Visual Speed of Processing and Publically Observable Feedback in Video-Game Players

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Abstract

Time spent playing action-oriented video-games has been proposed to improve the functioning of visual attention and perception in a number of areas. These benefits are not always consistently reported, however. It was hypothesized that an improvement to visual Speed of Processing (SOP) in action-oriented Video-Game Players (VGPs) underlies many of the benefits of action video-game play, and furthermore the expression of this improvement was modulated by a Hawthorne effect (individuals behaving differently when they believe they are under observation), resulting in the inconsistent results in the extant literature. This hypothesis was tested in three experiments which measured SOP in VGPs and controls in no feedback, public feedback, and private feedback conditions. Analyses showed that VGPs differed from controls only in the publically observable feedback condition, where VGPs demonstrated a superior SOP to the other two conditions, whereas controls did not differ significantly between experiments.

Keywords: Video Games; Attention; Perception; Speed of Processing; Hawthorne Effect

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List of Acronyms

Term	Initial components of the term
VGP	action-oriented Video-Game Player
NVGP	Non action-oriented Video-Game Player
TVA	Theory of Visual Attention
fMRI	Functional Magnetic Resonance Imaging
IOR	Inhibition of Return
WM	Working Memory
SOP	Speed of Processing
UFOV	Useful Field of View
ISI	Inter-Stimulus Interval
PEST	Parameter Estimation by Sequential Testing

Chapter 1.

Introduction

1.1. The Need for Selective Attention

William James (1890) is often quoted as saying “Everyone knows what attention is.” Though less catchy, I would argue that the sentences which follow are actually more important: “It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. It implies withdrawal from some things in order to deal effectively with others…” While there is much debate and research on the precise nature of attention, this description of focusing on a subset of things to the exclusion of others seems well taken. This is especially true when one considers the sheer volume of information to which our sensory organs have access. Attempting to simultaneously process the entirety of all the information from even one sense (such as vision) has been likened to attempting to drink from a fire hose (Kanwisher & Downing, 1998): a nearly impossible and overwhelming task. Following this metaphor, attention would be a mechanism by which we could divert a small amount of the water from the fire hose for our use while ignoring the massive excess that is beyond our means and needs. There follows a natural question: how can we get just the right amount of metaphorical water? How can we optimally employ attention? Can attention capabilities be improved through training or practice?

1.2. Selective Attention and Action Video Game Playing

In the late 80’s and early 90’s, video-games became an increasingly popular pastime. The rapid rise of this new type of entertainment medium sparked an interest in researching the effects of these video-games on those who play them. Of particular interest to cognitive psychologists was the extent to which action-oriented video-game play affects perception and attention. Action video-games tend to be fast paced, requiring players to make rapid, accurate decisions while monitoring and responding to a changing visual space. As games have become more sophisticated, their visual scenes have become more detailed and complex and their gameplay have presented more challenging perceptual tasks. Such games place a high demand on the visual attention system, and it has been proposed that practice in these games might improve many aspects of perception and attention. As expected, a substantive body of literature has demonstrated that video-game play influences both early and late stages of visual information processing (see Spence & Feng, 2010 for a review). Effects have been found in such low level processes as contrast sensitivity, but also in higher level processes such as visual working memory. Below, I outline a brief taxonomy of the effects of action video-game play on the perceptual and cognitive characteristics of video-game players.

1.2.1. Spatial Attention: Early Visual Processes

One area of particular interest has been how video-game play affects spatial attention. Spatial attention helps refine and improve perception of areas and objects to which it is directed. There is a substantive body of research on the effects of focused attention, the full extent of which is obviously beyond the scope of the present work (see Carrasco, 2011 for a review). To briefly summarize, focused attention not only improves the detection and identification of important stimuli, but also improves essential aspects of perception such as contrast sensitivity and spatial resolution (both things to which we will return to later in this section). Given the general theme of reacting quickly to events and identifying targets in a relatively complex visual space, it is reasonable to expect that experience in carrying out this kind of activity will have some impact on spatial attention. Therefore, playing action video-games is likely to have an effect on early stages of visual processing. In addition, if action video-game play affects attention and perception at the earliest stages, those changes are likely to influence performance in a wide variety of other tasks.

One such aspect of early perception is contrast sensitivity, the ability to distinguish between subtle differences in shades. While it is possible to improve contrast sensitivity through physical means such as corrective lenses or surgery, it would be preferable to be able to efficiently improve contrast sensitivity through a training exercise, especially for those in professions where highly acute vision is important. One study tested whether action video-game playing might represent just such an effective training exercise for contrast sensitivity (Li et al., 2009). Expert young adult action video-game players (VGPs) and matched non-players (NVGPs) were tested on a measure of the Contrast Sensitivity Function (CSF) to produce individual CSF ratings. VGPs showed superior contrast sensitivity relative to non-players. Given that this study used recruited, existing VGPs and NVGPs, there could be some question as to the direction of causality at work. It is possible that those individuals with superior visual traits (such as contrast sensitivity) simply excel at videogames and thus tend to play them more than others, rather than the time spent playing action games actually improving contrast sensitivity, for example. Such concerns over causality are a recurring theme in this field of literature, as will become apparent throughout this paper. In this case, the causal nature of this effect was upheld in a training experiment where typical individuals received either action video-game practice, or practice in a control, non-action video-game. Those who received the action video-game practice showed improved CSF compared to controls, mirroring the results of the first experiment. This improvement in the contrast sensitivity of VGPs is all the more relevant considering that the participants were young adults; precisely in the age range at which one would expect such a facet of vision to be already at its best.

Other aspects of early visual-spatial attention in VGPs have been studied using the Theory of Visual Attention (TVA, Bundesen, 1990). This set of assessment tools provides estimates of several relevant aspects of visual attention. Of special interest is perceptual threshold, measured in TVA as the minimum presentation duration necessary for a stimulus to be perceived. The importance of this parameter should be obvious: individuals with a higher perceptual threshold will be more likely to miss important visual stimuli which those with a lower threshold will be able to perceive and react to. Clearly, a lower perceptual threshold would be useful when playing a fast paced, action-oriented video game. Using TVA, Schubert and colleagues (2015) found that action VGPs had superior (lower) perceptual thresholds compared to NVGPs. Furthermore, this group difference was not moderated by any of a wide variety of personal characteristics. That action video-games could improve such an important and basic facet of vision is remarkable. Once again, however, the question of causality is raised when using recruited, self-selecting samples such as this. Notably, in this study a follow-up experiment using a 15 hour training regimen did not reproduce the effect. After detailed analysis, the authors concluded that the duration of the training was insufficient to produce the effects in TVA parameters found in the recruited sample of VGP experts from the first experiment. This raises an important question regarding how well such training interventions match the experience of existing VGPs, an issue to which I will return later in this the present work.

