EXAMINATION OF THE EFFECTS OF ACTION VIDEO GAME EXPERIENCE ON VISUAL REPRESENTATION OF OBJECTS

HANDE SUNGUR

BOGAZICI UNIVERSITY

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EXAMINATION OF THE EFFECTS OF ACTION VIDEO GAME EXPERIENCE ON VISUAL REPRESENTATION OF OBJECTS

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Hande Sungur

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Thesis Abstract

Hande Sungur, "Examination of the Effects of Action Video Game Experience on Visual Representation of Objects"

Previous research has demonstrated improvements in visual and spatial attention for expert action video game players. The present study investigated action video game play related improvements in (1) visual short-term memory capacity and (2) changes in the nature of object representations by comparing expert video game players (VGP) and non-video game players (NVGP) by employing the Multiple Identity Tracking (MIT) task, Color Wheel (CW) task and finally the Useful Field of View (UFOV). Firstly, results of the MIT task showed that VGPs could accurately track more objects and maintain object identities better than NVGPs. Secondly as demonstrated by the results of the CW task, VGPs could remember the color of a probed item on a briefly shown display more accurately than NVGPs. Finally, VGPs were more accurate in locating briefly appearing targets across the visual field. Overall, these results suggested that in addition to improving spatial attention, action video game experience also improves object processing abilities by enhancing some aspects of the visual short term memory processes.

Tez Özeti

Hande Sungur, "Aksiyon Türündeki Bilgisayar Oyunları Oynamanın Nesnelerin Temsili Üzerindeki Etkilerinin İncelenmesi"

Bu çalışma, aksiyon türündeki bilgisayar oyunları oynamanın görsel sistemde yol açtığı gelişmeleri deneyimli bilgisayar oyuncuları ve bilgisayar oyunları oynamayan kişileri karşılaştırarak inceledi. Özellikle, aksiyon oyunlarının (1) görsel kısa süreli hafızanın kapasitesine ve (2) nesnelerin görsel olarak temsil edilmesine yaptığı etkiler incelendi. Bu sorulara yanıt bulabilmek için üç farklı testten faydalanıldı. Bunlar: Çoklu Kimlik Takibi testi, Renk Çemberi testi ve son olarak da Kullanılabilir Görüş Alanı testleridir. Yapılan her ölçümde aksiyon oyuncuları için oyun oynamayan gruba göre anlamlı gelişmeler bulundu. Sonuçlar, aksiyon oyuncularının, oyun oynamayan kişilere oranla daha doğru olarak 1) hareket halindeki çok sayıdaki nesnenin kimliğini takip edip hatırlayabildiğini, 2) kısa süreli olarak gösterilen bir sunudaki nesnelerin renklerini hatırlayabildiğini ve yine 3) kısa süreli olarak ekranın farklı eksenlerinde ortaya çıkan nesnelerin yerlerini belirleyebildiklerini gösterdi. Bu sonuçlar, alansal dikkatte gözlenen ilerlemenin yanı sıra , aksiyon oyuncularının kısa süreli görsel hafızadaki bazı gelişmelerden dolayı, nesnelerin temsili konusunda da oyun oynamayan kişilere göre daha başarılı olduklarını göstermiştir.

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CONTENTS

CHAPTER 1

INTRODUCTION

In the last few decades, there has been growing interest in the impact of video games on cognitive skills. Action video games typically require players to process rapidly moving and peripheral objects as efficiently as slow moving and central ones; multiple target objects have to be simultaneously tracked and further processed. Cognitive psychologists have been interested in whether playing such demanding video games can improve basic cognitive functions, such as attention. Therefore, much research has compared video game players (VGPs) to non-players (NVGPs) across a number of cognitive domains, mostly involving visual information processing. These experiments found that VGPs have improved skills in the visual domain compared to NVGPs. Specifically, these experiments found that VGPs have greater central and peripheral attentional resources; thus they are better at localizing targets in all parts of the visual field (Green & Bavelier, 2006a). Also, VGPs have been shown to simultaneously apprehend and track a greater number of items compared to NVGPs (Green & Bavelier, 2006b, Trick, Jaspers-Fayer, & Sethi, 2005). Training studies have further confirmed that the aforementioned improvements are caused by video game playing and do not merely reflect higher ability individuals choosing to play video games. [1]

Previous research has focused on video game playing based improvements in visual and spatial attention abilities. However, the question of whether video game playing experience changes how objects are processed has not been explored. Video

[1] Green and Bavelier (2003, 2006a, 2006b, 2007), trained half of the NVGPs with an action video game and the other half with Tetris. After 10-30 hours of training, all the improvements observed for VGPs were observed for the action video game trained group but not for the Tetris trained one. See Achtman et al. for a review on training effects (Achtman, Green & Bavelier, 2008).

games do not only require determining spatial locations of objects, but also require fast and accurate identification of objects and their features. Therefore, it can be reasoned that object processing might benefit from video game play experience as well. In this thesis I investigated whether VGPs have more detailed and durable object representations.

