end of the final block of trials; both situations would result in the same post study awareness response. These points, combined with the fact that the literature itself is equivocal on whether awareness can positively (Kramer et al., 2000) or negatively (e.g., Moher & Egeth, 2012) influence performance, means that the suggestive finding from Chapters 2 and 3 that awareness reduces capture, and does not interact with action video game experience, must be treated with caution.

In order to better assess whether distractor awareness modulates capture, and setting aside for the moment the additional complexity of whether awareness interacts with gaming experience, we employed a direct manipulation of awareness, without altering any stimulus properties. Specifically, distractor awareness was manipulated by providing participants with different information prior to the beginning of the oculomotor capture task. One group of participants was informed that an abrupt onset could appear in the display (*aware* group) and a second group was not provided with any distractor information (*unaware* group). Critically, as display parameters were held constant across all conditions, if awareness alone is sufficient to modulate capture, then a difference in the degree of oculomotor capture is predicted between the aware group and the unaware group. And in case our simple awareness manipulation was not sufficiently strong to influence capture, a second manipulation was introduced whereby participants were informed about the distractor and instructed to avoid being captured by it (*avoid* group).

4.2 Method

Participants

Data from 36 participants (26 females, ages 16 – 28, mean: 19.9) recruited from the University of British Columbia are reported. Participants were divided equally among the three conditions. It is important to note that no eligibility restrictions for participation were set; therefore, recruitment was not specific to AVGPs and NVGPs. All participants provided written consent, reported normal or corrected-to-normal vision, and received course credit or monetary compensation for their participation.

Apparatus and task

The experimental setup and task design was identical to that used in Chapter 3.

Procedure

The procedure was identical to that used in Chapter 3 except for the following changes. All participants in the present study received the exact same general task instructions prior to beginning the task; however, the critical manipulation was the information participants received about the presence of a distractor. Participants assigned to the *unaware* condition received only the task instructions and were not informed of the possible appearance of an abrupt onset. In addition to task instructions, participants assigned to the *aware* condition were informed that an extra circle could appear on some of the trials. Finally, participants assigned to the *avoid* condition were informed that an extra circle could appear and that they should try to actively avoid looking at it.

The brief practice session confirmed that participants could properly detect the target circle amongst the non-targets as well as identify the location of the indent within the target. After practice, participants in the *aware* and *avoid* conditions were asked to confirm that they noticed the presence an abrupt onset distractor. Following the practice block, participants completed 6 experimental blocks, each consisting of 48 trials, for a total of 288 trials.

At the end of the experiment participants completed a questionnaire to confirm whether they were or were not aware of the abrupt onset. Specifically, participants were asked to indicate whether a number of aspects of the experiment were true or false. For example, all trials began with six circles (true), circles changed to red (false). Critically, one item asked whether an extra circle appeared in some of the trials. Reporting this statement as true and also answering the majority of the other questions correctly (mean 88%) was taken as evidence that the participant had been aware of the presence of the onset. Only those in the unaware condition who failed to report being aware of the abrupt onset via the post-experiment questionnaire were included in any analyses[4]. This questionnaire also assessed past experience with action video games.

4.3 Results

The same criteria as that used in previous chapters was applied to exclude certain trials from any analyses. This resulted in the loss of 13.4% of trials. To categorize accurate and capture trials, the following criteria were used – if a saccade landed within a window +/-35^{o}, centered on the target, the trial was considered accurate. If a saccade landed within the same window size, but centered on the abrupt onset, the trial was considered a capture trial. Saccades in any other direction were considered error trials and omitted from any analysis. Only 2 participants in the *aware* condition and 2 in the *avoid* condition met the criteria to be considered an AVGP.

Performance data are shown in Table 1. On trials where no abrupt onset appeared in the display, the majority of saccades (>80%) were oriented correctly to the target. An analysis of saccade accuracy revealed no differences across groups on onset absent trials ($F_{(2,35)}$=1.13, p>0.05). This was also the case for saccade latency in onset

[4] Thirty-two participants were tested to obtain 12 who were fully unaware of the distractor.

absent trials ($F_{(2,35)}$<1), indicating that all groups were equally able to perform the task. On trials where an abrupt onset did appear, a comparison of the proportion of trials where the initial saccade was oriented toward the abrupt onset was the critical analysis to assess the effect of awareness on oculomotor capture. Analysis of these data revealed a significant effect of condition ($F_{(2,35)}$=4.53, p<0.05). Post-hoc analysis demonstrated that participants in the *aware* condition experienced significantly less capture (29%) than those in the *unaware* (45%, p<0.05) and *avoid* (44%, p<0.05) conditions; whereas the *unaware* and *avoid* conditions did not differ (p>0.05)[5].

A 3 x 2 repeated measures ANOVA of manual reaction time, with condition (unaware, aware, avoid) and onset presence (absent vs. present) as factors, mirror the saccadic data pattern. There was a main effect of onset presence ($F_{(2,33)}$=3.77, p<0.05), indicating that all groups produced slower manual RTs when an onset appeared in the display. There was also a significant interaction ($F_{(2,33)}$=3.77, p<0.05), indicating that when the onset distractor was present performance was slowed to a greater extent for participants in the unaware (59ms) and avoid (63ms) groups than the aware group (39ms), reflecting the cost of making more saccades to the abrupt onset in the former two groups. Note that manual RT was measured from the beginning of the trial rather than once participants fixated the target (Chapter 3). A similar analysis of the manual response errors revealed that performance did not differ between onset present vs.

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[5] Given that "unawareness" was assessed post hoc, and not directly manipulated, a degree of caution needs to be applied when drawing a causal connection between the lack of distractor awareness and capture. That said, an analysis of the capture data from 18 of the participants (2 excluded due to equipment issues) in the unaware condition who were excluded because they reported becoming aware of the distractor at some point during the study provides converging evidence for a causal link. If distractor awareness causes a decline in capture, the performance for the participants who became aware during the study should reveal less capture than the unaware participants and greater capture than the (always) aware participants. This is precisely what our results revealed – capture for the participants excluded from the unaware condition (36%) fell between the capture observed for the participants in the unaware (45%) and aware (29%) conditions, but did not differ from either (ps>0.05).

absent trials ($F_{(1,33)}$=1.54, p>0.05) or groups ($F_{(2,33)}$<1), and these factors did not interact ($F_{(2,35)}$<1).

***Table 4.1** - Mean Saccade Accuracy and Saccade Latency in Onset Absent Trials, and Mean Oculomotor Capture and Cost to Manual RTs Across Conditions (standard error of the mean in parentheses).*

	Onset Absent Trials			
Condition	Saccade Accuracy	Saccade Latency	Oculomotor Capture	Manual RT Cost
Unaware	83.1% (2.2)	238ms (5.4)	44.6% (4.9)	59ms (7.3)
Aware	87.6% (2.6)	252ms (9.7)	29.0% (4.0)	39ms (7.4)
Avoid	83.7% (2.0)	250ms (11.0)	43.9% (3.4)	63ms (4.3)

4.4 Discussion

The aim of the present study was to determine if distractor awareness would influence oculomotor capture. Our data were unequivocal. A comparison of the *unaware* and *aware* conditions revealed that participants who were made aware of the presence of a task-irrelevant onset distractor were less susceptible to its interfering effect relative to those unaware of its presence. Our study also indicates that there is an important boundary condition to distractor awareness. When participants were made aware of the distractor and told to avoid being captured by it, the benefit of distractor awareness was abolished.

Given the present pattern of results, we feel our data helps to reconcile the divergent findings in the previously reviewed literature. Specifically, when considering the unaware condition as a baseline for oculomotor capture, we clearly demonstrate a benefit associated with being made aware of task irrelevant information. This finding is convergent with Kramer et al.'s (2000) finding that an increase in distractor awareness can reduce oculomotor capture. However, by placing greater emphasis on the distractor information, through a direct instruction to avoid being distracted, we eliminated the benefit associated with distractor awareness. This finding is consistent with recent evidence demonstrating that attempts to actively avoid distractor features can interfere with the ability to keep attention away from the to-be-ignored information (Moher & Egeth, 2012; Olivers, 2009). Thus, the present findings appear to map on well to an inverted-U function where susceptibility to distraction changes with the emphasis placed on the distracting information.

Convergent with the above explanation, Kramer et al. (2000), made their participants aware of the distractor in a manner akin to our aware group, and like us they found a benefit of distractor awareness on saccadic performance. Furthermore the studies that failed to observe a benefit of distractor awareness placed greater emphasis on the distractor (akin to our avoid group) by either a) presenting participants with known to-be-ignored spatial locations (Lahav et al., 2012; Tsal & Makovski 2006), b) asking participants explicitly to maintain distractor information in working memory (Downing, 2000; Olivers, 2006; Soto et al., 2005), or c) explicitly informing participants to ignore upcoming distractor features (Moher & Egeth, 2012; Olivers, 2009).

One can speculate at the neural mechanisms that may lead to these observed effects. Activity in the prefrontal cortex is thought to maintain working memory processes and is responsible for maintaining goal-directed behaviour and to inhibit reflexive saccades (Gaymard, Ploner, Rivaud, Vermersch, & Pierrot-Deseilligny, 1998;

Guitton, Buchtel, & Douglas, 1985; Olk, Change, Kingstone, & Ro, 2006). This is partially achieved via the inhibitory projections the prefrontal cortex sends to the superior colliculus (SC), which is largely responsible for the generation of saccades (Everling, Dorris, Klein, & Munoz, 1999; Schall, 1995; Wurtz & Optican, 1994). When individuals are made aware of the distractor, this allows for prefrontal processes to be brought to bear to inhibit SC activity, and the probability of being captured by the distractor declines. However, when unaware of the distractor, this precludes the possibility of conscious prefrontal-based control, leaving participants more susceptible to distraction. Placing too much emphasis on the distractor however could result in prefrontal resources being drawn away from the primary task and interfere with saccadic inhibition (e.g., Roberts et al., 1994), for example, by either establishing distractor avoidance as a competing primary task or increasing the relative saliency of the distractor which in turn requires greater prefrontal/working memory activity to inhibit this heightened bias toward the distractor.

There is, however, an alternative explanation for our data. Previous work has demonstrated that oculomotor capture is sensitive to the latency at which target directed eye movements are initiated, with faster eye movements being more likely to be captured (van Zoest, Donk, & Theeuwes, 2004). It is therefore possible that the *unaware* and *avoid* groups in the present study had shorter saccadic latencies than the *aware* group, and this is why the unaware and avoid groups had higher capture rates than the aware group. Comparison of the target saccadic latencies for distractor present and absent displays revealed no differences between groups (all $Fs_{(2,35)}$<1), indicating that the difference in capture rates between groups is not due to a speed-accuracy trade-off.

Conclusion

In the present investigation, we assessed the influence of a direct manipulation of distractor awareness on performance in an oculomotor capture task. We demonstrate a performance benefit associated with being aware of the presence of a distractor; however, this benefit is eliminated when an explicit instruction to avoid being distracted is provided. We suggest that our findings reconcile divergent findings in the literature on the influence of distractor awareness. Specifically, our results suggest that one's susceptibility to distraction is related to the relative emphasis placed on distracting information. While moderate emphasis of distractor information can benefit performance (Kramer et al., 2000) too much emphasis or a complete lack of distractor awareness can instead result in less efficient search performance. One outstanding question to be examined in the future is whether these findings are specific to overt oculomotor responses, or whether they generalize to covert attention and/or other responses domains.

5 The effect of distractor awareness on AVGP and NVGP performance

5.1 Introduction

Top-down attentional processes allow for the volitional selection of task-relevant information and the inhibition of irrelevant or distracting information. A fundamental aspect of top-down control involves a level of awareness for what information is being sought after. That is, knowing what you are searching for or where it is likely to appear can benefit search performance (Posner, Snyder, & Davidson, 1980). Interestingly, the literature has been a little less clear on the role of being aware of some task-irrelevant information and inhibiting distraction. Specifically, when distracting information is presented simultaneously with a search display, evidence has indicated that awareness can either help or hinder performance. Kramer, Hahn, Irwin, and Theeuwes (2000) demonstrated that being aware of the possible presence of an abrupt onset distractor allowed for top-down processes to better inhibit capture. In contrast, others have demonstrated that attention is first drawn to information maintained in working memory, even when irrelevant to one's current task (Downing, 2000; Han & Kim, 2009; Olivers, Meijer, & Theeuwes, 2006; Olivers, 2009; Soto, Heinke, & Humphreys, 2005; however, see Downing & Dodds, 2004; Houtkamp & Roelfsema, 2006; and Woodman & Luck, 2007) and that known-to-be ignored information is often attended earlier in time than target information (Humprhreys, Stalman, & Oliver, 2004; Moher & Egeth, 2012).

The findings from Chapter 4 provided evidence that accounted for this conflict. Results showed that if individuals are made aware of the presence of potentially distracting information, they are better able to inhibit the irrelevant information relative to those who are unaware. This result is consistent with Kramer et al.'s (2000) findings.

However, it was also found that this benefit is eliminated when the distractor information is over-emphasized. By placing too much emphasis on the distractor information, thus presumably making it more salient, makes inhibition more difficult. This latter result is consistent with the work demonstrating that distraction can be heightened by known-to-be ignored information (Lahav, Makovski, & Tasl, 2012; Tsal & Makovski, 2006; Moher & Egeth, 2012). Collectively, the findings from Chapter 4 provided evidence that distractor awareness enables the allocation of resources toward more efficient inhibition of task-irrelevant information which, as long as the distracting information is not emphasized to the point of being thought of as task-relevant, should improve search performance.

The knowledge that distractor awareness can positively affect oculomotor control begs the question whether it plays a significant role in the reduced oculomotor capture demonstrated by AVGPs. In the studies reported in Chapters 2 and 3 participants were not informed that a distractor could appear in the display but their awareness of the distractor was queried after testing. Revisiting these data yielded some indication that awareness may have been a relevant factor in general but that there was nothing specific to AVGPs. Specifically, consistent with the results of Chapter 4, a trend was observed where capture was numerically lower in those who reported becoming aware AVGPs: 28.0%; NVGPs: 39.8%) compared to those who were unaware (AVGPs: 32.4%; NVGPs: 43.6%). However, these data were qualified by a number of considerations, e.g., the observed trend was not significant and awareness was only assessed post-hoc, so there was no clear indication of *when* awareness had occurred. The present series of experiments were aimed to assess whether distractor awareness plays a part in the oculomotor control advantage demonstrated by AVGPs over NVGPs.

5.2.1 Study 1

Study 1 presents a replication of the experiment reported in Chapter 2, which had participants complete an oculomotor capture paradigm that required only saccade responses. In order to assess whether making participants aware of a task-irrelevant abrupt onset differentially affects the advantage of AVGPs compared to NVGPs, all participants were provided with instructions similar to that of the *aware* condition used in Chapter 4. That is, prior to beginning the task participants were told that an extra circle could appear in the display but that it was irrelevant to the search task. Based on previous findings (Kramer et al., 2000), including the results from Chapter 4 and the suggestive data from Chapters 2 and 3, we predicted that informing participants of the possible appearance of an abrupt onset should enable more efficient inhibition of this task-irrelevant information. This would be expressed by AVGPs and NVGPs demonstrating less capture than those tested in Chapter 2 where no distractor information was provided. However, if AVGPs advantage over NVGPs is derived from the fact that they are more aware of the distractor while NVGPs are not, then being made aware of the distractor may have a nominal effect on AVGPs and a significant effect on NVGPs.

5.2.2 Method

Participants

Data from 32 male participants (18-29 age range, mean of 20.9 years), evenly split into AVGP and NVGP groups, recruited from the University of British Columbia are reported. The criteria set to be considered an AVGP or NVGP was the same as that used in previous chapters. As a group, AVGPs reported playing an average of approximately 9 hours of action video games per week. NVGPs reported playing no action video games but averaged 1 hour per week of non-action video games. The only notable change from the previous investigations is that a covert recruitment strategy was employed. That is, participants were not aware that video game experience was a key component of the experiment until debriefing. All participants received course credit or monetary compensation for their time, reported normal or corrected-to-normal vision, and provided informed consent.