Another important facet of early perception is spatial resolution; how well one is able to resolve fine details in vision. Here too, the effects of action video-game play have been studied. Green and Bavelier (2007) compared VGPs and NVGPs on a measure of visual crowding, in which participants were required to report the orientation of a target letter T in the presence of two other Ts at varying eccentricities and orientations. When the flanking Ts are close to the target, it becomes difficult to resolve the features of the target compared to when the flanking items are further away. Thus, it is assumed that participants with finer spatial resolution will be able to tolerate greater crowding while still being able to resolve the orientation of the target as compared to those with coarser resolution. VGPs out-performed NVGPs, showing improved spatial resolution. The causality of this finding was also supported in a training experiment, in which individuals trained in an action video-game showed a reduced effect of visual crowding compared to subjects who played a control game. Once again, it is worth noting that this improvement in spatial resolution is being observed in individuals at the peak of typical visual acuity. These differences between players and non-players seem not to be merely compensation to degradation due to age or damage, but an improvement in the base functioning of the visual system.

While the above studies show a variety of improvements in early perception and attention, they all consist of behavioral data used to make inferences regarding the visual system at work. There is some question, then, as to the extent to which, and how, action video-game playing affects the neural functioning of the visual system. Researchers have employed a variety of brain imaging techniques in investigating this topic. One such study employed functional magnetic resonance imaging (fMRI) to study the activation of the visual motion-sensitive area (MT/MST) of the brain (Bavelier et al., 2012). Specifically, the study was interested in the efficiency of early attentional filtering. Subjects performed a task involving moving distractors which, if attended, would be expected to activate MT/MST. VGPs showed far less activation of this area as compared to NVGPs, suggesting that they attended less to the moving distractors, possibly due to superior earlier filtering of relevant information. Additionally, while NVGPs showed increasing recruitment of fronto-parietal brain areas as attentional demands increased in the task, VGPs showed virtually no extra activity in those areas in response to increasing attentional demands. Given that this network of fronto-parietal brain areas is hypothesized to be partially responsible for the allocation of top-down attention, this reduced activity in VGPs further supported the idea that VGPs may be filtering more efficiently early visual information, reducing the reliance on later attentional control mechanisms.

Other studies have also investigated early control of stimulus driven (exogenous) attention in VGPs, such as the filtering of irrelevant items. For example, in an anti-cuing task where attending to a frequently-invalid cue location will typically hinder performance, VGPs were found to be far less affected by the presence of these invalid cues compared to typical NVGPs (Cain et al., 2014). This has been interpreted as an improved ability to employ efficient early filtering of visual information, reducing the likelihood of deploying attention to irrelevant or detrimental stimuli. It might also be expected that this improved attentional filtering of sensory input would influence a variety of other aspects of visual spatial attention. Consider Inhibition of Return (IOR), the finding that observers are less likely to attend to stimuli which are presented in a recently-attended, peripheral location (Posner, Rafal, Choate, & Vaughan, 1985). It might be reasonable to assume that VGP’s improved early attentional filtering mechanisms would reduce IOR, allowing them to distribute attention more efficiently to target stimuli, regardless of location. Alternatively, given IOR's proposed role in facilitating efficient visual search, VGPs might be expected to have increased IOR instead. In contrast to either of these hypotheses, a study comparing IOR in VGPs and NVGPs found no difference between these groups on a measure of IOR (Castel, Pratt, Drummond, 2005), with both VGPs and NVGPs being equally good (or bad) at allocating attention to previously cued locations, although VGPs did show a faster response time in visual search tasks. This is somewhat surprising given the other improvements to the distribution of exogenous attention that have been observed. This kind of ambiguity regarding the exact nature of the effects of action video-game play is unfortunately not limited to this specific area, and is a topic to which we will return later in the paper.

In summary, it seems safe to conclude that VGPs differ from NVGPs in at least some aspects of early visual processing, though the precise nature of these differences remains to be established. Although the directionality of the relationship between attention and video games is still somewhat ambiguous, there is some evidence to suggest that action video-game playing does improve some aspects of spatial attention.

1.2.2. Spatial Attention: Late Visual Processes

The effects of action video-game play discussed in the previous section need not be interpreted as arising solely from activity in low-level cortical regions (such as early areas of visual cortex like V1). We should not discount the role that later processes might play in controlling early processes. As an example, we have seen that VGPs appear to have an improved ability to filter out irrelevant or distracting stimuli, even under difficult task conditions (Bavelier et al., 2012, Cain et al., 2014). We have interpreted this as a low-level benefit, as the irrelevant stimuli are filtered out early in visual processing. It must be acknowledged, however, that such early input filtering systems must be put in place as part of a higher-level attentional set, based on task demands. Such an ability to efficiently identify an appropriate attentional set for a task and to implement it appropriately would be most beneficial for an action video-game player, especially one who plays multiple types of video games. So it is not unreasonable to assume that VGPs would excel in this area as well.

Another relevant process that might be improved by action video-game playing is perceptual learning. Broadly speaking, perceptual learning refers to the finding that training in a perceptual task generally improves performance in that task (Sagi &Tanne, 1994). Such improvement, however, tends to be specific to the training task, which is to say that it does not generalize well to other tasks. Conversely, action video-game training has been shown to be highly generalizable. Green and Bavelier (2003) have shown that action video-game play generalizes to such disparate tasks as Useful Field of View (Sekuler & Ball, 1986), Attentional Blink (Raymond, Shapiro, & Arnell, 1992), and Object

Enumeration (Kaufman et al., 1949). These effects were observed not only in existing VGPs, but also for typical observers trained on an action video-game for as little as 10 hours, buttressing the causal nature of these improvements. Training in action video-game play has also been shown to generalize to divided attention tasks (Greenfield et al., 1994) in both self-reported and laboratory-trained VGPs. Although this improvement could be viewed as yet another example of generalized perceptual learning, it could also result from improved ability to establish efficient attentional sets, as discussed above.

When discussing higher-level perceptual processes, the concept of attention as a resource is often encountered. That is, when an observer directs attention to something, they draw from some finite pool of attentional resources. The important point is that resources which are invested in one task are unavailable to be used in another. Within this framework, it has been suggested that action VGPs may have more attentional resources than NVGPs, and/or may deploy these resources more efficiently. Several studies have used flanker interference tasks to investigate this hypothesis using both recruitment and training, and most have concluded that VGPs do possess some form of superior attentional resources (Dye, Green, & Bavelier, 2009; Green & Bavelier, 2003, 2006; but see Irons, Remington, & McLean,2008).Enhanced top-down control of attention in VGPs has been a recurring theme in the literature. Although the notion of attentional resources is not universally agreed upon, it would certainly be in keeping with that theme to find that VGPs were better able to manage those resources.