Video Game Playing and Improvements in Spatial Attention

Various studies have shown that VGPs are able to attend to a wider region and they are better at differentiating targets from distractors, especially when both targets and distractors are packed in a small region. In this section, I summarize the empirical basis for these conclusions.

Green and Bavelier (2006a) demonstrated that VGPs have greater spatial attentional resources compared to NVGPs. In their first study, they used the perceptual load paradigm. The perceptual load view argues that selective attention process is influenced by the perceptual load of a task (Lavie, Hirst, Viding, & de Fockert, 2004). In a detection task, when the perceptual load in a visual display is high (i.e. when there are distractors present in addition to the target task), the perceptual selection mechanism will discard these irrelevant distractors because there will not be enough resources to process them. Green & Bavelier (2006a) found that VGPs were distracted more than NVGPs when the perceptual load of a task was high. This suggested that VGPs had enough attentional resources left to process the distractors even under high loads while NVGPs were unable to spare any of their mental resource to process the distractors. Similarly, West and colleagues showed that VGPs were more sensitive to attention capturing effects of an exogenous cue

(West, Stevens, Pun & Pratt, 2008). In a second experiment, Green and Bavelier (2006a) used the Useful Field of View (UFOV) task to test viewers' ability to localize briefly presented targets. Targets were presented at three different eccentricities (10° = within, 20° = at the border, and 30° = beyond the action video game experience) to determine whether the enhancement gained by action video game experience altered processing throughout the visual field or just within the visual region typically encountered in video games. The results showed higher performance for VGPs to localize targets in all three eccentricities. Similarly, Feng and collegues also showed improvements for VGPs in the UFOV task (Feng, Spence, & Pratt, 2007). These experiments, demonstrated that VGPs have more attentional resources that can be utilized for processing items that are in the center as well as in the periphery of one's visual field. Thus, it is argued that visual attentional benefits from action video game playing experience generalize to the "untrained" parts of the visual space.

In addition to these tasks, Green and Bavelier (2007) used the crowding paradigm to show that action video game playing is indeed causing changes in the fundamental characteristics of visual processing. In visual search tasks, crowding refers to how it is more difficult to identify a target when the space/distance between itself and a distractor decreases. The space around a target where a distractor causes a decrease for the sensitivity of identifying that target is called the crowding region (Tripathy & Cavanagh, 2002). Crowding effect reflects a fundamental aspect of spatial attention because it involves the critical spacing needed for selection and identification of targets and the size of the crowding region is considered to be an index of spatial resolution (Intriligator & Cavanagh, 2001; Tripathy & Cavanagh, 2002). Green and Bavelier (2007) found that VGPs could identify targets that have smaller target-distractor distances compared to NVGPs. This improvement was observed similarly at different eccentricities. Seeing an improvement at 25° suggested that changes resulted by action video game experience were generalizable to the untrained areas. On the other hand, observing an improvement at the 0° eccentricity (at which everybody should have a very high resolution) showed that there can be improvements even within a region that was typically thought to have optimal resolution. In addition to these findings, they found that VGPs were able to discriminate smaller targets (in this case letter "t") than NVGPs. Together these results demonstrated that VGPs have smaller regions of crowding and higher visual acuity thresholds than NVGPs. Thus, VGPs are said to have higher spatial resolution.

Video game Playing and Improvements in Visual Attention

Video game playing improvements have been observed not only in spatial attention tasks but also with tasks that measure visual attention, especially those characterized with rapid information processing requirements. Specifically, Castel and colleagues (Castel, Pratt & Drummond, 2005) showed that VGPs have faster target detection abilities than NVGPs. They showed that VGPs have overall faster RTs than NVGPs on a visual search task (see Dye, Green, & Bavelier, 2009 for a review of findings on faster RT's for VGPs). Similarly West et al. showed that VGPs were more accurate at detecting the change in direction of motion than NVGPs across different eccentricities of the visual field (West et al., 2008). Also Li and colleagues recently showed that VGPs were more sensitive to changes in the contrast (small increases in shades of gray) than NVGPs (Li, Polat, Makous, & Bavelier, 2009).

Additionally, Green and Bavelier (2003) used an attentional blink paradigm to explore possible improvements for VGPs in the temporal characteristics of visual attention. Since action video games require rapid actions to be taken on various visual stimuli, this might have altered the temporal characteristics of visual processing and might have provided an enhancement on temporal bottlenecks such as the attentional blink. Attentional blink (AB) refers to the difficulty of reporting a second target item, which appears 200-500 ms after the onset of the first target in a rapid serial visual presentation (Raymond, Shapiro & Arnell, 1992). Green and Bavelier (2003) used an AB task and found that VGPs were around 30 % more accurate in identifying the second target item then NVGPs when there are up to five intervening items between the two targets. As the number of the intervening items increased the difficulty to identify the second target disappeared and two groups became comparable. Therefore, the results of these experiments showed that video game playing improves the processing of visual information over time, the speed of target detection and the ability to switch between identification and detection processes.