Apparatus & stimuli

The experimental setup and task was identical to that used in Chapter 2. Changes were however made to the post-experiment questionnaire used to assess participants' experience with action video games. First, the questionnaire was modified to assess participants' experience with various hobbies. Although the critical data were participants' self-reported experience with video games, the questionnaire also asked whether participants played any sports or musical instruments. Thus, it was not obvious that the study was specifically related to video game experience. Second, to address some recent concerns presented in the field (Boot, Blakely, Simons 2012; Kristjansson, 2013), participants were also asked how motivated they were during the task and how much they treated the task like a video game. The same questionnaire used in Chapter 4 was also used to assess distractor awareness. That is, participants were asked whether a number of aspects of the experiment were true or false. Correctly identifying that an “extra circle appeared in some of the trials” was taken as evidence that the participant had been aware of the presence of the onset.

Procedure

The procedure was identical to that used in Chapter 2 save for the following. First, after providing participants with task instructions, they were informed that an additional circle could appear in the display. Participants were told that this extra circle was irrelevant to the present task, and so it could simply be ignored. This instruction was meant to mimic the *aware* condition from the previous study. Second, following the completion of the practice trials, participants were asked to confirm whether they noticed the abrupt onset. Third, after completing the computer task, in addition to collecting demographic information and a report of prior experience with action video games, participants were asked to report how motivated they were during the task and how much they treated the task as a video game. Responses were provided on a 7-point Likert scale with low scores corresponding to low motivation and the task not being game-like at all, respectively.

5.2.3 Results

The same criteria used in previous chapters were applied for the exclusion of trials from any analyses. This resulted in a loss of 19.7% of trials (17.6% of AVGP trials and 21.8% of NVGP trials, $p>0.05$).

Saccade accuracy

A 2 x 2 repeated measures analysis (ANOVA) was conducted on saccade accuracy with video game experience (AVGP vs. NVGP) and onset presence (absent vs. present) as factors. Analysis revealed a main effect of onset presence ($F_{(1,30)}$ = 119.60, $p<0.001$), indicating that saccade accuracy was worse for onset present compared to onset absent trials. However, no main effect of game status was observed ($F_{(1,30)} < 1$), nor was there a significant interaction ($F_{(1,30)}$ = 1.52, $p>0.05$, Figure 5.2.1). Thus AVGP and NVGP were equally affected by the presence of an abrupt onset distractor. Consistent with this result, an analysis on the proportion of onset present trials where the eyes first oriented toward the abrupt onset revealed no difference in oculomotor capture between AVGPs (21.8%) and NVGPs (17.7%, $t_{(30)}$ = 1.37, p>0.05).

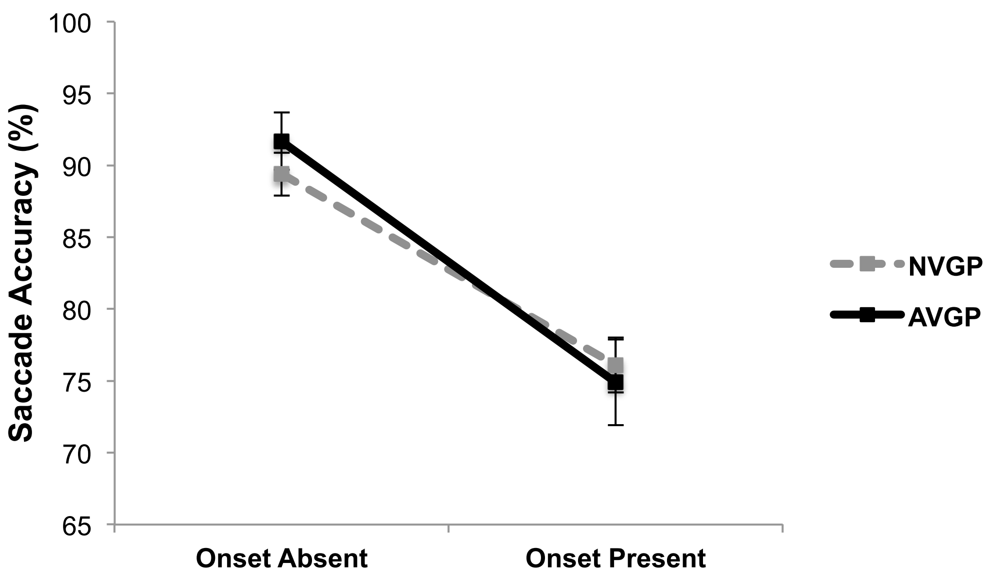

Figure 5.2.1 – Average saccade accuracy across onset absent and present trials when all participants were made aware of the possible appearance of a distractor. Error bars represent the standard error of the mean.

Saccade latency & correction time

A 2 x 2 repeated measures ANOVA was conducted on saccade latency with video game experience (AVGP vs. NVGP) and onset presence (absent vs. present) as factors. Only the latencies on correct trials were included (i.e., errors and capture trials excluded). Analysis revealed a marginal main effect of trial type ($F_{(1,30)}$=3.82, p<0.06), no main effect of gamer status ($F_{(1,30)}$=2.19, p>0.05), and no interaction ($F_{(1,30)}$=1.51, p>0.05, Figure 5.2.2). An analysis of the time taken to correct a saccade following capture also revealed no differences between AVGPs (88ms) and NVGPs (91ms, t(28)=0.29, p>0.05).

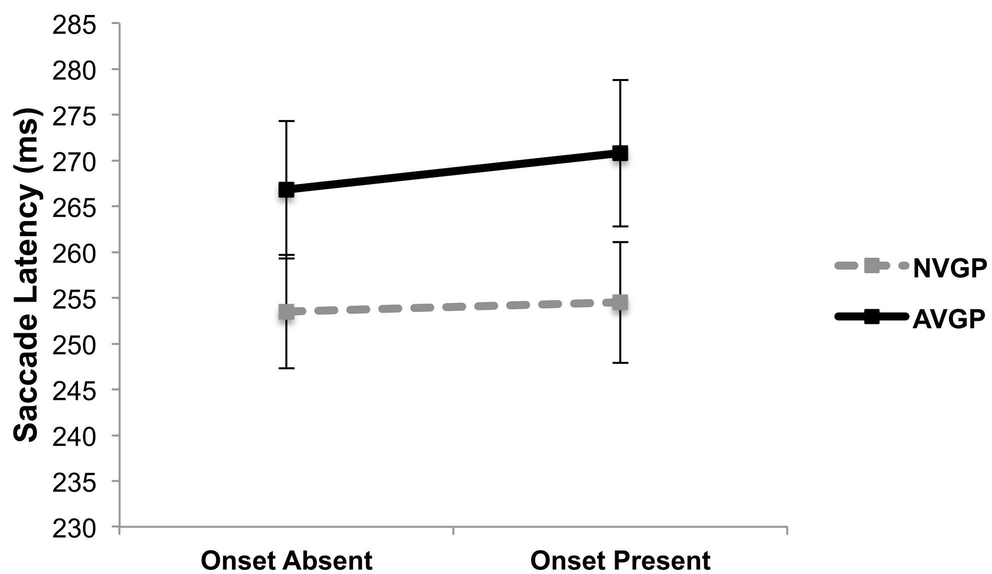

Figure 5.2.2 – Average AVGP and NVGP saccade latency across onset absent and present trials when all participants were made aware of the possible appearance of a distractor. Error bars represent the standard error of the mean.

Subjective reports

Analyses were conducted to compare whether AVGPs and NVGPs differed in their level of motivation while completing the task and whether they conceptualized the task as more or less like a video game. Participants provided responses on a 7-point Likert scale (e.g., low values corresponding to low motivation and the task not been game-like at all and high values corresponding to high motivation and the task being very game-like). Analysis of these data revealed no differences in motivation across groups (AVGPs=4.75, NVGPs=5.28, $t_{(30)}$=1.21, p>0.05). AVGPs also did not consider the task to be any more like a video game compared to NVGPs (AVGPs=4.20, NVGPs=3.53, $t_{(30)}$=1.08, p>0.05).

5.2.4 Discussion

The present study aimed to assess whether the effect of distractor awareness interacted with the observed benefits associated with action video game experience. Comparing performance across AVGPs and NVGPs, who were informed of the possible presence of a task-irrelevant abrupt onset, revealed no performance differences across any of the reported measures. Critically, both AVGP and NVGP experienced the same amount of oculomotor capture. This result is consistent with the prediction derived from Chapters 4 that AVGPs were generally more aware of potentially distracting information in Chapter 2. That is when participants were not made explicitly aware of the distractor (Chapter 2), a significant AVGP advantage was observed; however, when participants were made aware of the distractor this advantage was eliminated. Therefore, if AVGPS are naturally more aware of potentially distracting information, and identify it as task-irrelevant, this can give rise to more efficient inhibition. This account is further supported by the finding that AVGPs are better able to detect the appearance of an unexpected stimulus (Vallett, Lamb, & Annetta, 2013) as well as with the evidence suggesting that AVGPs are more sensitive to and make better use of sensory information (Green, Pouget, & Bavelier, 2010).

However, It is important to acknowledge that the lack of a difference between AVGPs and NVGPs in the present study could be merely interpreted as indicating that reduced oculomotor capture in AVGPs is not a particularly reliable effect. The lack of any motivational differences between AVGPs and NVGPs could be considered to provide some support for this account. Previous reports have suggested that active recruitment (used in Chapters 2 and 3) may lead to demand characteristics, which could influence performance (Boot et al., 2011; Kristjansson, 2013). For example, if AVGPs know that a study is about the effect of video game experience, they may be more motivated to perform well on the task compared to NVGPs. The fact that a covert recruitment strategy was used in the present study and that no differences were observed in motivation or whether AVGPs treated the task more like a game could argue that no demonstration of improved attentional control exists between AVGPs and NVGPs when proper controls are employed. In light of this, a second study was conducted to assess the viability of this account.

5.3.1 Study 2

Study 2 presents a replication of Chapter 3 where participants performed an oculomotor capture task that required saccade and manual responses. The same instructions as those used in Study 1 were provided in order to make all participants aware of the possible appearance of an abrupt onset. The aim of this investigation was to provide an additional assessment of the influence distractor awareness has on AVGP and NVGP oculomotor control and to further assess the reliability of the previously reported effects.

I proposed that the null effect in Study 1 said something meaningful in terms of how AVGPs outperform NVGPs. An alternate interpretation is that the null effect suggests that the reported differences between AVGPs and NVGPs are not reliable when one controls for motivation and mental states (Boot et al., 2012, Kristjansspn, 2013). For the present investigation, it is important to note that the awareness instruction is only associated with the initial target selection process. That is, making participants aware of the distractor should only improve one’s ability to inhibit the task-irrelevant information and should not impact any processes following target selection. Therefore, regardless of the effect distractor awareness has on oculomotor capture, if experience with action video games does positively affect AVGP performance, they should still outperform NVGPs when making manual responses. If, however, the previously reported AVGP advantages are due to demand characteristics associated with overt recruitment (e.g., motivational differences), then if motivation and mental state are equated, no differences should be observed in both target selection and response measures.

5.3.2 Method

Participants

Data from 30 male participants (18-29 age range, mean of 21.3 years), split evenly into AVGP and NVGP groups, were recruited from the University of British Columbia are reported. The criteria set to be considered an AVGP or NVGP was the same as that used in Study 1. As a group, AVGPs reported playing an average of approximately 7 hours of action video games per week. NVGPs reported playing no action video games but reported an average of approximately 2 hours per week of non-action video games. The same covert recruitment strategy used in Study 1 was also employed. All participants received course credit or monetary compensation for their time, reported normal or corrected-to-normal vision, and provided informed consent.

Apparatus & Stimuli

The experimental setup and task was identical to that used in Chapter 3 and the post-experiment questionnaires were all the same as those used in Study 1.

Procedure

The procedure was identical to that used in Chapter 3 except for the changes detailed in Study 1.

5.3.3 Results

The same exclusion criteria as that used in previous chapters was applied for removing trials from any analyses This resulted in a loss of 11.6% of trials (13.3% of AVGP trials and 9.9% of NVGP trials, $p>0.05$).

Saccade accuracy

A 2 x 2 repeated measures ANOVA was conducted on saccade accuracy with video game experience (AVGP vs. NVGP) and onset presence (absent vs. present) as factors. Analysis revealed a main effect of onset presence ($F_{(1,28)} = 97.21$, $p<0.001$), indicating that saccade accuracy was worse for onset present compared to onset absent trials. However, no main effect of video game experience was observed ($F_{(1,28)} < 1$), nor was there a significant interaction ($F_{(1,28)} < 1$, Figure 5.3.1). Thus AVGP and NVGP were equally affected by the presence of an abrupt onset distractor. Consistent with this result, an analysis on the proportion of onset present trials where the eyes first oriented toward the abrupt onset revealed no difference in oculomotor capture between AVGPs (34.8%) and NVGPs (37.0%, $t_{(28)} = 0.46$, $p>0.05$).

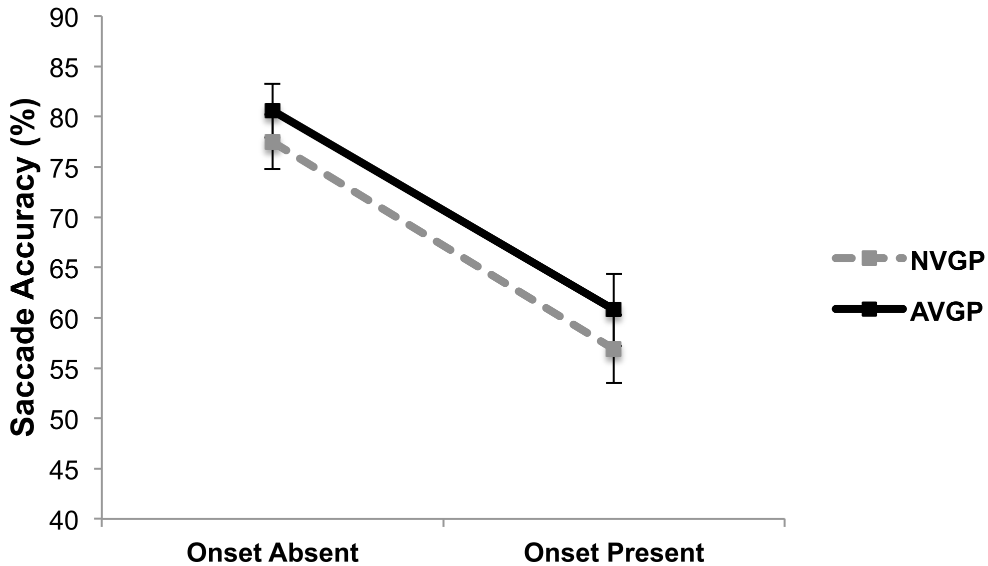

Figure 5.3.1 – Average AVGP and NVGP saccade accuracy across onset absent and present trials when all participants were made aware of the possible appearance of a distractor (saccade and manual version of task). Error bars represent the standard error of the mean.

Saccade latency & correction time

A 2 x 2 repeated measures ANOVA was conducted on saccade latency with video game experience (AVGP vs. NVGP) and onset presence (absent vs. present) as factors. Only the latencies on correct trials were included (i.e., errors and capture trials excluded). Analysis revealed a marginal effect of onset presence ($F_{(1,28)}$=2.95, p<0.10), but no main effect of video game experience ($F_{(1,28)}$=2.12, p>0.05), and no interaction ($F_{(1,28)}$<1, Figure 5.3.2). Analysis of the time taken to correct a captured saccade also revealed no significant difference between AVGPs (80ms) and NVGPs (87ms; $t_{(28)}$ = 1.42, p<0.05).