It should not, however, be assumed that action video-game training will generalize to all perceptual tasks. As an example, Karle, Watter, and Shedden (2010) investigated whether VGPs exhibited superior task-switching abilities, an area in which there is some ambiguity in the extant literature, (Andrews & Murphy, 2006; but see also Boot et al., 2008). VGPs demonstrated superior task switching abilities only when there was relatively little overlap between tasks, performing no better than NVGPs for tasks with greater overlap in stimuli and responses. The authors concluded that, rather than a generalized improvement in task switching (as might be expected from other perceptual learning tasks), the benefits found were due to improved allocation of selective attention, as discussed previously in this paper.

To summarize, the effects of action video-game play and training are not limited to early perceptual processes, but include a broad range of other benefits as well. Furthermore, it is likely that these two levels of processing work together to produce many of the behavioral improvements observed in VGPs.

1.2.3. Working Memory Effects

There is a substantial overlap in the study of attention and the study of working memory (WM). Given the close relationship between these two concepts, and given that action video-game play has some effect on attention, one might expect that it will also affect WM in some way. Change detection tasks, where observers are required to rapidly encode and remember a simple display (such as an array of coloured squares), are often used to assess WM. Using this paradigm Blacker, Curby, Klobusicky, and Chein (2014) found that observers trained on an action video-game showed significant improvement in WM compared to control observers. This improvement was not, however, found in two other more complex measures of WM. This inconsistency suggests that action video-game play improves a specific aspect of WM rather than providing a broad benefit to memory in general.

One option for the aspect of WM that is improved by playing video games is a person's encoding speed. Encoding speed is the rate at which observers are able to process information into WM, and has been suggested to be an important factor in change detection task performance (Jannati, McDonald, & Di Lollo, 2015). Given the rapid speed with which things happen in action video-games, faster encoding rate would lead to better performance. Consistent with this notion, Wilms, Petersen and Vangkilde (2013) found that expert VGPs did not differ from NVGPs in WM capacity, but did have a higher rate of encoding. That encoding rate is improved, but actual WM capacity is unaffected would also be consistent with the findings of Blacker and colleagues mentioned above, as well as other change detection studies in the extant literature (e.g. Boot et al., 2008). Faster, and more accurate, updating of WM in VGPs was also found when an N-back task was used, rather than using a change detection task (Colzato et al., 2013). Therefore, this improvement to WM encoding is not limited to change detection tasks. The authors of this study further suggest that VGPs may also move old, irrelevant items out of WM more rapidly, thus allowing for the efficient processing of more items without actually increasing WM capacity.

1.2.4. Action Video-Games and Gender

It is relevant to note that the majority of the studies reviewed in the present work have used exclusively male observers. For this reason, these studies could not reveal any possible interaction between observer gender and video-game playing. To be sure, there is some justification in this practice in that, historically, action video-games have had a primarily male player base, making representative samples of female VGPs difficult to find. How action video-game play interacts with gender should not be ignored, however, especially given that gender distribution of VGPs seems to be more even now than it once was.

Though there has been little research into the interaction of action video-game playing and gender, one early study by Subrahmanyam and Greenfield (1994) investigated the effects of action video-game playing on spatial attention in both girls and boys. Observers were tested on a measure of spatial attention before and after training in either an action video-game or a control game. The researchers found both a gender effect, whereby the boys out-performed the girls on this test of spatial attention, and a training effect, whereby action video-game training was more effective at improving spatial attention. These two factors, however, did not interact. In other words, in this study they found that both genders benefited equally from video game training.

While the previous study found that an existing gender difference was not changed by action video-game training, other studies have shown different patterns of results. For example, Feng, Spence and Pratt (2007) found that while males out-performed females on tests of spatial attention and mental rotation in pre-training tests, action video-game training eliminated this gender difference in spatial attention, and significantly reduced the disparity in mental rotation. One possible explanation for these inconsistent findings is that the above studies used different populations of observers. Subrahmanyam and Greenfield (1994) conducted their study on a sample of young girls and boys, while Feng et al. (2007) used college-aged observers. It is possible that the older participants were perceptually more developed, and so the improvement in training ran up against a performance ceiling which would result in the finding that males and females might differ before training but not after. Conversely, in the first study, the younger observers may not have been capable of reaching such a ceiling even with training, resulting in a comparable increase in performance for both genders. Whatever the reason, it is clear that more research into the interaction of gender and game play is necessary.

Chapter 2. The Present Work

As was illustrated in the previous chapter, action video-game play has been linked to changes in the functioning of perception and attention. We have seen improvements to such diverse areas as mental rotation, object tracking, WM, and attentional filtering. On the other hand, we have also seen some conflicting evidence, with inconclusive findings and failures to replicate in almost as many areas. Given these inconsistent findings, two pertinent questions need to be considered: what do the tasks which are improved by video-game play have in common, and how do the tasks where video-game play benefits could not be replicated differ from previous experiments using those tasks?

In attempting to answer the second of these questions, there are a number of possible explanations to consider. Firstly, although training studies may be ideal for assessing whether possible improvements in VGPs are due to the training in the games or some kind of self-selection process, it should be acknowledged that laboratory training may not accurately represent the full range of the experience of VGPs playing under normal circumstances. In particular, the social environment under which normal video-game play typically takes place may be absent in the more controlled laboratory training. Secondly, in the specific case of the seminal work of Green and Bavelier and those replicating it, there is the issue of the reliability of the flanker task being used as a measure of spatial attention. This particular flanker task is not widely used outside of this particular area of research, and it does not appear to have been extensively compared to more traditional flanker tasks. Even if researchers consistently find reliable differences between VGPs and NVGPs using this task, (but see Irons et al., 2011) the inferences we make from those results may not be in line with those drawn from traditional flanker interference tasks. Indeed, it may be pertinent to consider whether the tasks being used to examine the effects of video-game play are actually appropriate to measure what is actually being changed by that experience. While it is interesting to find a difference between VGPs and NVGPs on a task, if we cannot be confident in what that task is measuring those results are less impactful. *Whether* there is a difference is a less impactful question than *why* there is a difference (even if the first question must necessarily precede the second). This leaves us with the more difficult task of investigating the mechanisms responsible for those differences.

Consider the following as a possible answer to the two questions we proposed earlier. Firstly, let us assume that many of the improvements resulting from action video-game play are resulting from one underlying factor which is involved in a variety of perceptual tasks. If a second, generally unreported factor were modulating the first factor, it would produce the unreliable pattern of findings that seems to be present in the literature. The task then becomes to identify what these two factors could be.