Video Game Playing and Improvements in Enumeration and Multiple Object Tracking

In addition to showing improvements in the spatial distribution and temporal dynamics of visual attention, Green and Bavelier (2006b) in two separate paradigms, also demonstrated that action video game playing increases the number of visual objects that can be apprehended.

In the enumeration task several items are briefly flashed in a visual display and participants are required to determine the number of items in the display as accurately and as fast as possible (Trick & Pylyshyn, 1994).The general finding from enumeration tasks is that people can accurately and rapidly report when up to four items are presented. The range in which additional number of items can be attended without significant additional RT costs is called the subitizing range. When this range (up to four items) is exceeded, then accuracy drops and RT increases monotonically for each additional item. It is proposed that the subitizing range can be used to estimate the number of items that can be simultaneously attended and that this ability utilizes preattentive mechanisms (Pylyshyn, 1989). Preattentive processes occur in an automatic and parallel fashion prior to attention and provide an information basis for attentional selection (Logan, 1992).

Green and Bavelier (2006b) showed that VGPs were able to accurately enumerate about two more items than NVGPs. Exactly what underlies this benefit is unknown. According to Green and Bavelier (2006b), performance on the enumeration task may be determined by two main processes, (1) a parallel more automatic process which is preattentive and depends on subitizing ability and (2) a more active and conscious counting seen at higher numerosities. Green and Bavelier (2006b) attributed the improved performance of VGPs in the enumeration task to improvements in this latter “counting” phase. In the subitizing range (up to 3 items), VGPs and NVGPs had similarly flat RTs suggesting that video game play experience did not result in improvements in preattentive processes. However, when the two groups were compared beyond the subitizing range (when additional items had increased RT costs), it was seen that VGPs could accurately enumerate two more items than NVGPs. Since VGPs and NVGPs differed from each other beyond the subitizing range, Green and Bavelier (2006b) attributed the improvement to the latter “counting” aspect of the enumeration task. They argued that VGPs may be benefiting from improvements in some aspect of visual short- term memory. Specifically, they argued that VGPs compared to NVGPs, may be able to continue counting more objects from memory after these objects had disappeared from view. Another possibility they proposed was that VGPs could cycle through their memory traces faster and keep them active better than the NVGPs (Green & Bavelier, 2006b).

The Multiple Object Tracking (MOT) task is another task in which video game playing benefits in visual short-term/working memory have been reported. The MOT task requires one to track identical and yet randomly moving targets among identical distractors and has been thought to rely on preattentive skills (Pylyshyn, 1989). Green and Bavelier (2006b) was the first to compare VGPs and NVGPs on this task.

In the MOT task, people are required to track of multiple moving targets among distractors. In the typical version of this task, first, a number of identical objects are presented. Then, some of these objects are tagged and viewers are told to track this subset of items. The task requires viewers to keep track of these cued circles which are identical to the other non-cued distractors. Typically, people can track at least four items among eight identical items for 10sec, with 85-90 % accuracy[2] (Pylyshyn, 2004). Both Green and Bavelier (2006b) and Trick and colleagues demonstrated that VGPs were able to successfully track two more items than NVGPs (Trick et al., 2005). As the number of circles to track increased and the task got harder, performance decreased for both groups. Most improvement for the VGP group was observed when there were three to five circles to track. For conditions that require tracking of less than three or more than five circles VGP and

[2] Movement speed, methods used to identify the targets and other task related factors were shown to modify the performance in the MOT task (Alvarez & Franconeri, 2004; Oksama & Hyönä, 2004, 2008).

NVGP performance was comparable. This finding was similar with the finding from the enumeration task. In both tasks, VGPs and NVGPs seemed to have a similar performance for low numerosities while improvements for VGPs were observed after a critical threshold was reached. Given that VGP and NVGP performed similarly within the subitizing range, Green and Bavelier (2006b), once again argued that video game playing benefits in the MOT task cannot be attributed to improvements in preattentive processes. Rather, this improvement has been attributed to changes in visual short-term memory related processes

Object Processing and Multiple Object Tracking (MOT) Test

The focus of almost all previous research comparing VGPs and NVGPs has generally been on the improvements of the spatial distribution of visual attention. Up until now, video game playing related improvements on object processing has not been examined thoroughly. This is particularly interesting given how the MOT task is sometimes linked to object processing rather than just spatial attentional processing. In this section, I will briefly summarize different positions on the object processing requirements in the MOT task. Then, I will present evidence from a more recently designed paradigm which convincingly demonstrated that objects are content-addressable during object tracking.