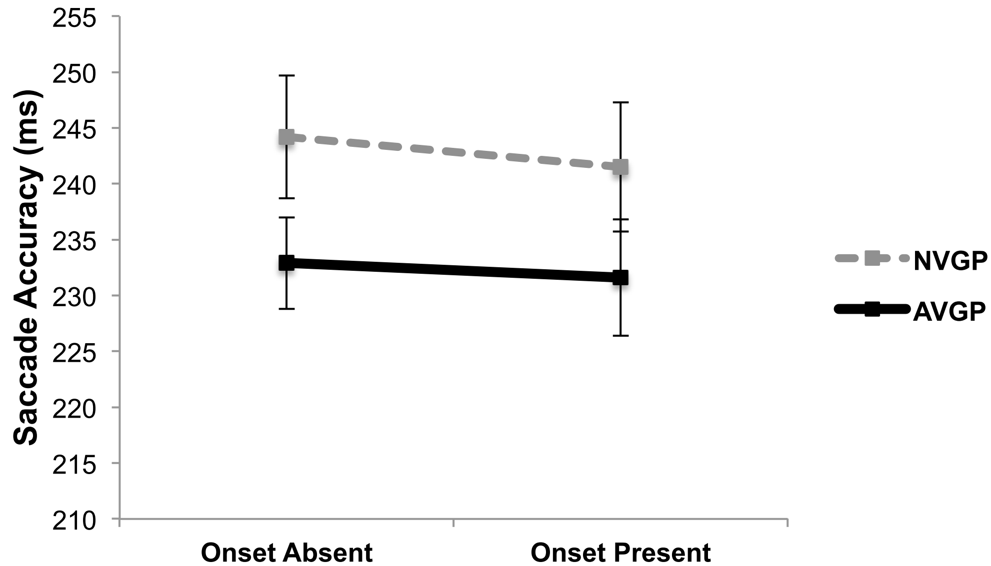

Figure 5.3.2 – Average AVGP and NVGP saccade latency across onset absent and present trials when all participants were made aware of the possible appearance of a distractor (saccade and manual version of task). Error bars represent the standard error of the mean.

Manual reaction time & errors

Trials where participants made saccade errors (i.e., not toward either target or abrupt onset) were not included in the analysis of manual response times (RT). In addition, trials were excluded from any analyses if participants made an incorrect manual response or where RTs were 2.5 standard deviations from within-subject means (loss of 4.3% of trials). As in Chapter 3, to acquire a measure of response selection without the contamination of all the stages that preceded the response, we standardized all responses to the time of arrival at the target. Thus, RT refers to the time taken to respond to the location of the indent from the moment the target was fixated.

To compare response selection efficiency across AVGPs and NVGPs, we conducted a 2 x 2 repeated measures ANOVA on both manual RT and manual response errors with onset presence (present vs. absent) and video game experience

(AVGP vs. NVGP) as factors. Analysis of manual RT revealed a main effect of video game experience ($F_{(1,28)}$= 6.31, p<0.05) but no main effect of distractor presence ($F_{(1,28)}$<1) and no significant interaction ($F_{(1,28)}$<1, Figure 5.3.3). Analysis of errors revealed no main effects and no interaction (all ($Fs_{(1,28)}$ < 1). These results indicate that AVGPs made the same percentage of errors (2.9%) than NVGPs (2.6%) yet produced, overall, faster manual responses.

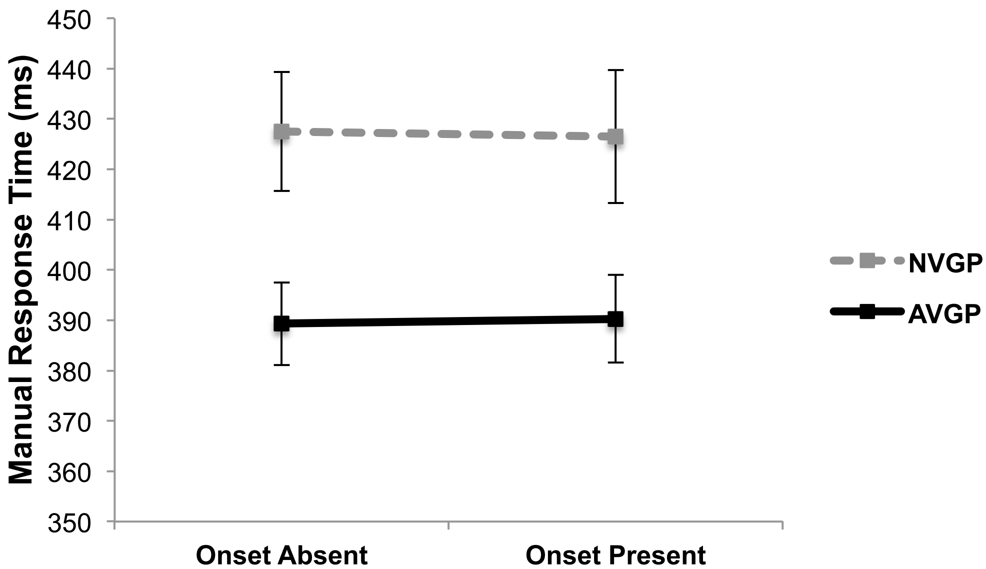

Figure 5.3.3 – Average AVGP and NVGP manual response time on onset absent and present trials when all participants were made aware of the possible appearance of a distractor (saccade and manual version of task). Error bars represent the standard error of the mean.

Subjective reports

Analyses were conducted to compare whether AVGPs and NVGPs differed in their level of motivation while completing the task and whether they conceptualized the task as more or less like a video game. Participants provided responses on a 7-point Likert scale (e.g., low values corresponding to low motivation and the task not been game-like at all and high values corresponding to high motivation and the task being very game-like). Analysis of these data revealed no differences in motivation across groups (AVGPs=5.38, NVGPs=5.77, $t_{(28)}$=1.15, p>0.05). AVGPs also did not consider the task to be any more like a video game compared to NVGPs (AVGPs=4.27, NVGPs=3.85, $t_{(28)}$=0.58, p>0.05).

5.3.4 Discussion

The aim of this study was to further assess the influence of distractor awareness on AVGP and NVGP and to test the reliability of the previously reported AVGP advantage. The results replicated that of Study 1, demonstrating that when AVGPs and NVGPs were both made aware of the presence of the abrupt onset, they again showed no difference across selection-based measures (i.e., saccade accuracy and latency). Therefore, making participants aware of the distractor resulted in equal oculomotor capture in AVGPs and NVGPs. AVGPs and NVGPs again did not differ in whether they treated the task like a video game and both reported equivalent levels of motivation. Importantly, although no AVGP advantage was seen in target selection performance, the present results replicated the finding in Chapter 3 demonstrating that AVGPs produced faster manual responses than NVGPs. Hence, these results provide evidence against the notion that the performance benefits observed in AVGP are the results of demand characteristics.

5.4 General discussion

In the two reported studies we assessed the relative influence of distractor awareness on AVGP and NVGP performance. Results revealed that when participants were informed that an abrupt onset distractor could appear in the display, oculomotor capture did not differ between AVGPs and NVGPs. Importantly, AVGPs still produced faster manual responses (Study 2), supporting the reliability of an AVGP advantage and indicating that the distractor instruction had a specific effect on the previously reported selection performance. To evaluate the relative effect distractor awareness had on AVGP and NVGP performance, an additional analysis comparing the results of the present investigation to those of Chapters 2 and 3 was conducted. Specifically, all the participants from Study 1 and 2 (31 AVGPs and 31 NVGPs; aware condition) were compared to the participants who reported being unaware (16 AVGPs and 17 NVGPs; unaware condition) and those who reported becoming aware (34 AVGPs and 33 NVGPs; became aware condition) of the distractor in Chapters 1 and 2. This analysis revealed a significant effect of video game experience ($F_{(1,91)}$=8.59, p<0.01), a significant effect of awareness ($F_{(1,91)}$=6.18, p<0.01), and a significant video game experience x awareness interaction ($F_{(1,91)}$=3.10, p<0.05). The significant interaction reveals that informing participants that an abrupt onset could appear in the display yielded improvements in NVGP performance but did not affect AVGP performance (Figure 5.4.1).

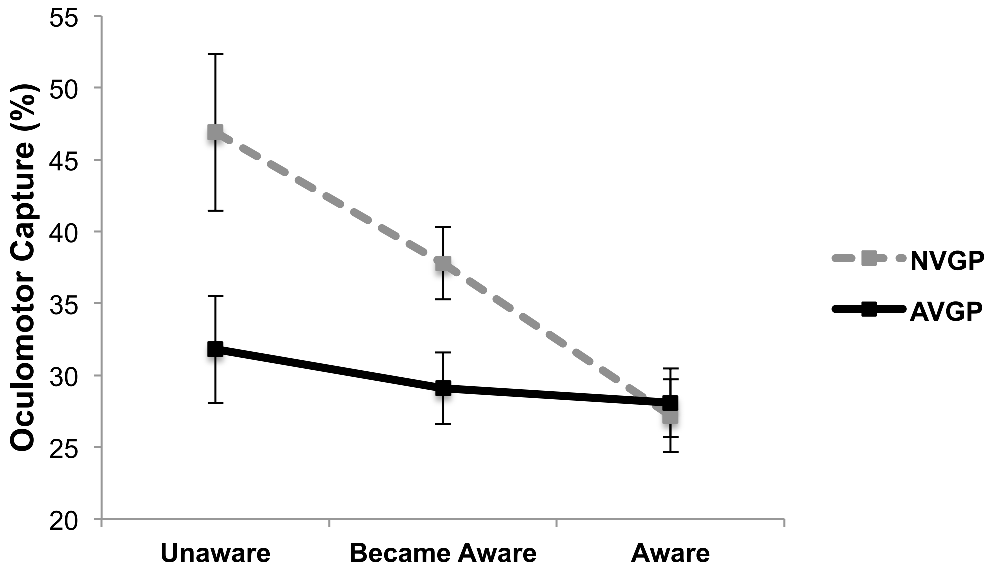

Figure 5.4.1 – Average AVGP and NVGP oculomotor capture as a function of distractor awareness. Unaware and Became Aware conditions are from the combined data from Chapters 1 and 2 and Aware condition is from Chapter 5 data. Error bars represent the standard error of the mean.

The results from Chapter 4 revealed that making individuals aware of potentially distracting information can give rise to enhanced distractor inhibition (also see Kramer et al., 2000). The fact that in the present two studies AVGPs did not benefit from this awareness instruction is consistent with the prediction that AVGPs were more aware of the distracting information when participants were not explicitly informed of its presence (Chapters 2 and 3). This observation again speaks to the proposed improvements in attentional control in AVGPs. That is, if AVGPs are more sensitive to sensory information (Green et al, 2010) such that they are better able to detect (Vallett et al., 2013) task-irrelevant information, this allows for more efficient inhibition of potentially distracting information (Chisholm et al., 2010; Krishnan et al., 2013; Mishra et al., 2011).

It is worth noting that looking further in the interaction reported above and comparing AVGP and NVGP performance when both groups reported being unaware revealed a significant effect ($F_{(1,31)}$=5.39, p<0.05). At first blush the account that that AVGPs outperform NVGPs because they are more awareness of distracting information would appear to conflict with the finding that AVGPs demonstrated reduced capture even when they self-reported being unaware of the distractor. However, as will be further discussed in Chapter 8, a post hoc measurement of memory as used in the present questionnaire is invariably limited by the fact that it depends on one's ability to explicitly recall a particular event. There is a large body of evidence in the domains of procedural memory, tacit knowledge, and implicit learning to suggest that when one is an expert in a particular domain, responses to events can be guided by knowledge that is difficult to express (e.g., Berry, 1987; Berry & Broadbent, 1984; Berry & Dienes, 1993; Cleeremans, Destrebecqz, & Boyer, 1998; Leprohon & Patel, 1995; Stanley, Mathews, Buss, & Kotler-Cope, 1989).

Indeed, the evidence demonstrating that AVGPs are more sensitive to and make better use of sensory evidence to guide behaviour (Green, et al., 2010) is convergent with this proposal. Collectively, these findings provide a potential basis for the general view of improved attentional control in AVGPs (Hubert-Wallander, Green, & Bavelier, 2010). That is, action video game experience trains AVGPs to be more responsive to sensory information such that resources can more be efficiently allocated toward producing better goal-related behaviour.

It is important to note that the findings of the present experiments speak to some of the criticisms that the field has recently faced (Boot et al., 2011, Kristjansson, 2013). Specially, a concern has been raised regarding overt participant recruitment possibly giving rise to demand characteristics (i.e., if AVGPs know that the study is about the effects of video games, they may be more motivated to perform well). Beyond recruitment, it is was also suggested that differences between AVGPs and NVGPs may simply be a byproduct of different motivational states (e.g., AVGPs may be naturally more motivated than NVGPs) or whether AVGPs think of the cognitive tasks more like a video game, where they have extensive experience prioritizing performance. Although the results from Study 1 provided reason for concern regarding the reliability of the differences observed between AVGPs and NVGPs, we argue that Study 2 provides compelling evidence that these concerns are unwarranted. Specifically, despite using a covert recruitment strategy and "controlling" for both motivation and how both groups approached the task, reliable differences were still observed between groups. Furthermore, replicating the effect seen in Chapter 3 with overt recruitment, AVGPs produced faster manual responses than NVGPs when discriminating the location of the indent within the target when covert recruitment was used.

Conclusion

Two studies were conducted to assess whether the previously reported benefits in AVGP performance could be accounted for by differences in distractor awareness. Results revealed that, while providing distractor awareness to NVGPs improved oculomotor control, AVGP behaviour was largely unaffected. This result was consistent with the prediction that AVGPs are more aware of potentially distracting information. Such awareness allows for more efficient allocation of resources toward inhibiting task-irrelevant information (Kramer et al., 2000; Chapter 4). Therefore, consistent with previous work (Green et al., 2010) it is proposed that these data speak to the notion that

AVGPs outperform NVGPs because of more efficient processing of sensory information and attentional allocation. Critically, data was also presented to suggest that this conclusion is based on a reliable difference between AVGPs and NVGPs rather than previously reported effects being a result of demand characteristics. The presented data also suggest that an investigation into the implicit aspects of AVGP performance may be a fruitful avenue for future research.

6 Oculomotor control in AVGPs with biologically relevant stimuli

6.1 Introduction

Research investigating the effects of action video game performance has demonstrated cognitive benefits across a variety of visual search paradigms. The earliest work in this general area demonstrated reduced visuospatial reorienting costs when targets appeared at low probability locations in a stimulus detection paradigm (Greenfield, DeWinstanley, Kilpatrick, & Kaye, 1994). The findings from this work provided an early account of possible attentional differences in AVGPs and NVGPs. Specifically, Greenfield et al. suggested that AVGPs are better able to allocate and divide selective attention toward improving task performance. Research over the past decade has provided further evidence for a visual search advantage in AVGPs. For example, AVGPs outperform NVGPS on basic visual search tasks (Castel, Pratt, & Drummond, 2005, Hubert-Wallander, Green, Sugarman, & Bavelier, 2011), useful-field of view tasks (Dye & Bavelier, 2010; Green & Bavelier, 2003, 2006a, Feng, Spence, & Pratt, 2007), flanker/load tasks (Dye, Green, & Bavelier, 2009a; Green & Bavelier, 2003, 2006a; Xuemin & Bin, 2010, though see Irons, Remington, & McLean, 2011), distraction-based tasks (Chisholm, Hickey, Theeuwes, & Kingstone, 2010), and a change detection task (Clark, Fleck, & Mitroff, 2011). Collectively these findings have continued to suggest that action video game experience provides players with enhanced control over the allocation of attentional resources (Hubert-Wallander, Green, & Bavelier, 2010). The work presented in this dissertation has extended these findings, demonstrating that action video game experience is also linked to improvements in oculomotor control.

Interestingly, despite the growing body of work on the effects of action video game experience, there has been little work investigating whether the cognitive benefits seen in the lab translate to more natural or complex contexts, with only a few notable exceptions. For example, Franceshini et al., (2013) demonstrated that action video game training can yield improvements in reading performance in dyslexic individuals. Studies have also revealed that prior video game experience (not specific to action video games) is correlated with laparoscopic surgery performance (Rosenberg, Landsittel, & Averch, 2005; Rosser et al., 2007; Yule et al., 2011) and improvements on various military-based tasks (Gopher, Weil, & Bareket, 1994; Kennedy, Bittner Jr., Jones, 1981; Lintern & Kennedy, 1984).

These investigations present encouraging results that action video game playing can positively affect performance in more complex contexts, however the vast majority of tasks have compared AVGP and NVGPs on traditional paradigms with very basic stimuli. Yet in light of the ubiquity of eye movements in everyday behaviour, one could argue that the demonstration that AVGPs outperform NVGPs on measures of oculomotor control supports the prediction that the attentional effects of action video game playing will generalize to more complex contexts. In an effort to further weigh in on this issue, the present investigation aimed to assess whether the improved oculomotor control demonstrated by AVGPs would generalize to a context that employed more complex and biologically relevant stimuli.