For the underlying factor improved by action video-game play, consider Speed of Processing (SOP). When we view an object, it may seem as though we are instantly able to assess its identity. In reality, this is not the case, and it takes some time (100 to 150ms at least) from the light of an object first impinging upon our retina until a perception of the object begins to reach conscious awareness (Thorpe, Fize, &Marlot, 1996). If the time it takes for an object to reach awareness is shorter for one individual, we would say that such an individual has a faster visual Speed of Processing. Now, suppose we assume that time spent playing action oriented video-games improves visual speed of processing. How would this faster SOP for VGPs translate into benefits in other attention and perception tasks?

Most obviously, individuals with faster SOP will likely be advantaged in tasks involving brief displays. Consider the Useful Field of View (UFOV) task (Sekuler & Ball, 1986). In this task, subjects are asked to identify the position of a peripherally presented target while simultaneously identifying the identity of a centrally presented target. Critically, the displays used in UFOV tasks are frequently quite brief, less than 100ms. While a subject with a superior UFOV would be expected to perform this task more proficiently, it should be clear that a subject with a faster SOP should also have an advantage in this task, as they will be more likely to fully process the stimuli in the brief period of time they are presented. This would, presumably, have a similar benefit to increasing the stimulus presentation time, which would undoubtedly improve performance. Indeed, as would be expected from this line of reasoning, VGPs have been shown to possess a superior UFOV in the extant literature. (Feng, Spence, & Pratt, 2007).

Improved SOP may also confer an advantage in other visual attention tasks with longer displays. As an example, recently VGPs were found to show a reduced cost of the presence of an additional singleton in a visual search paradigm (Chisolm, Hickey, Theeuwes, & Kingstone, 2010). In such a paradigm, participants are tasked with identifying some quality of a target that is defined by a unique property such as shape or color. On some trials though, one of the irrelevant distracting items will also have a unique (and often highly salient) property such as being colored red, and the presence of this *additional singleton* will commonly slow reaction time on such a task. The advantage VGPs have shown on this task is also compatible with our increased SOP hypothesis. If a VGP is captured by such an irrelevant singleton, they can process it more rapidly, thus allowing them to reallocate attention to the target sooner, producing less of an impairment on average in conditions where the irrelevant singleton is present. This is not the only interpretation of these results (VGPs may, for instance, be better able to *ignore* the distractor), but they are certainly compatible with our SOP hypothesis.

If we allow SOP to be a factor improved by VGP play, it must then be asked what could by the second factor which modulates this first factor? For this, let us consider the *Hawthorne Effect*. Generally speaking, the Hawthorne Effect is that individuals who believe that they are performing a task under observation tend to perform better than individuals who believe they are working relatively unobserved (Roethlisberger & Dickson, 1939). While the specifics of the Hawthorne effect have been the subject of much debate, the basic premise that performance may change when individuals believe they are under observation is what is relevant to the present work. There are two main reasons to suspect that this may be the modulating factor we are looking for. Firstly, video-games are increasingly being played in online environments. Multi-player games are dominating especially in the action-oriented video-game market, with first person shooters in particular increasingly promoting multi-player experiences over single-player experiences. Even ostensibly single player games frequently have online aspects, such as the automatic publication of a player's progress and achievements to social media services and messengers. The latest generation of consoles go so far as to include the option to send video of a player's play session live to the internet to allow their friends or even strangers to watch them play. Given that VGPs are used to performing under these highly monitored conditions, it might be reasoned that any advantages they have might be best expressed under similar conditions. This would be a similar effect to *encoding specificity* (Tulving & Thomson, 1973), the finding that individuals exhibit better recall for items memorized and remembered in the same environment, compared to those who memorize and remember in differing environments.

The second reason to suspect something akin to a Hawthorne Effect as the modulating factor is that the extent to which any given experiment or laboratory creates a feeling of being under observation may vary considerably, and is unlikely to be reported consistently. For instance, while the number of subjects that participated in an experiment will always be diligently reported by any responsible researcher, it is not generally reported how many subjects were supervised by how many researchers during testing. We can imagine that a participant being invigilated by a single researcher may feel substantially more monitored than if they were in a situation where five or more participants are being monitored by a single researcher simultaneously, as can be the case in larger labs. Furthermore, subtle details such as the construction and layout of a testing area may dramatically influence a feeling of monitoring. Some labs have multiple testing stations set up along a counter, separated by a divider but otherwise in a relatively public space, whereas other labs may have fully enclosed testing rooms, which may even be sound proofed, creating a feeling of privacy and isolation. As the level of privacy for participants is generally not considered to be a relevant factor for most studies of visual attention, many studies do not explicitly report on these conditions.

Now we have a possible two factor hypothesis that could explain the inconsistent benefit of action-oriented video-game play in the extant literature. Action-oriented video-game play improves SOP, resulting in improvements on a variety of tasks, but this improvement in VGPs is modulated by the privacy or publicity of the testing conditions, which may vary substantially between studies and laboratories without being reported in published results. This hypothesis leads to a relatively straightforward experimental design: VGPs and NVGPs are tested for SOP, and the privacy of the testing conditions is varied, if our hypothesis is correct, VGPs should show an improved SOP, but only under conditions which cause them to feel monitored (because then the testing environment would be similar to their learning environment). While it might be expected that VGPs should show superior SOP under all conditions, this would not explain the null effects and failed replications in the extant literature.

2.1. EXPERIMENT 1

2.1.1. Methods

Participants:

Participants were students at Simon Fraser University who participated for payment or course credit. All participants reported normal or correct to normal vision and were naïve to the purpose of the experiment. 61 NVGPs participated, all of whom reported playing 0 hours of action-oriented video-games on average per week in the last six months. We defined action-oriented video-games as those which require monitoring of a complex visual space, fast reaction times, and extended vigilance. Examples given of such games were First Person Shooters (such as *Call of Duty, Modern Warfare, or Counterstrike*), Massive Online Battle Arenas (*Defense of the Ancients 2, League of Legends, Heroes of the Storm*), and Third Person Action (*Uncharted, God of War, Infamous*). 57 VGPs participated, all of whom reported playing 8 or more hours of action-oriented video-games on average per week in the last six months. Three participants were excluded based on their self-reports of playing more than 60 hours per week on the reasoning that reports of this magnitude might be unreliable or if true would not be representative of most VGPs, leaving a remaining sample of 54 participants in this group.

Apparatus and Stimuli:

The visual stimuli in all experiments consisted of a target pair of black letters subtending 0.8° visual angle vertically, 0.4° vertically, with 0.4° separation, presented at fixation on white background, followed by a black mask 1.6° in diameter centred at fixation. As measured by a Minolta CS 100 Chroma Meter, the luminance of the white background was 154 cd/m2 (CIE x/y values: .308/.333), and the luminance of all stimuli was 0.31 cd/m2 (CIE x/y values: .360/.355). All stimuli were displayed on a 24-inch BenQ Model XL2410T refreshed at 120Hz, at a resolution of 1920×1080. While CRT monitors are traditionally considered superior for these types of experiments, research has shown that LCD monitors can be as good or better than CRTs for this type of research (Lagroix, Yanko, & Spalek, 2012).