There are different views about whether object processing is involved in the MOT task. The three main models which try to explain the mechanism behind tracking multiple objects are Preattentive indexes -FINST (Pylyshyn, 1989; 2004), Object files (Kahneman & Treisman, 1984; Kahneman, Treisman, & Gibbs, 1992), and Perceptual grouping (Yantis, 1992) theories (see Cavanagh & Alvarez, 2005 for more models). These models differ in their assumptions about whether object features can be processed during tracking.

The FINST (Fingers of Instantiation) theory states that MOT performance is mediated by preattentive representations (Pylyshyn, 1989, 2004). This view suggests that there is a preattentive mechanism in the visual system for individuating objects and for indexing their locations within the visual field. According to this view, there are finger like indexes that we can use to point to different objects which can then guide our attention. In the case of MOT, the preattentive FINST can be placed on the target objects at the start of the trial and then can be reported after tracking ends. When an index is placed on an object it does not need to be refreshed and attention is not required to keep the connection between the target and its location. According to FINST theory, content of the objects is not addressable while they are being tracked. The FINST view argues that these preattentive indexes can only pick out and track the individual items. It is argued that higher level processes, such as identification of object features and identities, can not penetrate these early preattentive processes. Thus, when items are indexed, they are all treated as if they are the same, and no individuation information about each is encoded (Pylyshyn, 2004).

According to Kahneman and Treisman's Object Files theory (Kahneman & Treisman, 1984; Kahneman, et al., 1992), a file is opened when an object is attended. Then the information about the object such as its location or features can be entered into this representation file. As the visual scene dynamically changes, the changing information about the object will accumulate in this file. This way a perceptual continuity is established in a dynamically changing tracking environment and we can know it is the same object even though the characteristics (location, features etc.) of the object have changed. Since the information about the object is constantly updated this view makes it possible to access the object information during multiple object tracking.

The final approach explaining how tracking multiple objects works is Yantis' perceptual grouping theory (Yantis, 1992). According to this theory, when multiple objects are tracked the target objects are grouped into a single virtual object. Participants create a virtual polygon in which the target items compose the corners of the polygon. Participants can keep track of the targets by following the movement of this virtual polygon. Yantis supported this view by showing that the ease of grouping and maintaining the polygon changed the performance in the MOT task. Participants showed better performance when targets formed a virtual canonical polygon (such as a triangle) with a coherent motion path, than when targets formed an irregular virtual polygon and the polygon collapsed over itself (folded) as the objects standing in for its vertices, moved.. This theory is not very clear about whether object identities are processed during tracking but according to Yantis, maintaining the virtual polygon requires an effortful, non-automatic, goal directed attention. Therefore, the virtual indexing involved in the perceptual grouping theory is different than Pylyshyn's FINST theory in which indexes get attached to targets and maintained during tracking automatically.

An answer for the question of whether object features can be processed during location tracking came from the development of the Multiple Identity Tracking (MIT) task (Oksama,& Hyönä, 2004). In the MIT task, instead of identical items, unique objects are tracked making it a closer analogue of real-world tracking tasks like keeping track of players during a football game or air traffic control. The MIT task is theoretically very important that it allows one to investigate the extent to which object content is addressable during tracking.

Horowitz and colleagues used unique cartoon animals as the objects in a multiple tracking task (Horowitz, Klieger, Fencsik, Yang, Alvarez & Wolfe, 2007). In this task, after tracking was completed the unique targets disappeared beyond occluders. Participants were then required to report either the locations of all cued animals (Standard condition), or the location of a particular animal (Specific condition). Since only the locations of objects are asked in the Standard condition, one would not need to know specific object identities. However, accurate answers in the Specific condition would need one to know exactly which object was hidden where, requiring identity of objects to be processed and maintained during tracking. Horowitz et al. (2007) found that participants were able to accurately identify objects in the Specific condition, suggesting that object content is addressable during tracking.

In an earlier MOT study, Pylyshyn (2004) could not find evidence that identity information was retained during tracking. In his experiment he used identical looking items but in the initial presentation these items were presented in the different corners of the screen or a number was briefly shown together with these items. Participants were required to remember this identity information during tracking and report at the end of the task. However, participants were not successful in keeping the identity information about the target and Pylyshyn concluded that it is not possible to process object information during tracking. Horowitz et al. (2007) pointed that the identity information regarding the objects were not based on any intrinsic features like shape or color. Instead, they were based on loose markers (the corner of the display the items started the trial, or which number is presented along with them). Additionally, these identity markers were not available through tracking but were only briefly presented before the trials began. Therefore, items looked identical during tracking. Horowitz et al. (2007) suggested that using extrinsic identity features and making them unavailable during tracking might have made it hard to maintain any content based object representations in Pylyshyn's experiment (2004). In Horowitz et al.'s (2007) and Oksama and Hyönä's (2004) designs the objects used for tracking had unique shapes and identities and these identities were available during the whole tracking process. Therefore, it was possible for them to observe that feature information can be attended when tracking multiple items.