Faces, like abrupt onsets, appear to be prioritized by the attentional system. For instance, the biological importance of faces has been supported by neurophysiological evidence that has revealed a neural region, called the fusiform face area, that is preferentially biased for the processing of face information (Kanwisher, McDermott, & Chun, 1997; Kanwisher & Yovel, 2006). Behavioual evidence has also demonstrated that when viewing natural scenes that include other people, participants often are biased to attend to faces rather than other regions (Birmingham, Bischof, & Kingstone, 2008, 2009). Preferentially attending to faces would appear to serve an important function in social interactions as facial cues can provide insight into the emotion or cognitive state of others. This bias has led researchers to investigate whether committing attention towards faces operates in a purely bottom-up manner, giving rise to traditional attentional capture, or whether attending to faces is modulated by top-down attentional control. Although some evidence has been provided to suggest that faces do capture attention in a bottom-up manner (Brosch, Sander, & Scherer, 2007; Devue, Belopolsky, & Theeuwes, 2012; Langton, Law, Burton, & Schweinberger, 2008; Theeuwes & Van der Stigchel, 2002 Weaver & Lauwereyns, 2011), other evidence suggests that the prioritization of faces can be modulated by top-down control (Bindemann, Burton, Langton, Schweinberger, & Doherty, 2007; Horstmann, 2007; Ro, Russell, & Lavie, 2001). Despite the debate over the precise basis for the prioritization of face stimuli, collectively, the evidence converges on the conclusion that faces are processed preferentially by the attentional system.

Given that AVGPs were better able to resist oculomotor capture from a basic stimulus that appeared as an abrupt onset (i.e., coloured circle), the present study sought to investigate whether this advantage would extend to a context that displays more complex face stimuli. Therefore, in the present investigation, we had participants complete the same oculomotor capture paradigm used in Chapter 2 and Chapter 5

(Study 1), but replaced the basic circle stimuli with schematic faces. As faces possess a unique status within the attentional system, a number of outcomes are possible. First, as faces are generally prioritized by the attentional system, coupling a face stimulus with an abrupt onset status may make distractor inhibition so difficult that it will eliminate the AVGP advantage reported in previous chapters. Second, as differences between AVGP and NVGP performance have been reported under more demanding tasks (e.g., Green & Bavelier, 2003, 2006; Hubert-Wallader et al., 2011), including faces may accentuate the AVGP advantage over NVGPs. Alternatively, the inclusion of face stimuli may not interact with the AVGP advantage and instead give rise to an equivalent increase in oculomotor capture across groups.

It is important to note an additional manipulation on top of the change to face stimuli. Specifically, when an abrupt onset face appeared in the display, it could depict either a neutral, happy, or inverted happy face. Much of the face processing literature has revealed particular biases for emotional faces (Fox, et al., 2000; Hodsoll, Viding, & Lavie, 2011; Notebart, Crombez, Van Damme, De Houwer, & Theeuwes, 2011; Vuillermeirer, Schwartz, 2001; Williams, Moss, Bradshaw, & Mattingley, 2005); therefore, this manipulation presents a context where distractor inhibition will be even more difficult to achieve and presents a stronger test of the predictions provided above. In addition, this manipulation allowed for the assessment of the possible influence of emotional content on AVGP performance. Currently it is unclear how emotional information may differentially affect AVGPs search performance compared to NVGPs. For example, one study demonstrated that playing violent video games was associated with a reduced happy-face advantage (Kirita & Endo, 1995; Leppanen & Hietanen, 2004; Leppanen, Tenhunen, & Hietanen, 2003) when having to detect whether a neutral face changed to either a happy or angry face (Kirsh & Mounts, 2007). More recent neurophysiological evidence has also indicated that experience with action video games, due to their violent nature, is associated with reduced attention to happy faces (Bailey & West, 2013). Thus, if AVGPs are particularly insensitive to positive affect, then it is possible that the ability of a distractor to capture AVGPs' attention will be especially weak when a happy face distractor is presented relative to when a neutral or inverted face distractor is presented. Or to put it differently, the AVGP advantage for avoiding capture by irrelevant distractors will be accentuated for happy faces.

6.2 Methods

Participants

Data from 32 undergraduate male participants (18-27 years old, mean: 21.4), evenly split into AVGP and NVGP groups, recruited from the University of British Columbia, are reported. Participants were assigned to the AVGPs and NVGPs group based on the same criteria used in previous Chapters. The AVGPs sample reported an average of approximately 8.2 hours of action games per week (e.g., *Counter-Strike: Global Offense, Team Fortress 2, Battlefield 3, Call of Duty*). NVGPs reported playing no action video games but did play an average of approximately 4.4[6] hours of non-action games per week. All participants were recruited covertly, where no mention of the video game nature of the experiment was provided in the advertisement and the self-

[6] This value is higher than previous Chapters largely due to 3 NVGPs who reported playing a lot (>10hrs/week) of a specific strategy game (*League of Legends, Starcraft II*). Although previous work demonstrated improvements in executive function in an elderly sample as a result of strategy video game training, no benefits on visuospatial attention tasks were observed (Basak, Boot, Voss, & Kramer, 2008).

reported measures were collected after completing the task. All participants provided written informed consent, reported normal or corrected-to-normal vision, and received course credit or monetary compensation for their participation.

Apparatus & stimuli

The experimental setup and task design was identical to that used in Chapter 2 except for the following changes. The displays consisted of six schematic face stimuli depicting a neutral face placed along the circumference of an imaginary circle. On half of the trials, an extra visual object, depicting either a neutral, happy, or inverted happy face (Figure 6.1). The same “hobby” questionnaire used in previous chapters was again given to participants to assess past video game experience and to acquire a measure of other subjective reports (i.e., motivation, game-like nature of task).

Figure 6.1 – Happy, neutral, and inverted happy schematic face stimuli used in study.

Procedure

The procedure for the present experiment was identical to that used in Chapter 2 Trial displays presented six gray neutral faces, each at equal distances from the central fixation point. After 2500ms, all but one gray neutral face changed to blue neutral faces.

Participants were instructed that once the colour change occurred, they were to make an eye movement to the location of the remaining gray neutral face (i.e., target). On 50% of trials, an additional blue object (abrupt onset) was added to the display at the same time the colour singleton was presented. The abrupt onset depicted either a neutral, happy, or inverted happy face. After fixating the target, participants were presented with a blank screen for 150ms prior to the start of the next trial. As in Chapters 2 and 3, participants were not informed that an abrupt onset face could appear in the display.

The target face appeared at each of the possible six positions around the imaginary circle an equal number of times, with the location of the abrupt onset appearing an equal number of times at 90 or 150 degrees from the target. Whether the abrupt onset depicted a neutral, happy, or inverted happy face, was also evenly split (48 trials each). Each participant began by completing a brief practice session of 12 trials and was then questioned to confirm that they could identify the target face amongst the non-targets. Following the practice block, participants completed six experimental blocks, each consisting of 48 trials, for a total of 288 test trials.

Similar to Chapter 5, upon completing the task, participants filled out a questionnaire assessing their experience with various hobbies (video games, sports, music) in order to assess whether they met AVGP or NVGP criteria. Participants also indicated how motivated they were to perform well during the task and how much they treated the task like a video game on 7-point Likert scales.

6.3 Results

The same exclusion criteria as that used in previous chapters was applied for removing trials from any analyses This resulted in a loss of 13.8% of trials (10.3% of AVGP trials and 17.4% of NVGP trials, $p>0.05$).

Saccade accuracy

A 2 x 2 repeated measures analysis of variance (ANOVA) was conducted on overall saccade accuracy with video game experience (AVGP vs. NVGP) and onset presence (absent vs. present) as factors. Analysis revealed a main effect of video game experience ($F_{(1,30)}$ = 12.84, $p<0.01$), indicating that AVGPs demonstrated greater overall accuracy compared to NVGPs. A main effect of onset presence was also observed ($F_{(1,30)}$ = 190.59, $p<0.001$), indicating that saccade accuracy was lower in onset present vs. onset absent trials. Critically, the significant interaction between video game experience and onset presence ($F_{(1,30)}$ =5.36, $p<0.05$), reveals that AVGPs were less affected by the appearance of the abrupt face compared to NVGPs (Figure 6.2). An analysis on the proportion of onset present trials where the eyes first oriented toward the abrupt onset revealed that this interaction is a result of AVGPs experiencing less oculomotor capture (27.6%) relative to NVGPs (42.5%; $t_{(30)}$ = 2.77, $p<0.01$).

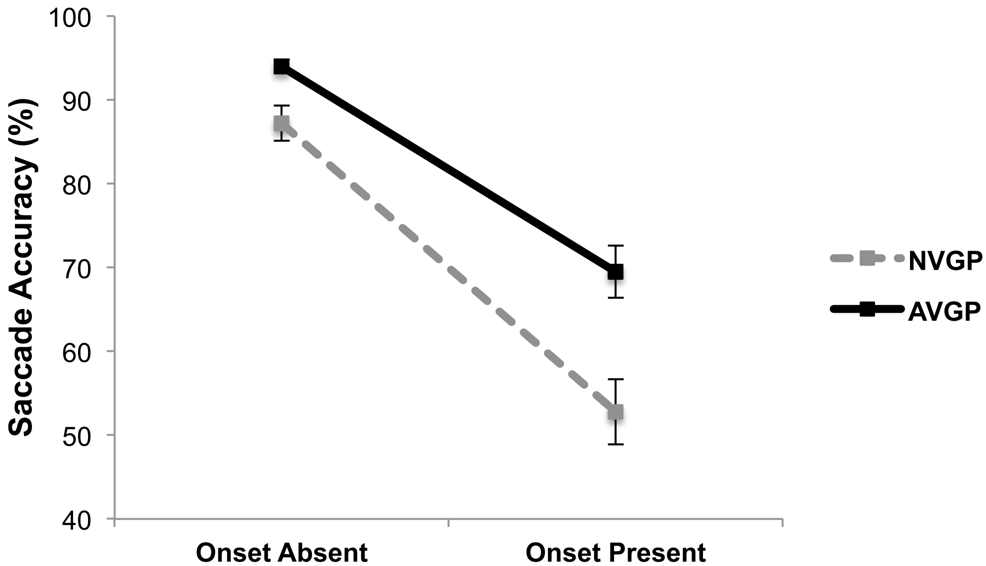

Figure 6.2 – Average AVGP and NVGP saccade accuracy across onset absent and onset present trials. Error bars represent standard error of the mean.

To assess the relative influence of the emotional content of the face stimuli on the capture of attention, a 2 x 3 repeated measures ANOVA was conducted with video game experience (AVGP vs. NVGP) and onset face (neutral, happy, or inverted happy) as factors. Analysis revealed no main effect of onset face ($F_{(2,60)}$=2.38, p>0.05) and no significant interaction between onset face and video game experience ($F_{(2,60)}$<1). However, a main effect of video game experience ($F_{(2,60)}$=7.84, p<0.01) again demonstrated reduced oculomotor capture in AVGPs, which occurred across all face types (Figure 6.3).

Figure 6.3 – Average oculomotor capture experienced by AVGPs and NVGPs across neutral, happy, and inverted face abrupt onset trials. Error bars represent standard error of the mean.

Saccade latency & saccade correction time

A 2 x 2 repeated measures ANOVA was conducted on overall saccade latency with video game experience (AVGP vs. NVGP) and onset presence (absent vs. present) as factors. For both onset absent and onset present trials, only the latencies on correct trials were included (i.e., errors and capture trials were excluded). Analysis revealed no main effect of onset presence ($F_{(1,30)}$=1.11, p>0.05), no main effect of video game experience ($F_{(1,30)}$=2.22, p>0.05), and no interaction ($F_{(1,30)}$<1, Figure 6.4).

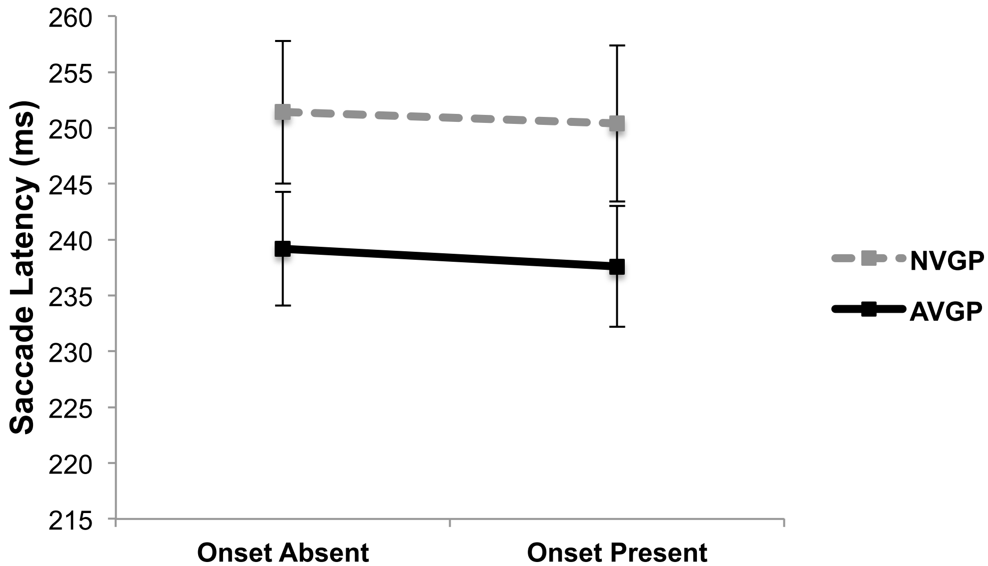

Figure 6.4 – Average AVGP and NVGP saccade latency across onset absent and onset absent trials. Error bars represent standard error of the mean.

Similar to the capture results, saccade latencies also did not differ across the different face types. Specifically, the 2 x 3 repeated measures ANOVA, with video game experience and onset face as factors, revealed no main effect of onset face ($F_{(2,60)}$=1.85, p>0.05), no main effect of video game experience ($F_{(1,30)}$=2.00, p>0.05), and no significant interaction ($F_{(2,60)}$=<1), indicating that AVGPs and NVGPs produced saccades at the same speed across conditions.

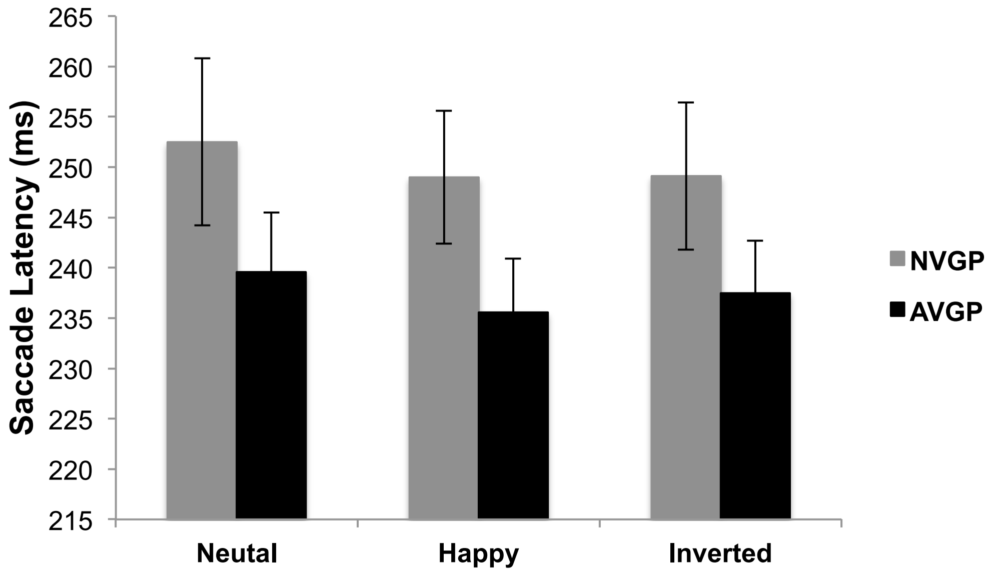

Figure 6.5 – Average AVGP and NVGP saccade latency across neutral, happy, and inverted face abrupt onset trials. Error bars represent standard error of the mean.