Procedure:

Observers sat in a dimly-lit 2m x 3.5m room, private room and viewed the displays binocularly from a distance of approximately 57cm. Prior to the experiment, observers were directed to read written instructions for the experiment by a research assistant and were given the opportunity to ask questions as desired. Once participants indicated that they were comfortable with the instructions, the research assistant closed the door to the testing room and observers were left to complete the experiment without intervention or observation.

At the start of each trial, a small black fixation cross was displayed in the centre of the display to indicate the location for the upcoming target stimuli. The fixation cross remained on the screen until participants initiated a trial by pressing the space bar. After pressing the space bar, two target letters are presented briefly at fixation for 16ms. This extremely brief presentation duration was used in order to ensure that the task was suitably difficult. The letters were randomly chosen on each trial and could be any two different letters of the English alphabet. Following the offset of the target letters, there was a variable duration Inter-Stimulus Interval (ISI) and then the mask was presented for 200ms, after which participants were prompted to report the identity of the target letters, one at a time from left to right using the keyboard (see Fig. 1 for full display sequence).. The duration of the ISI was systematically varied using the Parameter Estimation by Sequential Testing (PEST) technique (Taylor & Creelman, 1967) implemented in an E-Prime script. For each participant, the ISI began at 250ms, and then was dynamically adjusted to be shorter following correct trials and longer following incorrect trials until participants reached an average accuracy level of 80%. This was done until the direction of change in the ISI reversed direction three times, and at that point the assumption was that the 80% accuracy threshold had been reached and the next 12 trials were used to compute that observer's Critical ISI for that PEST session. Each observer completed three of these sessions, and an average of those three Critical ISIs was then computed and used for the analyses. This Critical ISI will be used as a measure of visual speed of processing (SOP), as it is assumed that observers with a faster SOP rate will require less time to identify the targets, and thus require a shorter ISI between the target offset and mask onset to reach 80% accuracy as compared to those with slower SOP.

Each observer completed 5 practice trials where the ISI was locked to 250ms, followed by three PEST sessions. The number of trials in each PEST session varied by observer depending on how rapidly a given observer was able to reach a stable performance level of 80%.

2.1.2. Results

For each observer, an overall Critical ISI was calculated by averaging together the Critical ISIs for the three PEST procedures. Average Critical ISI was 114.29ms (sd=52.1) for VGPs and 115.94ms (sd=54.8) for NVGPs (see Fig. 2). An independent samples t-test showed that the two groups did not differ significantly from one-another, *t*(113) = .165, *p* = .869 (Homogeneity of variance assumed).

Because the observers completed this experiment in a fairly private environment, these results are in-line with the predictions made above. That is, because the testing environment was dissimilar to their assumed typical learning (playing) environment there would be little transfer of that learning and so VGPs would not out-perform NVGPs. Experiment 2 will examine whether this effect changes when observers are induced to feel as though their performance is publically observable.

2.2. EXPERIMENT 2

2.2.1. Methods

Participants:

Participants in Experiment 2 had the same restrictions and were recruited using the same methods as those in Experiment 1. 73 NVGPs participated and 69 VGPs participated in this experiment. Three participants were excluded based on their self-reports of playing more than 60 hours per week, leaving a remaining sample of 66 participants in the VGP group.

Apparatus and Stimuli:

All visual stimuli in this experiment were identical to those used in Experiment 1. The only new stimulus was an 80db tone presented over speakers approximately 60cm from the participant whenever the observer made an incorrect response, and thus provided audio feedback to the participant and others in the lab.

Procedure:

All procedures were identical to those used in Experiment 1 with the following exceptions. Changes were made to the instructions to indicate to observers that they would receive audio feedback on incorrect trials to both aid them in learning the task, and so the research assistants could monitor their performance and intervene if it appeared that they required assistance. The supervising research assistant reinforced this concept by making it clear to the observer that they would be able to hear the feedback tones, and they could also hear the error tones from neighboring cubicles. As indicated in the instructions, whenever an observer failed to identify the target, the aforementioned 80db tone would be played through the computer's speakers for 500ms.

2.2.2. Results

For each observer, an over-all Critical ISI was calculated by averaging together the Critical ISIs for the three PEST procedures. Average Critical ISI was 98.7ms (sd=25.8) for VGPs and 125.8ms (sd=45.3) for NVGPs (see Fig. 3). An independent samples t-test showed that the two groups did differ significantly from one-another, $t(116.3) = 4.4$, $p < .001$ (Homogeneity of variance not assumed).

To directly compare the results of the two experiments, a 2 x 2 Univariate ANOVA was performed on the data from Experiments 1 and 2, using average cISI as the dependant measure, and with Gamer (VGP vs NVGP) and Experiment (E1 vs E2) as fixed factors. There was a significant main effect of Gamer, $F(1,246) = 5.11$, $p < .05$, no main effect of Experiment, $F(1,246) = 0.49$, $p = .482$ and a significant Gamer x Experiment interaction, $F(1,246) = 5.82$, $p < .05$. It should be noted that variance was not equal across all groups in this analysis. While this violates the assumptions of the Univariate ANOVA, given that the highest variance was only twice the lowest variance, it was assumed that this test would be robust enough to handle this violation. Planned independent samples t-tests were then conducted in order to clarify the nature of the Gamer x Experiment interaction reported above. These t-tests revealed that the difference in Critical ISI between E1 (Mean = 115ms, sd=52.1) and E2 (Mean = 98.7ms, sd=25.8) was significant within the VGP sample, *t*(72.1) = 2.01, *p* <.05 (Homogeneity of variances not assumed), but not for the NVGPs (E1 Mean = 115.9ms, sd = 54.8; E2 Mean = 125.8ms, sd = 45.3), *t*(132) = 1.15, *p* =.25 (Homogeneity of variances assumed). Once again, the results were consistent with the predictions outlined above. That is, when observers felt that their performance was publically observable (similar to their typical learning environment), VGPs exhibited a significant SOP advantage compared to NVGPs, in contrast to the private conditions of Experiment 1, where VGPs did not differ from NVGPs. Furthermore, in comparing the results of the two experiments directly, we can see that this difference is primarily due to a difference in the VGPs between experiments, as opposed to the NVGPs who did not differ significantly between E1 and E2. There is, however, and alternative explanation for these results. In addition to changing whether observers' performance was publicly observable, the simple fact that auditory feedback was provided in Experiment 2 was different than what occurred in Experiment 1. Therefore, it is possible that the difference in performance between these two experiments was actually based on VGPs and NVGPs benefitting differentially from feedback. Alternatively the results could be due to VGPs experiencing differing arousal levels than NVGPs in response to the relatively loud feedback tones. To test these alternative hypotheses, Experiment 3 was conducted, in which observers received the same auditory feedback regarding their performance as in Experiment 2, except that it was presented so that only they could hear it (i.e., privately).