In conclusion, the results of two separate MIT studies (Oksoma & Hyönä, 2004; Horowitz, et al., 2007) have provided strong evidence for content-addressability in multiple object tracking. Evidence from MOT tasks have clearly shown video game playing improvements on this task, attributed particularly due visual short-term memory related processes. Given object processing related improvements in VGPs, I predicted that these individuals would perform disproportionately better on the MIT task than NVGPs.

Aim of This Thesis

Previously mentioned studies demonstrated improvements for VGPs in visual and spatial attention (Achtman et al., 2008, Castel et al., 2005, Feng et al., 2007, Green & Bavelier; 2003, 2006a, 2006b, 2007, West et al., 2008). Given the close link between attentional processes and short-term memory processes (e.g. Wheeler & Treisman, 2002), in this thesis, I directly investigated action video game playing related improvements in 1) visual short-term memory capacity and 2) changes in the nature of object representations. To pursue these questions, I utilized two separate paradigms, the MIT task and a color wheel task (described below). In the next section, I discuss these two tasks and predictions for each, in greater detail.

In the MIT task, as discussed above, performance is determined not only by an ability to track the movement of indexed items, but also by an ability to remember their individual features. Such maintenance in visual short-term memory is modulated by visual attention. Given that VGPs have increased visual attentional resources, I predicted that action video game experience would increase accuracy in the specific condition. Furthermore, since the Standard condition of the MIT task is analogous to the MOT task, I expected VGPs to do better than NVGPs in line with previous findings (Green & Bavelier, 2006b; Trick et al., 2005).

Visual Short-Term Memory Capacity and Nature of Object Representations

Visual short-term memory capacity is typically measured by the visual change detection paradigm. In this paradigm, people are presented with two consequent displays and they are asked to determine whether a change occurs between these two displays. By varying the types of information changed between the first and second displays, a researcher can infer how many features a participant can maintain in short-term stores. Early studies clearly demonstrated that visual short-term memory capacity was around four objects (e.g. Alvarez & Cavanagh, 2004; Luck and Vogel, 1997). However, no consensus has been reached regarding the impact of object complexity on capacity. Luck and Vogel (1997) argued that the capacity of visual short-term memory was fixed to four based on the finding that participants could successfully detect a change between two displays when four simple objects were presented. Participants also performed equally well when these four objects had up to four features each. However, when object number was beyond four, change detection accuracy dropped. Therefore, they concluded that capacity is determined mainly by the object number and not complexity or the number of the features. However, Alvarez and Cavanagh (2004) demonstrated that the capacity of visual short-term memory was inversely related to the complexity of items. They showed that a maximum of four objects can be maintained in short-term memory for less complex object categories such as colored squares compared to more complex ones like Chinese characters. This finding suggested that an inverse relationship between capacity and object complexity may exit and that representation resolution is a critical factor in determining capacity.

In a more recent study, Zhang and Luck (2008) investigated the relationship between representation resolution and capacity using a method that allowed them to independently estimate the VSTM capacity and the "resolution" of representations maintained in VSTM. In their experiment they presented viewers a number of colored squares. Then, in the test phase they probed one of the locations where the objects appeared at and asked participants to report the color of the probed square from a color wheel including 180 color options. To test the relationship between capacity and resolution of representations, Zhang and Luck manipulated the study load and compared participants' responses across different conditions. Zhang and Luck argued that there were two kinds of responses in this task: If the probed item was in the memory, then the participants were expected to choose a color similar to the studied color. The degree of similarity between the probed color and the color picked by the participant was taken to indicate how well the color was represented. In other words, the greater the similarity between the studied and the chosen color, the higher the resolution of the represented item is. However, Zhang and Luck (2008) argued that for the trials in which the probed item had not been stored, then the responses should be random.

To account for both types of responses, Zhang and Luck (2008) used a mixture model. The mixture model consisted of two distributions: 1) For the items in memory, they expected the distance between studied item and responses to be normally distributed, 2) for items that were not in memory they assumed that the random responses would be a uniform distribution. These two distributions were combined and certain variables of the outcome distribution were compared across different memory loads. There were two critical variables of the outcome distribution, Pm was the peak of the outcome distribution and reflected the probability of having the probed item in memory, and was used as an index of VSTM capacity. The second variable was the standard deviation of the outcome distribution, indicating the average deviation of the color responses from the actual value of the color. This value was taken to be an index of the resolution of the representation. Comparing across high and low memory loads, Zhang and Luck (2008) demonstrated that memory load did not lead to changes in representation resolution. In other words, they found evidence that there are a fixed number of representation slots allowing each one of the objects to be represented with equal resolution (fixed slot, fixed resolution model). However, more recently Bays and Husain (2009) questioned their modeling assumptions and conclusions.

In this thesis I used the above-described color wheel task to investigate whether there is any video game playing related changes in object representations. Specifically, I compared VGP and NVGPs on both VSTM capacity and representation resolution. If video game playing increases VSTM capacity, then VGPs would be expected to make less errors, and may even have a greater proportion of low error trials. Furthermore, given that video games typically force viewers to differentiate between visually similar targets, it is possible that players would form higher resolution representations than NVGPs. Thus, I expected the variance of the distribution of VGP responses to be less than that of the NVGPs'.