A final analysis was conducted to assess whether the emotional content of the onset influenced the time taken to correct a captured saccade. A 2 x 3 repeated measures ANOVA, with video game experience and onset face as factors, revealed no main effect of onset face ($F_{(2,60)}$<1), no main effect of video game experience ($F_{(1,30)}$<1), and no significant interaction ($F_{(2,60)}$<1), indicating that the emotional content of the face did not differentially affect the time needed to correct a captured saccade (Figure 6.6).

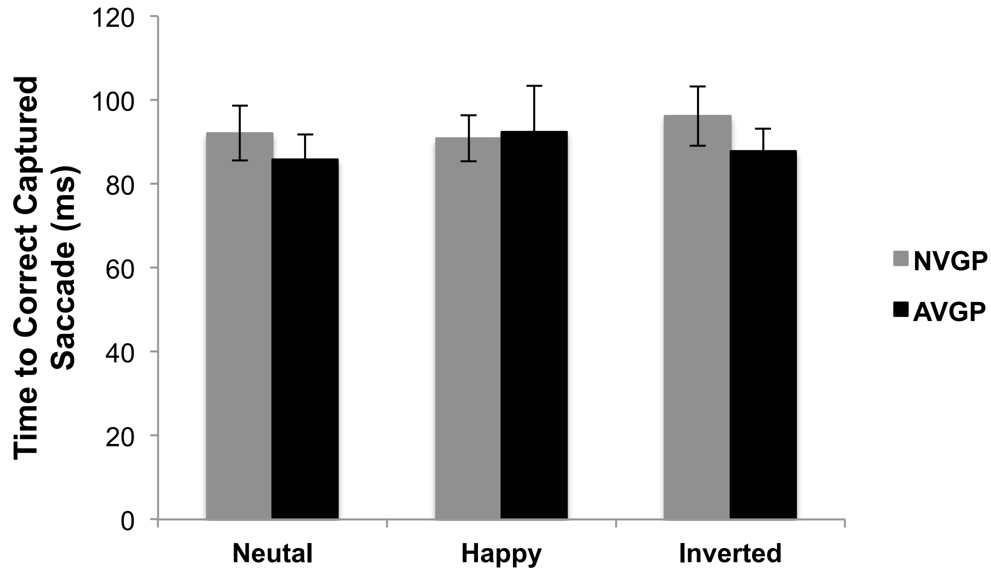

Figure 6.6 – Average time AVGPs and NVGPs took to correct captured saccades across neutral, happy, and inverted face abrupt onsets. Error bars represent standard error of the mean.

Motivation & game-like nature of task

Analyses were conducted to compare whether AVGPs and NVGPs differed in their level of motivation while completing the task and whether they conceptualized the task as more or less like a video game. Participants provided responses on a 7-point Likert scale (e.g., low values corresponding to low motivation and the task not been game-like at all and high values corresponding to high motivation and the task being very game-like). Analysis of these data revealed no differences in motivation across groups (AVGPs=5.94, NVGPs=5.47, $t_{(30)}$=1.37, p>0.05). AVGPs also did not consider the task to be any more like a video game compared to NVGPs (AVGPs=5.13, NVGPs=4.22, $t_{(30)}$=1.39, p>0.05).

6.4 Discussion

The results revealed that AVGPs experienced less oculomotor capture by the abrupt appearance of a task-irrelevant face stimulus. This finding represents another replication of the findings reported in Chapters 2 and 3, providing further evidence for the reliability of improved oculomotor control in AVGPs under the conditions of covert recruitment.

A primary aim of the present investigation was to assess whether adding biologically relevant information to an oculomotor capture paradigm would differentially affect AVGP and NVGP performance. Given that faces receive attentional priority (e.g., Birmingham, et al., 2008; Fox, et al., 2000; Langton, et al., 2008; Ro, et al., 2001), it was unclear whether presenting face stimuli in the previously employed oculomotor capture task would eliminate, accentuate, or have no effect on the previously reported AVGP performance advantage over NVGPs. To evaluate the prediction of whether the inclusion of face stimuli interacts with action video game experience, the results of the present investigation were compared to those of Chapter 2 (i.e., identical paradigm minus face stimuli). The results of this analysis reveal that although the inclusion of face stimuli increased overall capture (26.1% with basic stimuli vs. 35.0% with face stimuli, $F_{(1,71)} = 6.15$, $p<0.05$), this increase did not interact with video game experience ($F_{(1,71)} < 1$). Therefore, although the inclusion of face stimuli made it more difficult to inhibit distraction, both AVGPs and NVGPs were equally affected by this manipulation. Ultimately, the fact that AVGPs experienced less oculomotor capture when biologically relevant information was present in the display, compared to basic stimuli, provides evidence that that the improvements in attentional and oculomotor control associated with action video game experience generalize to contexts that present more complex or natural stimuli.

Interestingly, manipulating the emotional content of the abrupt onset had no impact on performance. Both groups experienced the same amount of oculomotor capture whether the abrupt onset was a neutral, happy, or inverted happy face. Saccade latency and the time needed to correct a captured saccade also did not differ as a function of emotional content. These findings argue against AVGPs demonstrating less sensitivity to happy faces (Bailey & West, 2013; Kirsh & Mounts, 2007); however, they are also inconsistent with previous reports suggesting that emotional faces attract attention more than neutral faces (Fox, et al., 2000; Hodsoll, et al., 2011; Notebart, et al., 2011; Vuillermeirer, Schwartz, 2001; Williams, et al., 2005). Instead, the present results appear in line with a recent report indicating that emotional content does not draw attention unless emotion is a search-relevant feature (Hunt, Cooper, Hungr, & Kingstone, 2007). Given that the target was defined as a unique colour singleton and emotion was irrelevant to the search task, participants may have adopted a specific search strategy for a colour singleton (Bacon & Egeth, 1994; Folk, Remington, & Johnston, 1992) allowing them to disregard the content of the distractor.

It is worth noting that much of the literature investigating the impact of emotional faces on search performance has demonstrated that the visual system is also particularly sensitive to the appearance of threatening faces (e.g., Bannerman, Milders, de Gelder, & Sahraie, 2009; Fox, Russo, & Dutton, 2002; Hansen & Hansen, 1988; Notebaert et al., 2011; Ohman, Lundqvist, & Esteves, 2001; Williams et al., 2005). A happy face distractor was chosen because previous work had suggested that AVGPs were less sensitive to positive affect (Bailey & West, 2013; Kirsh & Mounts, 2007); however, additional neurophysiological evidence has been provided that AVGPs may be *more* sensitive threat related content (Bailey, West, & Anderson, 2011). This observation was again attributed to players' extensive exposure to the violent content of action video games and the fact that while playing action video games, players must constantly monitor for the appearance of potential threats. Therefore, one avenue for future work would be to assess the influence of threatening faces in the present context on AVGP performance.

Conclusion

In Chapter 5, when covert recruitment was used and groups did not differ in motivation or whether they treated the task like a video game (Boot, Blakely, & Simons, 2011; Kristjansson, 2013), no differences were observed in target selection between AVGPs and NVGPs. In contrast to being a result of the provided awareness instruction, these findings instead raised some concern regarding the reliability of the proposed improved oculomotor control in AVGPs. In the present investigation, we established the same controls; however, critically still demonstrated an AVGP advantage in oculomotor control. Specifically, despite using a covert recruitment strategy and showing no differences across groups in terms of motivation and whether they treated the task like a video game, a significant AVGP performance benefit was observed. Given the present results, we can feel more confident in the reliability of the reported effect and our interpretation of the findings in Chapter 5.

In summary, the results of the present experiment demonstrate that AVGPs experienced less oculomotor capture by an abrupt onset compared to NVGPs when biologically relevant stimuli were added to the display. This finding provides the third instance where we have demonstrated improved oculomotor control in AVGPs and, importantly, this effect was not associated with differences in motivation or how either group approached the task. We also demonstrated that the inclusion of face stimuli increased capture relative to when non-face stimuli were used; however, manipulating the emotional content of the abrupt onset had no effect on AVGP and NVGP performance. Consistent with past work (Hunt et al., 2007), we have suggested that the emotional content of the distractor was less effective in capturing attention because it was completely irrelevant to the search task. Although, more research is needed, the present results provide some encouraging results that the performance benefits demonstrated by AVGPs can scale up to contexts that involve more complex and natural stimuli.

7 A test of the learning to learn account of AVGP performance benefits

7.1 Introduction

Up to this point, the performance benefits demonstrated by AVGPs have been discussed exclusively in terms of improvements in attentional control. Specifically, I have argued that the improved oculomotor control demonstrated by AVGPs reflects a more efficient allocation of attentional resources toward satisfying task goals. This benefit has manifested as fewer reflexive saccades generated toward an abrupt onset distractor. This attention-based benefit also provides an account for faster manual response times when discriminating between a relatively difficult left/right decision as attention can enhance the signal of attended information (e.g. Carrasco, Ling, & Read, 2004; Carrasco & McElree, 2001; Carrasco, Penpeci-Talgar, & Eckstein, 2000). The attention-based account for the differences in AVGP and NVGP performance is very well supported by the literature on the effects of action video game experience. The vast majority of studies have demonstrated AVGP benefits in tasks that require the engagement of selective attentional processes. As previously reviewed, AVGPs demonstrate improvements in contrast sensitivity (Li, Polat, Makous, & Bavelier, 2009), multiple object tracking (Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Green & Bavelier, 2006b; Trick, Jasper-Fayer, & Sethi, 2005), visual search performance (Castel, Pratt, & Drummond, 2005; Chisholm, Hickey, Theeuwes, & Kingstone, 2010; Hubert-Wallander, Green, Sugarman, & Bavelier, 2011), spatially distributing attention (Dye & Bavelier, 2010; Green & Bavelier, 2003, 2006a; Feng, Spence, & Pratt, 2007), speed of information acquisition (Appelbaum, Cain, Darling, & Mitroff, 2013; Pohl et al., 2014; Wilms, Petersen, & Vangkilde, 2013), and distractor suppression (Krishnan, Kang, Sperling, & Srinivasan, 2013; Mishra, Zinni, Bavelier, & Hillyard, 2011). However, despite the evidence in favour of an attention-based account being the cause of AVGP benefits, a competing proposal has recently emerged which has approached the benefits demonstrated by AVGPs from a framework centered on perceptual learning.

Green, Li, and Bavelier (2010), proposed that much of the effects demonstrated by action gamers are consistent with behavioural models of perceptual learning. Coupled with this, they highlighted how video game experience itself provides many of the features that are thought to encourage more generalized perceptual learning. For example, action video games often engage a certain level of enjoyment and arousal (Hébert, Béland, Dionne-Fournelle, Crête, & Lupien, 2005; Segal & Dietz, 1991), provides increasing challenge (Ahissar & Hochstein, 1997), and affects neural regions associated with reward, such as the striatum (Kuhn et al., 2011; Koepp et al., 1998). Therefore, as action video games present a more dynamic and complex context, it is possible that rather than enhancing processes that are highly specific to the training environment (Fahle, 2005), they benefit processes that generalize to different situations (Byers & Serences, 2012; Sireteanu & Rettenbach, 1995, 2000).

Within this framework, Green, Li, and Bavelier (2010) highlight that neural models of perceptual learning tend to implicate sensory signal enhancement/sharpening or noise reduction, which they propose, could allow AVGPs to learn to be more efficient in extracting information relevant to improving task performance (i.e., task relevant statistics). According to this account, the generalization of AVGP benefits emerges from the ability to adjust neural networks or “templates” on a task-by-task basis, allowing AVGPs to better adapt to various situations. This perceptual-learning based account suggests that increased efficiency in extracting information relevant to one's task is what allows AVGPs to produce quicker or more accurate perceptual decisions. The finding that AVGPs show improvements in performing probabilistic inferences has provided support for this account. That is, on coherent motion dot and auditory tone discrimination tasks, AVGPs were better able to extract and integrate task related sensory information, allowing them to make more efficient perceptual decisions (Green, Pouget, & Bavelier, 2010). Some neurophysiological evidence has also been provided to suggest improved perceptual decisions in AVGPs. An investigation by Mishra et al. (2011) revealed a difference in the amplitude of the P3 ERP component between AVGPs and NVGPs when covertly detecting a target presented in central or peripheral visual streams. Although the amplitude of the P3 component is traditionally considered to index the amount of attention allocated to a given stimulus (Johnson, 1988; Mangun & Hillyard, 1990), Mishra et al., argued that the difference observed between AVGPs and NVGPs could reflect enhanced confidence in AVGPs' decisions.

Over the last several years the perceptual-learning based account has developed to argue now that action video game experience leads to generalized performance enhancements due to AVGPs capacity for "learning to learn" (term taken from Kemp, Goodman, & Tenenbaum, 2010). The learning to learn account argues that performance on any task improves over time as a result of making use of task related information extracted through the process of being exposed to the task (Bavelier, Green, Pouget, & Schrater, 2012; Green & Bavelier, 2012). This has been suggested to include more efficient acquisition of generalized task knowledge, which can be used to more effectively engage various processes to improve task performance (e.g., better suppression of task relevant information while focusing on task-relevant information). Thus, this account ultimately suggests that action video games enable AVGPs to learn to extract relevant task information in order to enhance the speed/efficiency at which they learn to perform a task. Training such higher-level cognitive processes, rather than lower level perceptual processes, provides an explanation for how action gamers are able to transfer the skills learned from the video game environment to other tasks. In line with this account, neuroimaging studies have highlighted an anatomical impact of video game experience that could give rise to improvements in learning rates. For example, using positron emission tomography, Koepp et al. (1998) demonstrated significant increases in the release and binding of dopamine in the striatum during video game playing. Although not specific to action video games, video game playing in general has also been associated with increases in (left) striatal grey matter volume (Kuhn et al., 2011). Striatal volume appears not only affected by gaming but also appears to predict learning on a video game task (Erickson et al., 2010).

One appealing aspect of the learning to learn proposal is that it makes a very clear prediction in terms of how AVGPs come to outperform NVGPs. Specifically, if improved performance is based on adapting to a given situation, then some amount of exposure to that situation would be necessary prior to the emergence of any hypothesized neural tuning or observable behavioural benefits. Providing experience on the task or with specific stimuli would thus be required in order to allow individuals to learn how to perform the task more efficiently. Without such exposure, whether someone is an AVGP or not, one would be unable to adapt how they respond to stimuli that has yet to be presented. Therefore, at the beginning of any task, where AVGPs and

NVGPs have received no exposure to the stimuli, the learning to learn proposal predicts that there should be no differences in how the two groups perform. It is only over time that a difference should emerge. As AVGPs are expected to extract the task related information more efficiently or quickly, then they should only begin to outperform NVGPs as the task progresses. This proposal suggests that the typical main effects demonstrated between actions and non-gamers should actually reflect an interaction over time. In other words, the two groups should demonstrate equal performance during the early portion of a task and then diverge at some later point.

Bavelier et al. (2012) and Green & Bavelier (2012) acknowledge the breadth of evidence implicating enhancements in attentional processing; however, they suggest that enhanced attentional control acts simply as the vehicle by which learning can occur rather than the direct cause of the performance benefits. In other words, through enhanced attentional control, AVGPs are better able to extract task relevant information, giving rise to quicker improvement of performance on a task over time. However, to the best of my knowledge, only some preliminary evidence (Zhang et al., 2012) along with one published paper (West, Al-Aidroos, & Pratt, 2013) has provided any empirical support for the learning to learn proposal. West et al., who also investigated oculomotor control in AVGP via a saccade trajectory deviation task, demonstrated that both AVGPs and NVGPs produced an equal number of errors during the first half of the experiment, however, during the second half, AVGPs produced fewer errors compared to NVGPs[7].

[7] The import of this finding is questionable, however, as "errors" were not just failure to saccade to the correct location. Failure to fixate center at the start of a trial as well as failure to initiate a saccade before timeout occurred were also included in this measure. At present a fuller breakdown is required.

Aside from these reports, there is very little evidence available to evaluate the learning to learn proposal.