2.3. EXPERIMENT 3

2.3.1. Methods

Participants:

Participants in Experiment 3 had the same restrictions and recruitment methods as those in Experiments 1 and 2. 30 NVGPs and 34 VGPs participated in this experiment. One participant was excluded based on their self-report of playing more than 60 hours per week, leaving a remaining sample of 33 participants in the VGP group. It should be noted that practical constraints on subject acquisition limited the number of participants in this experiment to a smaller size than those employed in Experiments 1 and 2.

Apparatus and Stimuli:

All visual stimuli in this experiment were identical to those in Experiment 2. The intensity of the feedback tone was recalibrated to produce an 80db tone as heard through headphones rather than through speakers.

Procedure:

All procedures were identical to those used in Experiment 2 with the following exception. The written instructions and research assistant verbal instructions were changed to indicate that the error feedback tone was purely for the observer's benefit for learning, and participants wore headphones such that only the observer would be able to hear it.

2.3.2. Results

For each observer, an over-all Critical ISI was calculated by averaging together the Critical ISIs for the three PEST procedures. Average Critical ISI was 112.1ms (sd=45.5) for VGPs and 123.7ms (sd=48.9) for NVGPs (see Fig. 4). An independent samples t-test showed that the two groups did not differ significantly from one-another $t(61) = .973$, $p = .335$ (Homogeneity of variance assumed).

These results are inconsistent with the alternative interpretation of the results presented in the Results section of Experiment 2. That is, the difference between the results of Experiments 1 and 2 cannot simply be ascribed to the fact that auditory feedback was presented in Experiment 2, but not in Experiment 1. Instead these results are consistent with the predictions outlined above, and support our previous conclusion that the difference between VGPs and NVGPs in Experiment 2 was due to making their performance publicly observable.

2.4. General Discussion

The objective of the present work was to attempt to establish whether action-oriented video-game players have improved visual speed of processing (SOP) relative to non-players, and if so, whether this improvement is conditional on the extent to which VGPs feel that they are being observed. It was originally hypothesized that VGPs would show an SOP improvement compared to NVGPs, but only when the testing conditions were similar to their typical playing conditions (i.e., when e they felt their performance was publically observable). The reason being that the transfer of learning would likely be best in these matching contexts (similar to what is observed in memory for studied items; e.g., Tulving & Thomson, 1973).

Experiments 1 and 2 supported this hypothesis, with VGPs performing no better than NVGPs when they were operating in privacy, but showing a significant SOP advantage when they were operating in conditions where they felt their performance was publically observable. Furthermore, Experiment 3 provided evidence to suggest that the difference observed in Experiment 2 was not simply due to the presence of feedback, but rather to the public conditions in which it was conveyed. It should be noted, however, that in our study we recruited participants based on their self-reports of their own time spent playing action video-games. Given this, we cannot determine whether a true causal link exists between video-game play and SOP. It may be possible that individuals who have a faster SOP, when their performance is being monitored, do better at playing video games, and thus find the experience more enjoyable and, therefore, play more. Conversely, those who have slower SOP, when their performance is being monitored, have difficulties with these games and, therefore, choose to stop playing them. A training, or longitudinal study would be necessary to make a causal claim about the effects of action video-game play on SOP.

2.4.1. Theoretical Implications:

These findings have important implications for both existing research on the effects of video-game play, as well as for future studies. Firstly, if the SOP advantage for VGPs can be expressed or not based on general laboratory conditions, it may help explain why some findings in this area have been inconsistently reported in the extant literature. That is, if the extent to which VGPs feel they are being observed is varying unrecorded between experiments, the SOP of VGPs will likewise vary. This would then result in improved performance for VGP when the experimental context provides a publicly-observable situation, but not when it is private. As previously mentioned, SOP may contribute to performance in a wide range of visual tasks. Thus, if SOP is varying between tasks due to an undocumented difference in testing parameters, it could lead to differing performance in those tasks in otherwise identical replications. It might be possible to review some of these existing conflicts in the literature, and see whether laboratory conditions differed between the studies. This would require contacting the researchers, and asking if they could provide a more detailed account of the methodologies that were used.

Secondly, these results should motivate a stronger focus on reporting general laboratory conditions when dealing with VGPs. It may be easy to forget that another researcher's laboratory may be laid out very differently than one's own, especially given that one spends a lot of time in one's own laboratory, and comparatively little time in others. By spending the extra effort, researchers can ensure that small differences in environment are not affecting results, especially when dealing with a group (such as VGPs) whose performance seems to be sensitive to such environmental conditions.

Thirdly, if the improvement found in VGPs is due to the very public conditions under which most VGPs typically play, this may have important implications for training studies. As mentioned previously, training studies do allow for stronger causal claims about the effects of video-game play, but care should be taken in the specifics of the training used. It may be tempting to train observers to play the video-game of choice in a controlled, offline laboratory environment to ensure that each observer has as similar a training experience as possible. If, however, the social environment in which games are being played is affecting research performance, such trained VGPs may not perform in the same fashion as those who play under more naturalistic conditions.

2.4.2. Future Research:

The most obvious direction for future research is to train VGPs rather than recruit them in order to make a causal claim. Ideally such a study would include conditions for non-action video-game play, action-video game play in a private environment, and finally action video-game play in a naturalistic online environment. Such conditions combined with the experimental paradigm used in this paper would clarify further the specific effects of action video-game play while eliminating the possibility of the effects observed here being due to self-selection. An additional avenue of research would be to investigate the extent to which SOP does influence other tests of attention and perception, as we proposed previously. By replicating previous experiments while also measuring SOP, it would be possible to see on which tasks SOP is correlated with task performance, and on which it is independent.