In addition to these two tasks the Useful Field of View (UFOV) task was also administered. The UFOV task measures the ability to locate briefly presented objects across the visual field. Green and Bavelier (2006a) found improvements in VGPs' performance in this task and concluded that they have greater spatial attention. This task was included to confirm that our sample showed benefits in visual attention tasks in which previous literature has consistently revealed action video game related improvements.

In sum, I expected to find (1) an increased number of remembered objects in the Specific condition of MIT task and (2) less errors and smaller deviations of the reported colors from the actual colors in the color wheel task for VGPs compared to NVGPs. Additionally, I expected to observe: (3) increased number of remembered objects in, the Standard condition of MIT task and (4) improved performance in the UFOV task for VGP group.

CHAPTER 2

METHOD

Participants

The same criterion was used for the selection of video game players as in Green and Bavelier's studies (2003, 2006a, 2006b, 2007). To be considered a VGP, one had to be playing action video games a minimum of three to four days a week, for at least one hour per day for the last six months. Among the games VGPs reported playing were Call of Duty, Counter Strike, Half Life, Serious Sam, Grand Theft Auto, Assassins Creed, and World of Warcraft-PvP. NVGPs had no action video game play experience in the last six months. However, these participants may have played video games belonging to other genres (e.g. Strategy, puzzle, adventure, role playing, construction, and management games). Nevertheless, in our sample, many NVGPs (17 out of 38, 45%), reported no video game experience at all. Remaining participants reported to play video games from other genres as little as once in a month. Participants were all Bogazici University students and were given course credit in return of their participation. Twenty-four male VGPs and thirty-eight NVGP (21 male and 17 female) participated in this study. For the VGP group the average age was 19.9 (*S.D*= .97) and for the NVGP group it was 20.7 (*S.D*=1.42) years. All participants had normal or corrected to normal vision.

Due to software malfunctioning in the MIT task and changes in script in the color wheel task, the data included in analyses varied. Furthermore, for each task outlier performance was determined and those subjects were selectively excluded from analyses. Below, I provide a break-down of the sample for each task.

UFOV Task

Twenty-four male VGPs and thirty-eight NVGPs (21male and 17 female) participated in the experiment. Data from one male and three female NVGPs' were not included in the analyses since the accuracy of responses for these participants were two standard deviations lower than the average mean (also the performances were below chance level). Additionally, one female NVGP could not complete the task. Therefore, data from twenty-four VGPs and thirty-three NVGPs is reported.

MIT Standard Condition

Twenty-four male VGPs and thirty-eight NVGPs (21 male and 17 female) participated in the experiment. Data from three male NVGPs were removed from analysis because of a program error that occurred during the data collection. Therefore, analyses were based on twenty-four VGPs and thirty-five NVGPs.

MIT Specific Condition

Twenty-three male VGPs and thirty-one NVGPs (20 male and 11 female) participated in the experiment[3]. Similarly, data from three male NVGPs could not be included in the analysis because of program error. Data from twenty-three VGP and twenty-eight NVGP is reported.

[3] There were less participants in the Specific MIT task. Eight participants (1 VGP and 7 NVGP) could not take the Specific condition of the MIT task since this task was not fully completed at the beginning of the data collection process.

Color Wheel Task

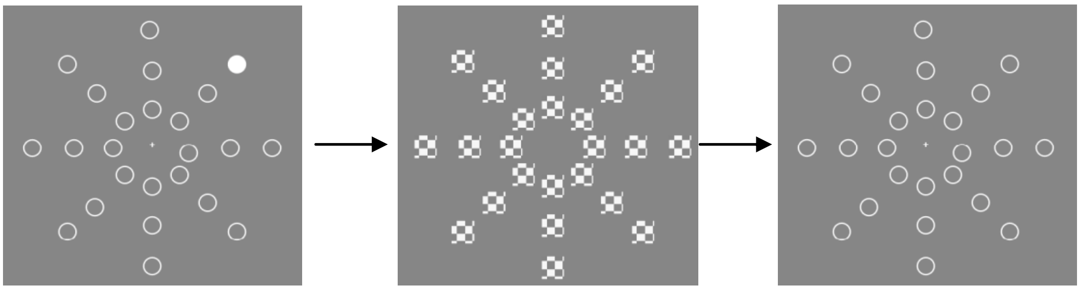
Twenty-four male VGPs and thirty-five NVGPs (20 male and 15 female) took the color wheel task. However, I realized that a shift had occurred during the creation of the color wheel, which led to an incompatibility between cued colors and the colors on the color wheel. Therefore, the data collected on the incorrect version of the task had to be discarded. Therefore, the data from thirteen male VGPs and eighteen NVGPs (12 male and 6 female) was reported in the analyses.