The purpose of the present chapter is to provide a test of the learning to learn proposal. To this end, a meta-analysis of data from all previous chapters comparing AVGPs and NVGPs was conducted. To test the prediction put forth by the learning to learn proposal, time-course analyses were conducted to assess how AVGP and NVGP performance does or does not differ over time. In addition to analyzing the previously reported significant findings (i.e., oculomotor capture and manual response times), other, previously non-significant measures were also subjected to a time-course analysis, as it is possible that with increased power previously non-significant effects may now be revealed as significant.

7.2 Methods

Sample & procedure

The meta-analysis included all the participants reported in previous chapters that compared AVGP and NVGP performance. This produced a sample of 192 male participants – 97 AVGPs and 95 NVGPs. All participants were included to assess the oculomotor capture and the selection-based measures; however, only a smaller subset of these data was included in the analysis of manual response performance (42 AVGPs and 43 NVGPs) because not all the experiments involved a manual response.

In order to conduct the time-course analyses, saccade accuracy, saccade latency, oculomotor capture, and manual response time were computed across each of the first 4 experimental blocks of trials. On average, each block consisted of 30-40 trials (split among onset absent and onset present trials) and participants took approximately 5-10 minutes to complete a block.

7.3 Results

Oculomotor capture

A 2 x 4 analysis of variance (ANOVA) was conducted on oculomotor capture with video game experience (AVGPs vs. NVGPs) and blocks (1,2,3,4) as factors. The time-course analysis revealed a significant main effect of block ($F_{(3,570)} = 12.85$, $p<0.001$) and video game experience ($F_{(1,190)} = 9.00$, $p<0.01$); however, no interaction was observed ($F_{(3,570)} < 1$). These results indicate that, overall, oculomotor capture decreased across blocks and AVGPs experienced significantly less capture than NVGPs, but this difference remained constant across blocks (Figure 7.1). To further evaluate the learning to learn proposal, multiple comparisons were performed to assess AVGP and NVGP performance at each block. A Bonferonni correction was applied to maintain family-wise error at $\alpha_{\text{FWE}} = 0.05$. This resulted in an adjusted alpha level of $\alpha_{\text{B}} = 0.0125$. These analyses revealed that a significant AVGP advantage during Block 1 ($t_{(192)} = 2.66$, $p<0.01$), Block 2 ($t_{(192)} = 2.93$, $p<0.01$), Block 3 ($t_{(192)} = 3.01$, $p<0.01$), and an effect that brushes significance in Block 4 ($t_{(192)} = 2.49$, $p<0.015$).

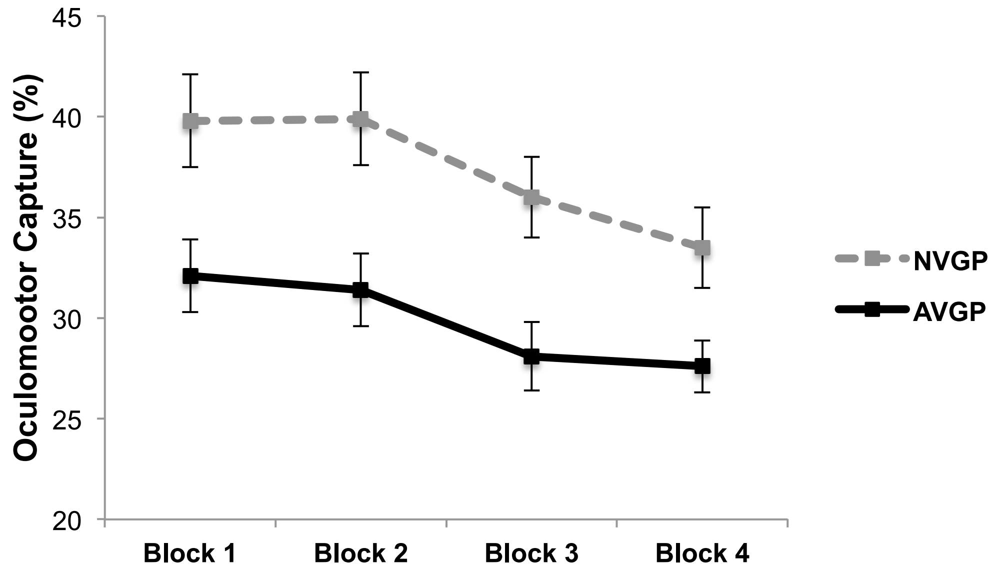

Figure 7.1 – Average AVGP and NVGP oculomotor capture across Blocks. Error bars represent standard error of the means.

Manual response

A 2 x 2 x 4 ANOVA was conducted on manual response time (RT) with onset presence (absent vs. present), video game experience (AVGPs vs. NVGPs) and blocks (1,2,3,4) as factors. The results revealed a main effect of onset presence ($F_{(1,255)}$ = 4.13, p<0.05), video game experience ($F_{(1,85)}$ = 18.25, p<0.001), and block ($F_{(1,255)}$ = 6.58, p<0.001). None of the interactions were significant (all *p'*s>0.05), including the video game experience x block interaction ($F_{(1,255)}$ = 1.89, p>0.05; Figure 7.2). These results revealed that manual RT was slower on onset present trials (398ms) compared to onset absent trials (394ms) and that manual RT performance improved across blocks. Critically, AVGPs demonstrated an overall manual RT advantage over NVGPs and this did not interact with block. To again further evaluate the learning to learn proposal, multiple comparisons were performed to compare AVGP and NVGP performance at each block. The same Bonferonni correction reported above was also applied. These analyses revealed that a significant AVGP advantage during Block 1 ($F_{(1,85)}$ = 16.29, p<0.001), Block 2 ($F_{(1,85)}$ = 21.46, p<0.001), Block 3 ($F_{(1,85)}$ = 12.49, p<0.01), and Block 4 ($F_{(1,85)}$ = 9.97, p<0.01).

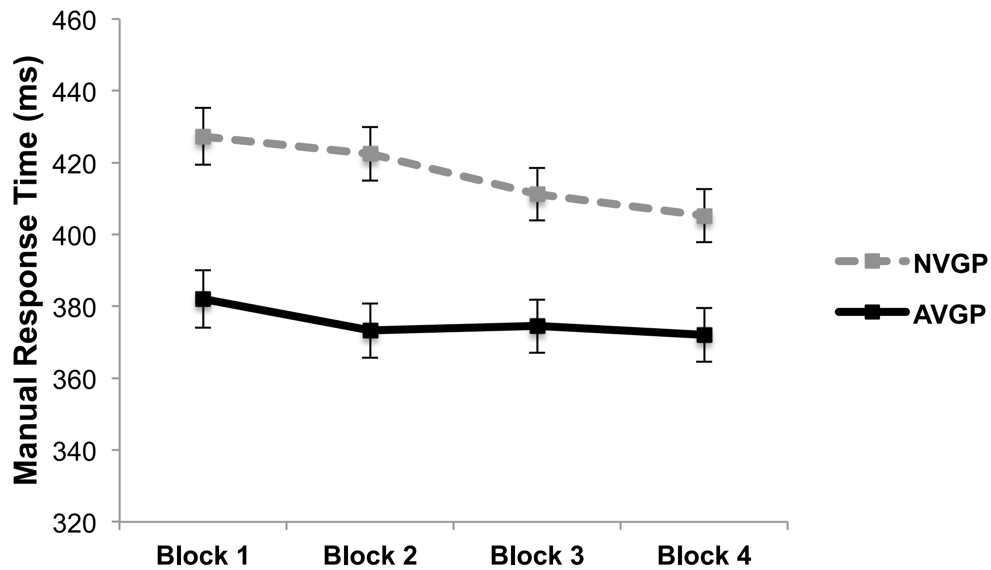

Figure 7.2 – Average AVGP and NVGP manual responses (collapsed across onset absent and present trials) across blocks. Error bars represent the standard error of the means.

Saccade accuracy

A 2 x 4 ANOVA was conducted on saccade accuracy with video game experience (AVGPs vs. NVGPs) and blocks (1,2,3,4) as factors. The time-course analysis of saccade accuracy when no abrupt onset appeared in the display revealed a main effect of block ($F_{(3,576)}$ = 11.56, p<0.001), a marginal effect of video game experience ($F_{(1,192)}$ = 3.23, p<0.08) but no significant interaction ($F_{(3,576)}$ = 1.03, p>0.05, Figure 7.4). These results reveal that saccade accuracy improved across blocks and, although AVGPs show a marginal benefit over NVGPs, this difference does not change across blocks.

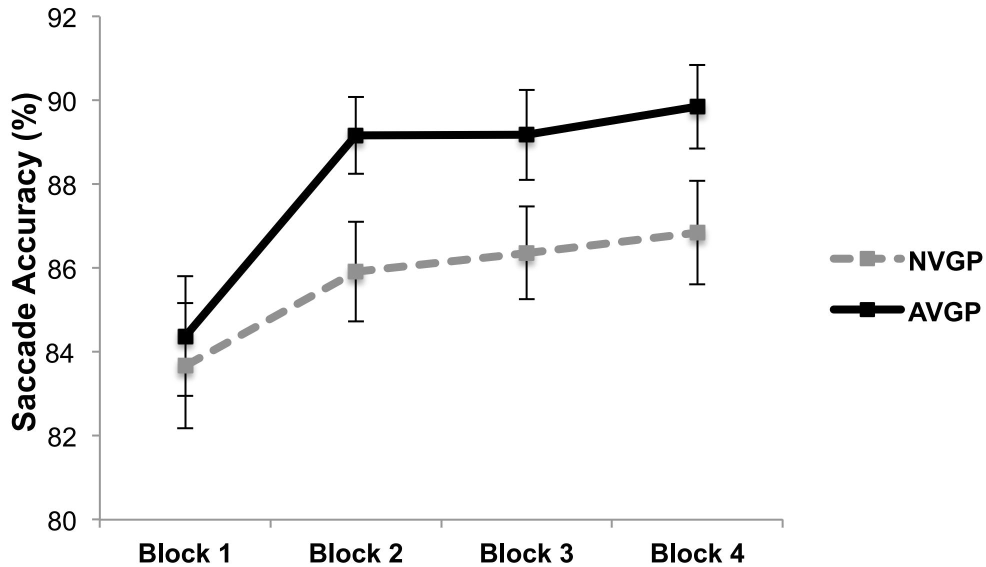

Figure 7.3 – Average AVGP and NVGP saccade accuracy across blocks. Error bars represent the standard error of the means.

Saccade latency

A 2 x 2 x 4 ANOVA was conducted on saccade latency with onset presence (absent vs. present), video game experience (AVGPs vs. NVGPs) and blocks (1,2,3,4) as factors. The results revealed a main effect of block ($F_{(1,576)}$ = 46.88, p<0.001) and a marginal effect of video game experience ($F_{(1,576)}$ = 2.87, p<0.10). No other main effects or interactions were significant (all p's > 0.05), including the video game experience x block interaction ($F_{(1,576)}$ = 1.39, p>0.05, Figure 7.4). These results revealed that saccade latency improved across blocks and that AVGPs produced marginally faster saccades than NVGPs; however, this advantage was constant across blocks.

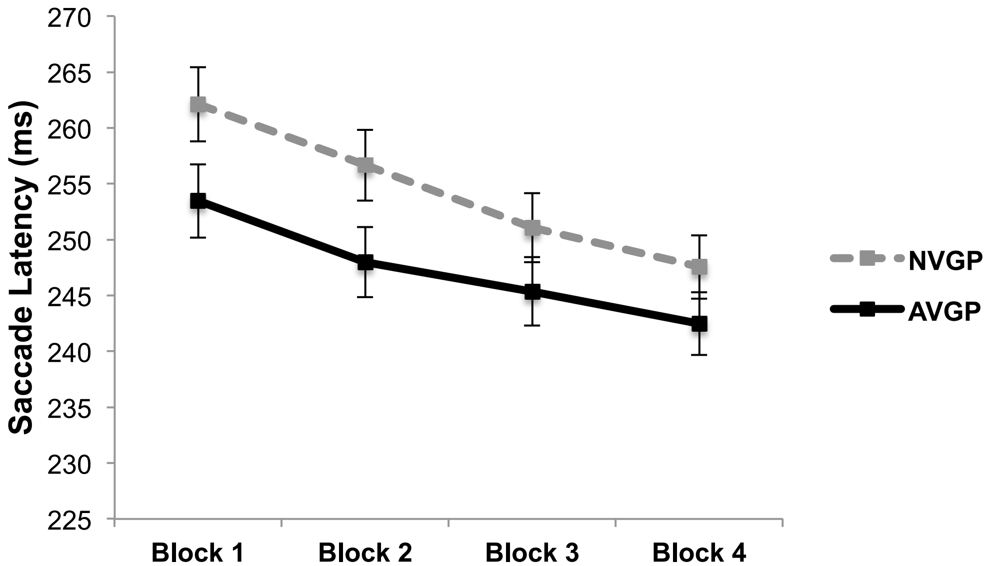

Figure 7.4 – Average AVGP and NVGP saccade latency (collapsed across onset absent and onset present trials) across blocks. Error bars represent the standard error of the means.

7.4 Discussion

The present study conducted a number of analyses to test the learning to learn account of AVGP benefits (Bavelier, et al., 2012; Green & Bavelier, 2012). This account proposes that the improvements in performance demonstrated by AVGPs are based an ability to adapt more quickly to task demands over time. As exposure to task parameters are necessary for learning to occur, both AVGPs and NVGPs enter the task with the same amount of task knowledge and thus performance is predicted to be equal across groups early in time. However, as AVGPs demonstrate a greater propensity for extracting and making use of task-relevant information (Green et al., 2010), differences are predicted to emerge later in time, after sufficient learning has occurred.

The present results are inconsistent with the learning to learn proposal. The time-course analysis of oculomotor capture across groups revealed that AVGPs outperformed NVGPs at the outset of the task (i.e. Block 1) and this benefit persisted steadily throughout the experiment. This same pattern of results was observed for manual response times. Therefore, the previously reported AVGP advantage, reported as main effects, in avoiding capture (Chapters 2, 3, and 6) and manual response times (Chapters 3 and 5), did not mask any differences in performance across time.

Despite previous reports showing no AVGP and NVGP differences in terms of saccade accuracy and saccade latency, time-course analyses were also performed on these measures as it remained possible that an interaction between gamer status and block could emerge even if the overall means did not differ. The results of analyzing saccade accuracy when no distractor appeared in the display revealed a pattern of results that trended toward what the learning to learn account predicted: that is, performance was more aligned during Block 1 and deviated by Block 2. However, there was no main effect of video game experience and no significant interaction which fails to provide support for the learning to learn account.

Together, the present results indicate that the learning to learn (Bavelier et al., 2012; Green & Bavelier, 2012) proposal does not provide a satisfactory account of how AVGPs outperform NVGPs. Instead, I would argue that the results are in line with an attention-based account. Given the relationship between controlled attention and learning (Byers & Serences, 2012), it is likely that improved attentional processing could yield improved learning on a novel task. However, the present study clearly demonstrates that differential learning rates do not account for the reported benefits in AVGP performance. Instead, if action video game experience trains players to possess more efficient control over attentional processes (Hubert-Wallander, Green, & Bavelier, 2010), when presented with a task, this is a skill they presumably are able to engage from beginning to end. As a result, one could argue that action video game experience trains attention-based enhancements that improve the baseline level of performance seen in AVGPs.

The learning to learn proposal could argue that the differences between AVGPs and NVGPs emerged very early during Block 1 or from practice alone. That is, after only very minimal exposure AVGPs learn how to succeed on the task, and that difference is solidified from that point onwards. An extreme case could even suggest that exposure to a single trial or a visual example of a trial prior to beginning the task is sufficient to induce learning in AVGPs. However, this rapid snapshot form of information acquisition is not currently articulated by the learning to learn account, and would represent a strong departure from its current formulation, as it proposes that improvements emerge from the accumulation and integration of information over time. That said, a cursory look at the practice data in the present thesis suggests that AVGPs are still numerically outperforming NVGPs at this initial stage of the task; however, given the small number trials (i.e., 12 trials at best, split across two trial types) it is difficult to put any strong claims on this finding.