2.5. Figures

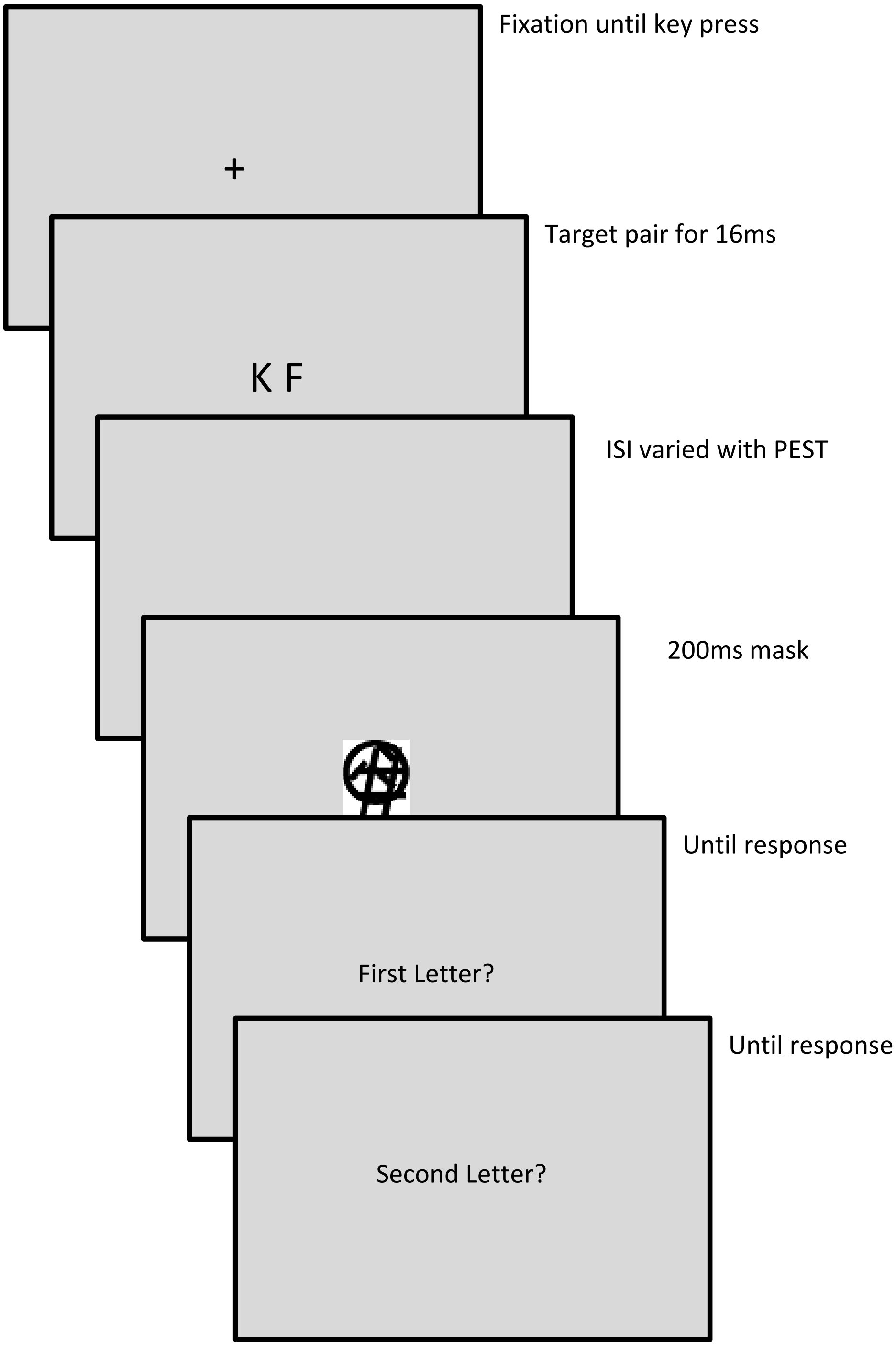

Figure 1: **Display Sequence**

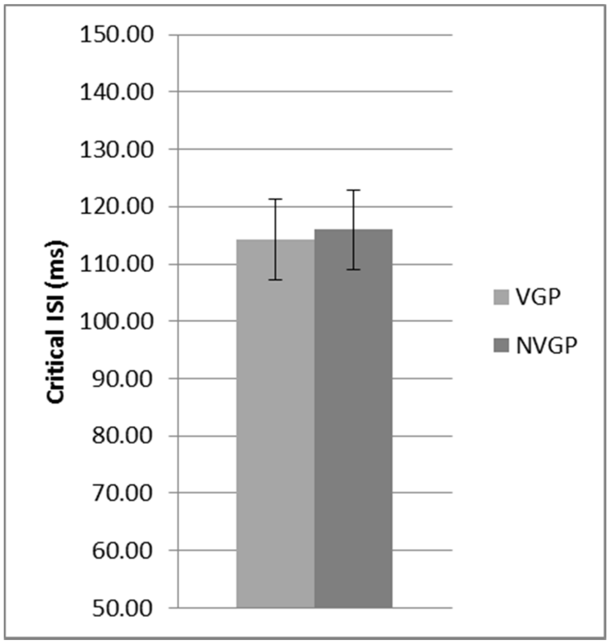

Figure 2: **Mean Critical ISI for VGPs and NVGPs in Experiment 1 with Standard Error Bars.**

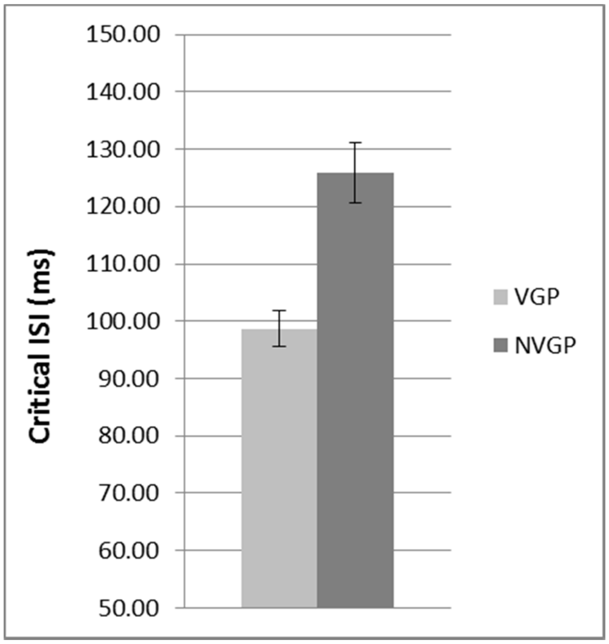

Figure 3: **Mean Critical ISI for VGPs and NVGPs in Experiment 2 with Standard Error Bars.**

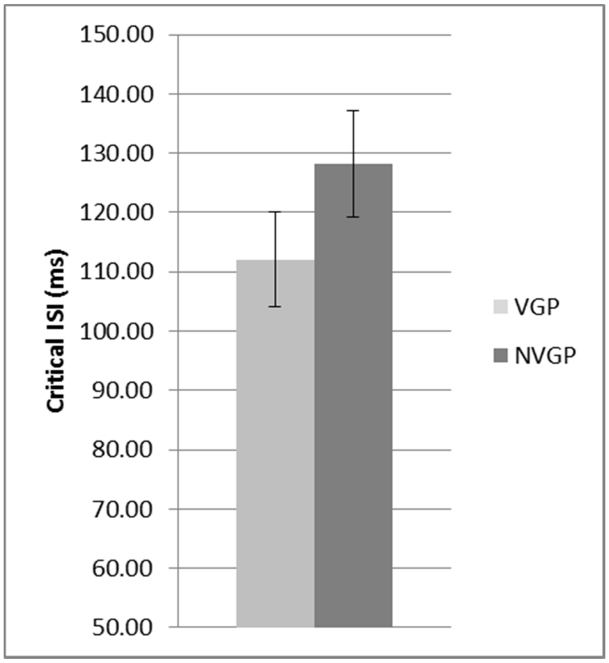

Figure 4: **Mean Critical ISI for VGPs and NVGPs in Experiment 3 with Standard Error Bars.**

References

Andrews, G., & Murphy, K. (2006). Does video game playing improve executive functioning?. In M. A. Vanchevsky, M. A. Vanchevsky (Eds.) , *Frontiers in: Cognitive psychology* (pp. 145-161). Hauppauge, NY, US: Nova Science Publishers.