Materials

Useful Field of View (UFOV) Task

In the UFOV task participants were asked to locate a briefly presented target that appeared at different eccentricities (10°, 20° and 30°) (Ball et al.,1990). The target appeared in one of twenty-four locations which were equally distributed around a common center forming three co-centric circles. The three eccentricities used in this task corresponded to visual fields which are; 10°= inside, 20° = border and 30°= outside of common video game play experience. The target appeared at each eccentricity and each location equally often (3 times at each location).

After seeing the target, participants then had to determine where they had seen the target. There were ten practice trials in which accuracy feedback was given. Upon completion of the practice trials, participants completed seventy-two experimental trials. Only the data from this part of the experiment was used in the analysis. Accuracy, reaction time and the location of the response were recorded. Figure 1 depicts a typical trial of the UFOV task.



67 msec. 1000 msec. Until response

Fig. 1 Progression of the UFOV task. A target appears for 67msec. in one of the twenty-four positions. Then for 1000 msec. all possible locations are masked. Finally the response screen appears with the twenty-four possible locations. Response screen stays until a response is given.

Each trial began with the question “Ready?” appearing in the middle of the screen. Once the participants were ready, they clicked the mouse and a white target appeared randomly in one of the twenty-four locations for 67 msec. Following the target, a checkerboard pattern mask appeared covering all possible locations for 1000ms to prevent any afterimages. Then a response screen with the twenty-four empty circles displaying all possible response locations appeared. Participants were asked to click on where the object appeared as accurately and as quickly as possible.

Multiple Identity Tracking (MIT) task

The MIT task developed by Horowitz[4] et al. (2007) was adopted with minor differences. In this task contrary to identical objects used in typical MOT tasks, unique cartoon animals were used. Eight unique animals were randomly selected among 23 possible animal images at the beginning of the experiment. (A) Four randomly selected images among these eight were highlighted by blue squares for 3 seconds and identified as target objects. After 3 seconds these blue squares disappeared and (B) the images started to move around the screen with 5° per second. When two items came too close they repelled each other and bounced off following the natural trajectory for that occasion. Objects similarly moved when they came close to the boundaries of the screen. Objects moved between 5-10 seconds Trial duration varied to keep the participants attention on the task. (C) After the objects stop they were masked by gray squares which hid their identities. At this point depending on the condition the requirement of the task changed.

Standard Condition:

In the Standard condition of the MIT task, participants were required to report all the target items by clicking on the images which were covered by the gray squares in the order they desired.

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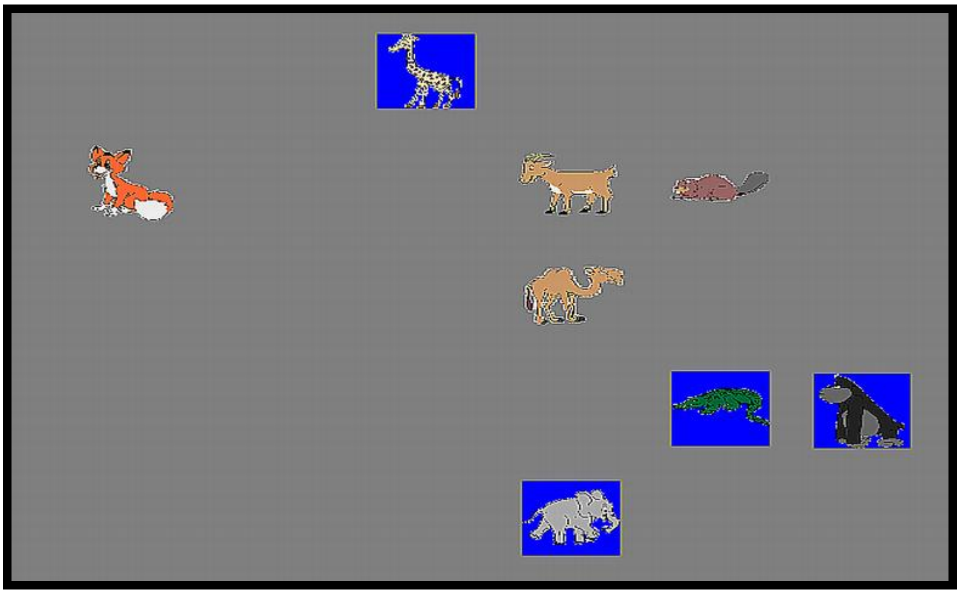
[4] I would like to thank Todd Horowitz for sharing the script for the MIT task.