Conclusion

The present investigation demonstrated two measures where AVGPs outperformed NVGPs – oculomotor capture and manual responses. Time-course analyses of these measures revealed that AVGPs were outperforming NVGPs as soon as Block 1 and this advantage persisted throughout the entire task. This pattern of results is inconsistent with the predictions put forth by the recently proposed learning to learn account (Bavelier, et al., 2012; Green & Bavelier, 2012), which has argued that the mechanism subserving AVGP performance benefits is one of differential learning rates. Instead, the presented data is readily accommodated by the prevailing explanation that AVGPs possess more efficient attentional control.

8 General discussion

The present dissertation has provided evidence for individual differences in oculomotor control. Specifically, this work has revealed an association between extensive action video game experience and the ability to suppress distraction by salient visual onsets. By employing a paradigm that allows for a measure of overt attentional allocation, this work aimed to answer 4 main questions (see Chapter 1), related to understanding the performance benefits demonstrated by AVGPs. Below I use the results acquired from the reported studies to address these questions.

8.1 Do the performance benefits demonstrated by AVGPs in covert tasks extend to overt attention?

To date the vast majority of research investigating differences in AVGP and NVGP performances have employed covert attention tasks (e.g., Chisholm, Hickey. Theeuwes, & Kingstone, 2010; Feng, Spence, & Pratt, 2007, Green & Bavelier, 2003, 2006a, 2006b, 2007; Hubert-Wallander, Sugarman, Green, & Bavelier, 2011, Li, Polat, Makous, & Bavelier, 2009). Although there is a coupling between covert and overt attention (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler, Anderson, Dosher, & Blaser, 1995; Moore & Fallah, 2001; Rayner, McConkie, & Ehrlich, 1978; Shepard, Findlay, & Hockey, 1986; Van der Stigchel & Theeuwes, 2007), whether the observed attentional benefits extend to overt attention was very much an outstanding question. Some work has allowed AVGPs to make eye movements while completing a given task, but oculomotor behaviour was never the focus of the investigation (e.g., Castel, Pratt, & Drummond, 2005; Clark, Fleck, & Mitroff, 2011). To the best of my knowledge, aside from the work in the present dissertation, only one other study focused on the oculomotor effects of action video game experience. Specifically, West, Al-Aidroos, and Pratt (2013) compared AVGPs and NVGPs performance in a saccade trajectory task. Saccade deviation was measured across of saccade latency bins. Although only a marginal interaction was observed (p=0.10), the results revealed that both AVGPs and NVGPs produced identical behaviour at the fastest time bin (approximately 175ms), but AVGPs demonstrated greater distractor inhibition at longer saccade latencies (latencies longer than 200ms). In contrast to the inhibition reflected in saccade trajectories, West et al. also observed that AVGPs and NVGPS had the same number of saccades landing on the distractor stimulus. Therefore, although these findings provide some evidence of oculomotor differences in AVGPs, it has yet to be sufficiently established that the performance benefits demonstrated by AVGPs generalize to tasks that required overt attention.

Results from 4 studies in the present work (Chapters 2, 3, 5b, and 6) provide compelling evidence that the benefits observed by AVGPs in covert tasks extend to an overt task. Although AVGPs and NVGPs did not differ in saccade latencies when a distractor appeared, AVGPs consistently demonstrated less oculomotor capture by an abrupt onset distractor. This finding presents an overt representation of the reduced attentional capture observed in the conceptually similar covert attention singleton task (Chisholm et al., 2010). Although not specific to oculomotor behaviour, the benefit in manual responses seen in Chapters 3 and 5b also replicates one of the most consistent findings in the action video game literature (Dye, Green, & Bavelier, 2009b). That is, AVGPs consistently demonstrate faster response times without yielding any additional cost to response accuracy.

The results of the present dissertation thus maps on very well to the findings reported when covert attention tasks were employed and demonstrate that the AVGP benefits observed in covert tasks do generalize to overt attentional/oculomotor control. These findings highlight the utility of overt attention paradigms as a novel tool to further our understanding of how AVGPs may be able to outperform NVGPs. For example, as demonstrated in the present dissertation, overt attention paradigms can provide a more direct measure of the allocation of spatial attention to investigate the proposed attention-based mechanism(s) subserving the enhanced performance demonstrated by AVGPs.

8.2 What is the basis for reduced distraction in AVGPs?

The literature to date has suggested that AVGPs outperform NVGPs because they possess improved or more flexible control over the allocation of attentional resources (Hubert-Wallander, Green, & Bavelier, 2010). However, given that the concept of “better control of resources” on its own is fairly nebulous, coupled with the fact that in covert attention tasks, attentional processes must be inferred from manual response times, it can be unclear how “better control” actually gives rise to improvements in behaviour. Take as an example my MA work, where AVGPs experienced less attentional capture than NVGPs in a singleton paradigm (Chisholm et al., 2010). Although attentional capture is thought to occur as a result of attention being spatially allocated to the distracting stimulus (Hickey, Mcdonald, & Theeuwes, 2006;

Theeuwes, 1991, 1992; Theeuwes & Burger, 1998), such an account has also argued that capture is insensitive to top-down attentional processes (Bacon & Egeth, 1994; Folk, Remington, Johnston, 1992; Leber & Egeth, 2006). Therefore, as capture is indexed by differences in reaction time between distractor present and absent trials, although it was clear that AVGPs demonstrated less capture, it was unclear how this occurred. Consistent with a bottom-up account of capture (i.e., that capture occurs independent of any top-down control processes, e.g., Theeuwes, 1991, 1992, 2004), both AVGPs and NVGPs could have experienced the same amount of attentional capture; however, AVGPs engaged enhanced attentional control retroactively to recover and reorient attention to the target more quickly than NVGPs. An alternative account of the data suggested that AVGPs were instead able to engage attentional control proactively in order to avoid allocating attention to the spatial location of the distractor. Therefore, two possible accounts were provided that could not be resolved with a covert task.

The use of the oculomotor capture paradigm was critical in addressing this question for two primary reasons. First, as covert and overt attentional capture is believed to be governed by the same orienting mechanism, the use of an oculomotor capture task provides a conceptual replication of the additional singleton paradigm. This allowed for a more direct comparison of the present findings with those reported from a similar covert task. Second, the oculomotor capture paradigm requires that participants select targets via an eye movement. Given the link between covert and overt attention when eye movements are executed (e.g., Hoffman & Subramaniam, 1995; Moore & Fallah, 2001; Van der Stigchel & Theeuwes, 2007), this allowed for a direct measure of where participants allocated attention. With such an overt measure of attention, a direct comparison of the two aforementioned accounts of how AVGPs outperform NVGPs on a capture task could be performed.

Results from Chapter 2 provided an answer into the basis for the reduced capture demonstrated by AVGPs. Specifically, AVGPs made fewer incorrect eye movements toward the appearance of a task-irrelevant distractor. This finding is consistent with the proactive account presented above which proposed that AVGPs reduced capture by preventing attention from being spatially allocated to the distracting stimulus. Collectively, the evidence suggests that being better able to avoid salient but task-irrelevant visual distractions is a reliable benefit associated with action video game experience.

Having established that AVGPs engage attentional control to avoid attending to the spatial location of distracting stimuli, Chapter 3 aimed to dig further into the basis for this benefit. Specifically, Chapter 3 assessed whether reduced capture was a result of enhancements in target selection or in response-based processes. As covert tasks index attentional processes via manual responses, and a strictly oculomotor capture task (i.e., saccade responses only) also confounds selection and response, it is difficult, to distinguish between target selection based processes and response or decision based processes. By adding a manual response to the end of the oculomotor capture task, this allowed for the independent measurement of these two processes. That is, target selection processes were indexed by oculomotor behaviour (i.e., accuracy, latency) and response processes were indexed by manual response reaction times. Results from Chapter 3 revealed that AVGPs demonstrated improvements in both selection and response processes. Improvements in selection presumably underlined AVGPs' reduced oculomotor capture and provide a possible basis the improved target detection in previous work (e.g., Dye, Green, & Bavlier, 2009a; Feng et al., 2007; Green & Bavelier, 2003, 2006a, West, Stevens, Pun, & Pratt, 2008). In addition, improvements in response processes are also consistent with previous work demonstrating faster perceptual decisions in AVGPs (Green, Pouget, Bavelier, 2010). Therefore, the present dissertation provides evidence that the basis for reduced capture in AVGPs is a result of improved target selection-based processes that help prevent incorrect saccades/attentional shifts to the spatial location of distracting stimuli.

Finally, Chapter 5 provided critical insight into the basis for the general improvements in AVGP performance. Based on the fact that in Chapters 2 and 3 participants were not made aware that an abrupt onset could appear in the display and the findings from Chapter 4 which demonstrated that distractor awareness is linked to reduced oculomotor capture, Chapter 5 assessed whether the benefits demonstrated by AVGPs could be accounted for by their being more aware of distracting information. By making all participants aware that a distractor could appear in the display, the AVGP benefits previously seen in Chapters 2 and 3 were eliminated. As proposed in Chapter 4, when unaware of potentially distracting information, individuals are unable to engage conscious prefrontal-based inhibitory control, leaving them more susceptible to distraction. However, being aware of such information allows for prefrontal processes to inhibit the reflexive saccade behaviour, reducing the likelihood of being capture. This account is consistent with previous work demonstrating a benefit associated with distractor awareness (Kramer, Hahn, Irwin, & Theeuwes, 2000) as well as work showing increases in reflexive saccades under increased cognitive load (Roberts, Hager, & Heron, 1994). Therefore, the observation that making participants aware of the distracting information benefited NVGP oculomotor performance but had no effect on AVGPs is consistent with the notion that AVGPs were generally more aware of the distracting information, allowing for greater inhibition of the distracting information.

However, a result was observed where AVGPs experienced less oculomotor capture even when they reported being unaware of the distracting information (see Figure 5.4.1). Although this finding presents a potential peculiarity for an awareness-based account of AVGP improvements, it was noted that assessing participants' awareness post-hoc depends on one's ability to explicitly recall a particular event. That is, research has demonstrated that individuals can respond to visual stimuli without possessing conscious awareness of those stimuli (e.g., hemispatial neglect; Berti & Rizzolatti, 1992; Driver & Mattingley, 1998; blindsight, Weiskrantz, 1986; 1996). More on point with the case of action video game experience, research has suggested that when one is an expert in a particular domain, behaviour can be guided by knowledge that is difficult to express (Berry, 1987; Berry & Broadbent, 1984; Berry & Dienes, 1993; Cleeremans, Destrebecqz, & Boyer, 1998; Leprohon & Patel, 1995; Stanley, Mathews, Buss, & Kotler-Cope, 1989). For example, Berry and Broadbent (1984) demonstrated that as participants became more practiced at a task, performance improved but they were no better at answering questions related to how they were managing to improve on the task. Further demonstrating a dissociating between explicit and implicit knowledge, other work has revealed that despite the performance benefits demonstrated by experts, they are often not aware of or able to explicitly verbalize the factors that contribute to their expertise (Berry 1987; Berry & Dienes, 1993; Leprohon & Patel, 1995). Therefore, as AVGPs represent a population who are presumably experts in processing and responding to sensory information, the benefit in performance may arise due to certain attentional processes being engaged implicitly. That is, action video game experience requires players to engage efficient goal-directed allocation of resources in order to succeed in the games they play. As one gains expertise, this efficient allocation of resources likely begins to occur in a more automatic fashion. As a result, expert AVGPs may not be explicitly aware of all the sensory information that their attentional system is processing despite its influence on their behaviour. The trade-off for this lack of awareness is that it frees up attentional resources that can instead be allocated to other, less automated, aspects of a given task. This notion thus provides a more general basis for the performance improvements demonstrated by AVGPs – that action video game experience enhances the efficiency of processing and responding to sensory information.

8.3 Does an AVGP benefit persist when using more biologically relevant stimuli?

The potential cognitive benefits associated with action video game experience have largely been investigated with traditional paradigms that make use of very basic stimuli. The fact that the cognitive benefits observed by AVGPs scale up to overt attention provides some evidence for the generalization of effects to more natural behaviour. However, Chapter 6 was conducted to take a step toward assessing whether the benefits observed by AVGPs extend to a context that presents more complex and biologically relevant stimuli. The inclusion of schematic face stimuli in the oculomotor capture paradigm provided some insight into this issue. Critically, the results replicated those of Chapters 2 and 3. That is, with face stimuli, AVGPs still experienced less oculomotor capture than NVGPs. Coupled with the work that has found some associations with video game experience and improvements in various "real-world" behaviour (Franceshini et al., 2013; Gopher, Weil, & Bareket, 1994; Kennedy, Bittner Jr., Jones, 1981; Lintern & Kennedy, 1984; Rosenberg, Landsittel, & Averch, 2005; Rosser et al., 2007; Yule et al., 2011), these findings provide encouraging evidence that the cognitive benefits associated with action video game experience do generalize to everyday contexts/settings. However, given the importance of this question, more work is still needed.

Interestingly, despite previous work demonstrating differential processing of emotional content in AVGPs (Bailey & West, 2013; Kirsh & Mounts, 2007), the present work failed to reveal a difference in capture by an emotion (i.e., happy) face. That is, AVGPs demonstrated less capture by an abrupt onset compared to NVGPs regardless of whether it depicted a neutral, happy, or inverted happy face. Capture within groups also did not differ as a function of the emotional content of the stimuli. These results could be interpreted as suggesting that AVGPs and NVGPs do not differ in how they process emotional content; however, an alternative account is that both groups did not particularly attend to the emotional content of the faces as it was irrelevant to the search task (Hunt, Cooper, Hungr, & Kingstone, 2007). To provide a more powerful assessment of possible differences in processing emotion, future investigations can make the emotional content more relevant to the search task. In addition, coupling the nature of action video games, where players must constantly monitor for potential threats with the finding that AVGPs may process threat differently (Bailey, West, & Anderson, 2011), future work could assess the influence of adding threatening faces/stimuli to search displays. Nevertheless, the findings of Chapter 7 demonstrate an AVGP advantage even when searching a display with more complex stimuli.

8.4 Does an attention-based account of AVGP benefits provide a satisfactory explanation of the extant literature?

As reviewed in Chapter 1, action video game experience has been associated with improvements across a host of cognitive tests that require participants to engage selective attention (e.g., Castel et al., 2005; Chisholm et al., 2010; Feng et al., 2007, Green & Bavelier, 2003, 2006a, Hubert-Wallander et al., 2013). Collectively this evidence has suggested that the benefits observed by AVGPs are based on improvements in attentional control (Hubert-Wallander et al., 2010). The work reported in the present dissertation provides a number of findings that lend further support to this account. First, the fact that AVGPs demonstrated reduced oculomotor capture suggests that they were better able to avoid generating reflexive saccades toward salient task-irrelevant information. Previous work has demonstrated that the likelihood of generating reflexive saccades is sensitive to the availability of cognitive resources (e.g., Mitchell, Macrae, & Gilchrist, 2002; Roberts et al. 1994). Specifically, when fewer resources are available (e.g., in dual-task settings), individuals are more likely to produce incorrect reflexive saccades. Taken together, the findings suggest AVGPs possess more attentional resources (Dye et al., 2009a; Green & Bavelier, 2003, 2006a) or engage more efficient allocation of available resources (Bavelier, Achtman, Mani, & Focker, 2012),

Second, the fact that a manipulation aimed at improving attentional control had no impact on AVGP oculomotor behaviour provides further evidence for the attention-based account. Specifically, Chapter 4 demonstrated that making participants aware of potentially distracting information gave rise to less oculomotor capture. To account for this result, it was proposed that distractor awareness allows for more appropriate allocation of resources to inhibit information known to be irrelevant information (also see Kramer et al., 2000). Consistent with this finding, Chapter 5 revealed that NVGPs performance improved when they were provided with the instruction that a task-irrelevant distractor could appear in the display. In contrast, AVGPs did not show any benefit associated with distractor awareness. I have proposed that this finding may represent more implicit inhibition of distracting information. This notion suggests that action video game experience leads to an increase in the efficiency of processing sensory information to the point of it becoming more automatic. This would free attentional resources to be allocated to other aspects of a given task. This increase in efficiency leading to greater availability of resources thus provides a basis for the reported improvements in attentional control. To the best of my knowledge, an assessment of the possible implicit aspects of AVGPs behaviour has not yet been provided making this an interesting and potentially critical avenue for future investigation.