Bavelier, D., Achtman, R. L., Mani, M., & Föcker, J. (2012). Neural bases of selective attention in action video game players. *Vision research*, 61, 132-143.

Blacker, K. J., Curby, K. M., Klobusicky, E., & Chein, J. M. (2014). Effects of action video game training on visual working memory. *Journal Of Experimental Psychology: Human Perception And Performance*, *40*(5), 1992-2004. doi:10.1037/a0037556

Boot, W. R., Kramer, A. F., Simons, D. J., Fabiani, M., &Gratton, G. (2008).The effects of video game playing on attention, memory, and executive control. *Actapsychologica,* 129(3), 387-398.

Bundesen, C. (1990). A theory of visual attention*. Psychological review*, 97(4), 523.

Cain, M. S., Prinzmetal, W., Shimamura, A. P., & Landau, A. N. (2014). Improved control of exogenous attention in action video game players. *Frontiers in psychology*, 5.

Carrasco, M. (2011). Visual attention: The past 25 years. *Vision research*, *51*(13), 1484-1525.

Castel, A. D., Pratt, J., & Drummond, E. (2005). The effects of action video game experience on the time course of inhibition of return and the efficiency of visual search. *Acta psychologica*, 119(2), 217-230.

Chisholm, J. D., Hickey, C., Theeuwes, J., & Kingstone, A. (2010).Reduced attentional capture in action video game players. *Attention, Perception, & Psychophysics*, 72(3), 667-671.

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

Dorval, M., & Pepin, M. (1986). Effect of playing a video game on a measure of spatial visualization. *Perceptual and motor skills*, 62(1), 159-162.

Dye, M. W., Green, C. S., & Bavelier, D. (2009). The development of attention skills in action video game players. *Neuropsychologia*, 47(8), 1780-1789.

Eriksen, C. W., & Schultz, D. W. (1979). Information processing in visual search: A continuous flow conception and experimental results. *Perception & Psychophysics*, 25(4), 249-263.

Feng, J., Spence, I., & Pratt, J. (2007). Playing an action video game reduces gender differences in spatial cognition*. Psychological science*, 18(10), 850-855.

Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature*, 423(6939), 534-537.

Green, C. S., & Bavelier, D. (2006).Effect of action video games on the spatial distribution of visuospatial attention. *Journal of experimental psychology*: *Human perception and performance*, 32(6), 1465.

Green, C. S., & Bavelier, D. (2007). Action-video-game experience alters the spatial resolution of vision. *Psychological science*, 18(1), 88-94.

Greenfield, P. M., DeWinstanley, P., Kilpatrick, H., & Kaye, D. (1994). Action video games and informal education: Effects on strategies for dividing visual attention. *Journal of applied developmental psychology,* 15(1), 105-123.

Irons, J. L., Remington, R. W., & McLean, J. P. (2011). Not so fast: Rethinking the effects of action video games on attentional capacity. *Australian Journal of Psychology*, 63(4), 224-231.

James, W. (1890). The principles of psychology. New York: Henry Holt and company.

Jannati, A., McDonald, J. J., & Di Lollo, V. (2015). Individual differences in rate of encoding predict estimates of visual short-term memory capacity (K). *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale*, *69*(2), 213.

Karle, J. W., Watter, S., & Shedden, J. M. (2010). Task switching in video game players: Benefits of selective attention but not resistance to proactive interference. *Acta psychologica,* 134(1), 70-78.

Kaufman, E. L., Lord, M. W., Reese, T. W., & Volkmann, J. (1949). The discrimination of visual number. *The American journal of psychology*, 498-525.

Lagroix, H. E., Yanko, M. R., & Spalek, T. M. (2012). LCDs are better: Psychophysical and photometric estimates of the temporal characteristics of CRT and LCD monitors. *Attention, Perception, & Psychophysics*, *74*(5), 1033-1041.

Li, R., Polat, U., Makous, W., & Bavelier, D. (2009). Enhancing the contrast sensitivity function through action video game training*. Nature neuroscience*, 12(5), 549-551.

Posner, M. I., Rafal, R. D., Choate, L. S., & Vaughan, J. (1985). Inhibition of return: Neural basis and function. *Cognitive neuropsychology*, 2(3), 211-228.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink*? Journal of Experimental Psychology: Human Perception and Performance*, 18(3), 849.

Roethlisberger, F. J., & Dickson, W. J. (2003). Management and the Worker (Vol. 5). Psychology Press.

Sagi, D., & Tanne, D. (1994). Perceptual learning: learning to see. *Current opinion in neurobiology*, 4(2), 195-199.

Schubert, T., Finke, K., Redel, P., Kluckow, S., Müller, H., &Strobach, T. (2015). Video game experience and its influence on visual attention parameters: an investigation using the framework of the Theory of Visual Attention (TVA). *Actapsychologica,* 157, 200-214.

Sekuler, R., & Ball, K. (1986). Visual localization: Age and practice. *JOSA A*, 3(6), 864-867.

Spence, I., & Feng, J. (2010).Video games and spatial cognition. *Review of General Psychology*, 14(2), 92.

Subrahmanyam, K., & Greenfield, P. M. (1994). Effect of video game practice on spatial skills in girls and boys. *Journal of applied developmental psychology*, 15(1), 13-32.

Taylor, M., & Creelman, C. D. (1967). PEST: Efficient estimates on probability functions. *The Journal of the Acoustical Society of America,* 41(4A), 782-787.

Thorpe, S., Fize, D., & Marlot, C. (1996). Speed of processing in the human visual system. *Nature*, 381(6582), 520-522.

Tulving, E., & Thomson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory*. Psychological review*, 80(5), 352.

Wilms, I. L., Petersen, A., & Vangkilde, S. (2013). Intensive video gaming improves encoding speed to visual short-term memory in young male adults. *Actapsychologica*, 142(1), 108-118.