Collectively, the results of the present dissertation are consistent with the account that extensive action video game experience is associated with improvements in the control of attention. However, another account has recently challenged this attention-based explanation of AVGP benefits. Specifically, combining the evidence from the action video game literature with that of perceptual learning, the proposed learning to learn account (Bavelier, Green, Pouget, & Schrater, 2013; Green & Bavelier, 2012) argues that action video game experience provides players with an enhanced ability to learn relevant aspects of a task. By being more efficient in extracting task-relevant information, AVGPs are able to improve performance more quickly over time that NVGPs (i.e., faster learning rate). Thus, although AVGPs exhibit behaviour that is reflective of improved attentional control, this account proposes that the mechanism underlying the benefits associated with action video game experience is actually one of learning.

Chapter 7 presented a meta-analysis of all the AVGP vs. NVGP data collected for this dissertation to test of the learning to learn proposal. This account proposed that, rather than being the direct or proximal cause of AVGP improvements, enhanced attentional control is the means by which improved learning can occur. This account thus predicted equal performance between AVGP and NVGPs at the outset of a task, but that differences would emerge later in time, after AVGPs have the chance to learn the aspects of a task important for improving performance. Results from the series of time-course analyses conducted in Chapter 7 were entirely inconsistent with this prediction. Instead, AVGPs outperformed NVGPs at the outset of the task (i.e., Block 1) on oculomotor capture and manual response measures. Specifically, AVGPs demonstrated reduced oculomotor capture and faster manual responses in Block 1. This early AVGP advantage largely persisted at a steady level throughout the entire task. These findings provide compelling evidence that the learning to learn (Bavelier, et al., 2013; Green & Bavelier, 2012) proposal does not provide a sufficient account of the benefits demonstrated by AVGPs. Collectively, the data present in this dissertation indicate that, rather than enhanced attention being a means to an end, with the end being improved learning, improvements in the efficiency of attentional control can directly account for the benefits demonstrated by AVGPs.

8.5 Implications of findings

8.5.1 Understanding the benefits of action video game experience

The findings reported in the present dissertation provide significant contributions to the literature on the effects of action video game experience. Overall, the results speak to the mechanism underlying the performance improvements exhibited by AVGPs. Although the prevailing view accounting for these effects proposes that AVGPs possess enhanced control over the allocation of attentional resources (Hubert-Wallader et al., 2010), the results from this dissertation provide a more direct measure of *how* that control can be manifested behaviourally. For example, although research has previously demonstrated that AVGPs are less susceptible to attentional capture (Chisholm et al., 2010), it was not clear how AVGPs gave rise to this behavioural effect. The present findings suggest that AVGPs can engage attentional control to reduce the likelihood of attending to the spatial location of distracting information. This finding is consistent with other reports of greater distractor inhibition in AVGPs (Chisholm et al., 2010; Krishnan, Kang, Sperling, & Srinivasan, 2013; Mishra, Zinni, Bavelier, & Hillyard, 2011; Wu et al.,

2012) but, critically, provides a direct measure of attentional allocation to assess these claims.

Moreover, the reported findings revealed that AVGPs achieve heightened performance as a result of improvements in both selection and response-based processes. Presumably the ability to allocate resources more efficiently gives rise to improvements in selecting relevant information over irrelevant information. This finding is again consistent with previous work demonstrating reduced distraction (Chisholm et al., 2010; Krishnan, et al., 2013; Mishra, et al., 2011; Wu et al., 2012), but also research showing general improvements in search performance (Castel et al., 2005; Feng et al., 2007; Green & Bavelier, 2003, 2006a; Hubert-Wallander et al., 2011). Although these previous reports speculated that performance improvements were a result of improved selection, the fact that selection and response-based processes were confounded in covert tasks made it difficult to unequivocally support this conclusion. By employing a direct measure of attentional allocation, the present findings provide support for the notion that both processes can benefit from action video game experience.

Although the results of Chapter 2 and 3 provide insight into specific cases of how AVGPs outperform NVGPs, the results from Chapter 5 perhaps provides the most revealing insight into how AVGPs come to outperform NVGPs in general. Based on the finding that NVGPs benefited from being made aware of distracting information (i.e., reduced oculomotor capture) but AVGPs did not, it was proposed that the AVGP advantage may arise from more implicit processing of sensory information. Action video games are typically described as being fast paced and attentionally demanding. In order to succeed at playing these games, one must be able to manage the demands placed on the cognitive system. Therefore, what is critical for achieving success in action video games is a refinement of the processes necessary to manage the demands presented by the games. As one gains expertise in these games, one becomes more efficient in processing and responding to the presented sensory information. As in other cases of expertise, the processes by which performance improves on a task can become more automated and operate at a level below the explicit awareness of the expert (e.g., Berry 1987; Berry & Broadbent, 1984). By automating certain procedural knowledge, this frees up resources that would otherwise be committed to these processes. The results of Chapter 5 suggest that action video game experience improves the efficiency of processing sensory information, which can free resources from more implicit procedural processes and allow them to be allocated to other aspects of a task. This notion of increased efficiency is supported by recent neuroimaging evidence (Bavelier, et al., 2012). That is, despite outperforming NVGPs on a perceptual load task, AVGPs demonstrated significantly less recruitment of activity in the dorsal fronto-parietal network, which is believed to control and regulate selective attention (Corbetta & Shulman, 2002). The idea of more efficient processing provides an alternative account to the proposal that AVGPs possess a greater attentional resource capacity than NVGPs (Dye et al., 2009a; Green & Bavelier, 2003, 2006a). That is, the present account argues for more efficient allocation of resources rather than an increase in the maximum capacity of available resources. Therefore, the findings present in this dissertation are consistent with an attention-based account of the advantages demonstrated by AVGPs. Specifically, the results lead to the proposal that the improved attentional control demonstrated by AVGPs across a range of contexts is the result of action video game experience giving rise to more efficient (and perhaps automated) processing of sensory information.

The present results also provide some insight into whether the benefits exhibited by AVGPs generalize to other contexts. Given the ubiquity of eye movements in everyday moment-to-moment behaviour, the demonstration that action video game experience is associated with improvements in oculomotor control is encouraging evidence that the benefits exhibited by AVGPs will generalize to more natural everyday behaviour. Furthermore, demonstrating that AVGPs experience less oculomotor capture when biologically relevant information was added to the search display also suggests that the benefits may generalize to contexts that present more complex stimuli. Given the growing interest in using video games as a rehabilitative tool, understanding the extent to which the observed benefits generalize to other everyday situations will be critical. The evidence presented in this dissertation provides some suggestive evidence that the benefits will generalize to more natural everyday settings.

Finally, Chapter 7 provided a critical contribution toward further understanding the overall mechanism underlying AVGP benefits. Specifically, the time-course analyses provided a test of the learning to learn account (Bavelier, et al., 2013; Green & Bavelier, 2012) of AVGP benefits. Although this learning to learn proposal, heavily based in the perceptual learning literature, appears theoretically sound, to date there is very little direct data in support of the account (see a paper by West et al., 2013 and a poster by Zhang et al., 2012). Therefore, in order to resolve any conflict between competing accounts, this dissertation provided an important test of the predictions put forth by the learning to learn account. As the results of this test failed to provide any support for the learning to learn proposal, the findings reported in the dissertation provide support for the aforementioned attention-based explanation for how action video game experience leads to better performance. Specifically, these results suggest that the proposed increase in efficiency of processing sensory information can be applied at the outset of a novel task. Taken together, the present dissertation is not only largely consistent with the extant literature, by demonstrating an AVGP advantage in an attention-based task, but the suggested enhancement in the efficiency of processing sensory information also presents a mechanism that may form the basis for the improved attentional control that has been proposed to account for AVGP benefits.

8.5.2 Concern of demand characteristics

Recently, a couple of publications have raised a number of concerns regarding the reliability of the effects demonstrated in the action video game literature (Boot, Blakely, & Simons, 2011; Kristjansson, 2013). One of the critical concerns that emerged from these commentaries was the possible effect of actively recruiting special samples of participants. Specifically, if an investigation recruited participants by advertising that they wanted action video game players to participate in a study about the effects of video games, there is a legitimate concern that such an approach would give rise to demand characters. As a result, any benefits associated with action video game experience could have emerged, for example, as a result of AVGPs being more motivated to perform well rather than any reliable differences in attentional control. In light of this concern, a number of experiments reported in this dissertation used covert recruitment and asked participants to rate how motivated they were while performing the task. In addition, as AVGPs may be more likely to adopt a “video game” mindset, perhaps placing them in a more familiar cognitive state, participants were also asked to indicate how much they treated the oculomotor capture task like a video game.

Results from the experiments that employed covert recruitment revealed that both AVGPs and NVGPs reported equivalent motivation and did not differ in how they conceptualized the task. This dissertation demonstrates that AVGP effects replicate across situations where active (Chapters 2 and 3) or covert (Chapters 5 and 6) recruitment strategies were employed. This is consistent with the findings of a previous report that employed a covert recruitment strategy and still demonstrated an AVGP performance advantage (Clark, et al., 2011; Donohue, Woldoff, & Mitroff, 2010). However, the dissertation goes one step further by having participants report motivation and whether they approached the task like a game. Even when controlling for these factors (i.e., via equivalent subjective reports), an AVGP advantage still emerges. Therefore, this dissertation provides evidence that these group differences are not the result of recruitment strategy or demand characteristics (Boot et al., 2011; Kristjansson, 2013).

8.5.3 Implications for the field of visual attention

The findings presented in this dissertation also have important implications for the field of visual attention. Specifically, it speaks the to relative influence of top-down factors in the capture of attention. The field of visual attention has seen an ongoing debate that began over 30 years ago, in terms of whether the capture of attention is driven solely in a bottom-up stimulus driven manner or whether it is governed by top-down attentional control settings. The bottom-up account has argued that attention will always orient/select the most salient item in the display regardless of any top-down control settings (Theeuwes, 1991, 1992, 2004). In contrast, the top-down account suggests that capture can depends on whether the distracting stimulus shares features with the sought after target (Bacon & Egeth, 1994; Folk, Remington, Johnston, 1992). Both a bottom-up and top-down explanation was provided to account for the reduced attentional capture previously demonstrated by AVGPs (Chisholm et al., 2010). However, results from the present investigations support the top-down account that AVGPs are able to engage attentional control to reduce the number of incorrect saccades made to a distractor. This finding weighs in on the ongoing debate to suggest that capture can be modulated by top-down control. The fact that AVGPs are thought to possess enhanced attentional control also makes them an interesting population to sample from to test other models of attentional control.

The results from Chapter 4 also speak to the top-down modulation of capture. Specifically, Chapter 4 revealed that awareness, perhaps the quintessential top-down factor, influences oculomotor capture. Importantly, in addition to further demonstrating that oculomotor capture can be modulated by top-down factors, this work also helped resolve divergent findings in the visual attention literature. Specifically, research had provided evidence that being aware of to-be-ignored information could help search performance (Kramer et al., 2000) but others demonstrated that such awareness could interfere with performance (e.g., Moher & Egeth, 2012). The results of Chapter 4 revealed that being aware of task-irrelevant information is beneficial for search performance; however, this benefit disappears when this information is over-emphasized (i.e., told to actively avoid). Therefore, these results indicate that the emphasis placed on distracting information can influence the extent to which someone will be distracted, providing additional evidence for the top-down modulation of capture.

Finally, the present work also speaks to the effect of task load on oculomotor capture. Implicating the role of top-down control in capture, previous work has argued that increasing cognitive load results in greater distraction (e.g., Lavie & De Fockert, 2005; Roberts et al., 1994). In the present series of experiments a similar effect was observed. That is, by adding a manual response to the task, the amount of capture experienced by both groups increased. Presumably, the inclusion of a manual response was treated like an additional task that drew resources away from the target selection task. With fewer available resources, participants were more susceptible to producing reflexive saccades. However, the increase in capture was also associated with a decrease in saccade latencies. Previous work has demonstrated a relationship with saccade latency and capture, with shorter latency saccades being more likely to be captured (van Zoest, Donk, & Theeuwes, 2004). It is currently unclear why the added manual response would speed saccades; however, one can speculate that the manual task may have been treated as the primary task and selection the secondary or means-to-an-end aspect of the task. Because the trial did not end with an eye movement the decision threshold for executing a saccade may have been lowered, resulting in shorter saccade latencies. That is, there was “less riding on” the eye movement when a manual response was added. This is perhaps a related component to the saccade behaviour no longer being a primary response in the task. Providing participants with feedback only on their manual response performance may have encouraged this mindset.

8.6 Limitations of this dissertation

Despite the consistency of the reported improvements in oculomotor control exhibited by AVGPs, it is important to note the limitations associated with cross-sectional studies. Specifically, given that participants were selected based on some specific criteria, it is difficult to make any causal claims regarding the effect of action video game experience. That is, it remains a possibility that rather than action video game experience giving rise to improvements in attentional and oculomotor control, that those who already possess said improvements are drawn to play action video games. As reviewed in Chapter 1, many training studies have been conducted to establish a causal relationship between action video game experience and subsequent improvements on cognitive tasks. Such training studies have replicated cross-sectional across multiple experiments (e.g., Green & Bavelier, 2003, 2006a, 2006b, 2007; Green et al., 2010) as well as across different research groups (e.g., Feng, Spence, Pratt, 2007; Greenfield, DeWinstanley, Kilpatrick, & Kaye, 1994; Wu et al., 2012). However, as highlighted by Kristjansson (2013) simply because one effect emerged from training does not mean all will. Therefore, although providing multiple instances of AVGPs demonstrating improved oculomotor control across does provide compelling evidence that this represents a reliable effect, one could nevertheless make the comment that the current findings are limited by not having conducted any training study.

One other limitation worth mentioning relates to AVGPs' and NVGPs' subjective reports of motivation and how they treated the capture task. Although AVGPs and NVGPs did not differ on these measures, one could question whether AVGPs and NVGPs differ in how they experience motivation or conceptualize what constitutes a task as “game-like”. In other words, a Likert score of 5 for an AVGP may not be phenomenologically equivalent to a 5 for NVGPs. To address this concern, a future investigation could have AVGPs and NVGPs complete separate tasks that are clearly more or less game-like as well as employ different tasks that clearly encourage more or less motivated states. Having the within group data from this kind of design can provide important insight into possible differences in baseline motivation or differences in how AVGPs and NVGPs define a task to be game-like.

8.7 Future direction

Taken together, the present dissertation provides further evidence that the benefits demonstrated by AVGPs is a result of action video game playing conferring improved efficiency in the control of attentional processes. Given the growing interest in using video games as a rehabilitative tool (Achtman, Green, & Bavelier, 2008; Anguera et al., 2013; Franceschini et al., 2013; Li, Ngo, Nguyen, & Levi, 2011), it will be important for the field to continue to demonstrate the reliability of the observed effects inside the lab and to further investigate the extent to which these effects generalize to in more natural contexts. Specifically, more training studies are needed to address the concerns raised by recent commentaries on the field (Boot et al., 2011; Kristjansson, 2013). Furthermore, although the present work provided some evidence that the benefits associated with action video game experience extend to more complex stimuli, more work is needed further evaluate the extent to which the reported benefits generalize to other more natural contexts (e.g., situations that do not involve sitting in front of a display). For example, future investigations could implement more naturalistic visual search tasks (e.g., Foulsham, Walker, & Kingstone, 2011).

There are also a number of outstanding questions associated with action video game training effects. First, it is unclear how long any benefits associated with action video game persists once the training ends. One study reported that the benefits lasted up to 5 months post-training (Feng et al., 2007), however, more evidence will be important for informing rehabilitative programs. Moreover, although the evidence collectively demonstrates beneficial effects associated with action video game experience, it remains unclear what aspects of the experience is critical for these benefits to emerge. For example, are the improvements in attentional control a result of interacting in a visually complex environment, being presented with near constant challenge, experiencing high levels of engagement and motivation, or some combination of these factors?

Taken together, furthering our understanding of the mechanism(s) by which AVGPs outperform NVGPs, coupled with isolating the factors that give rise to such underlying changes, is a challenge that the field should address. In working toward answering these questions, this will move the field toward a more complete understanding of the effects and practical application of action video games. Gaining such an understanding will also be important for isolating those who may benefit from video game-based rehabilitative interventions (e.g. those with impairments in attentional control).

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