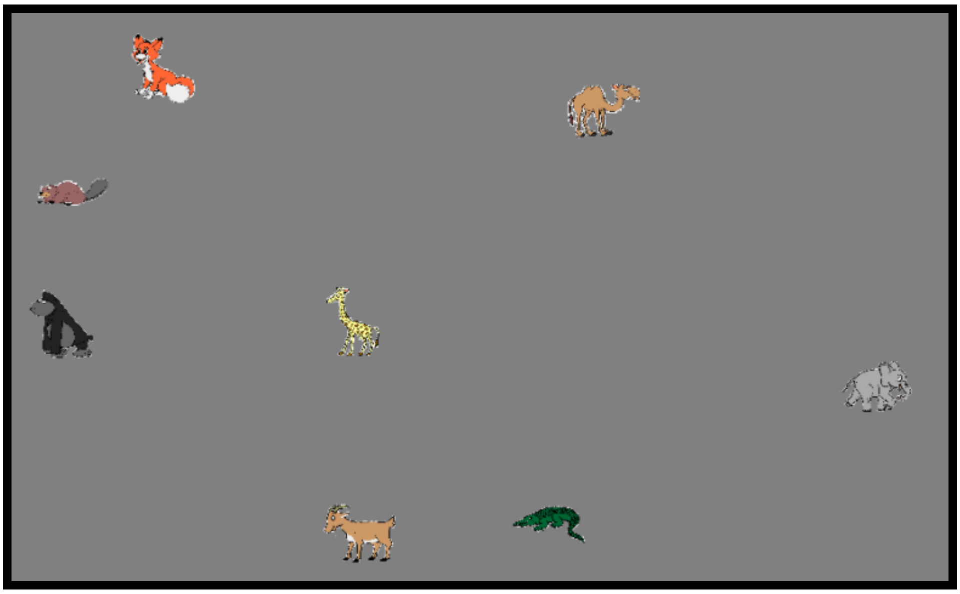
Specific condition:

In the Specific condition after the images were hidden by the gray squares the name of one of the four target animals appeared on the screen. This animal was selected randomly among the four targets every trial. The participants then had to click on the gray square which they thought was the requested target animal. The names which were used to refer to the animals in the experiment were shown to participants prior to the experiment to prevent any different labeling by the participant.

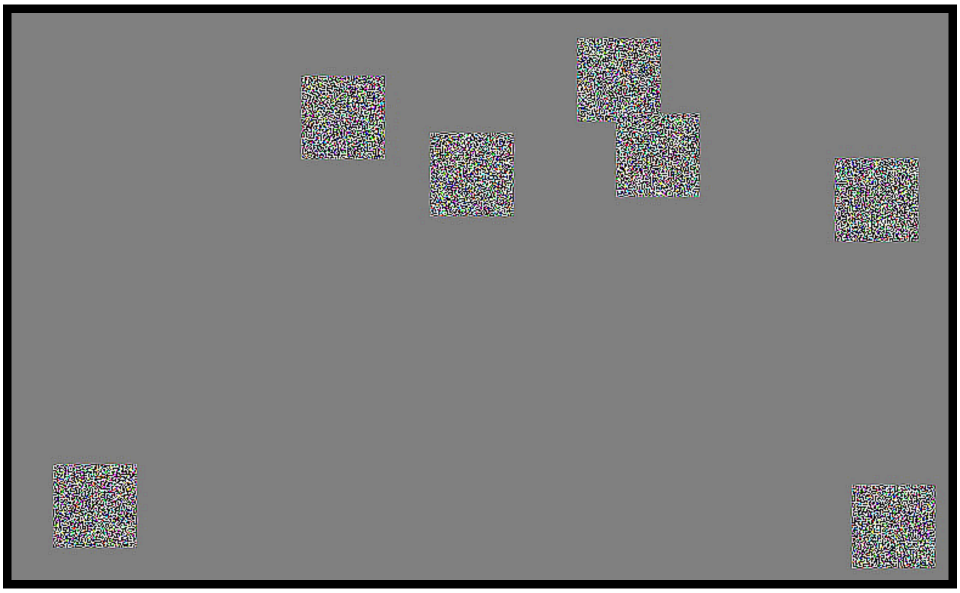
Target objects stayed constant through out the experiment for both of the conditions. By doing so it was aimed to prevent any memory interference or negative priming that may result from trying to track items which were non-targets on previous trials or similarly refrain from tracking items which were targets on previous trials (Horowitz et al., 2007). Even though the set of items displayed stayed constant for a participant, the selection of this set was done randomly for each participant. Participants took each condition as separate blocks. There were ten practice and fifty experimental trials for each block. Number of correctly tracked objects for each trial was recorded. Only the data from the fifty experimental trials were used in the analysis. The progression of the MIT task can be seen in Figure 2:



(A)



(B)



(C)

Fig. 2 Progression of the MIT task. Four animals among eight animals are highlighted with blue squares for 3 seconds (A). After the blue squares disappear animals begin to move for 5-10 seconds (B). After the movement is over, all animals are masked until a response is given (C).

Color Wheel (CW) Task

Color wheel task developed by Zhang and Luck (2008) was adapted to measure the capacity and the resolution of visual representations retained in the VSTM. A color wheel with the thickness of 2X2° and radius of 8x2° was generated. The color wheel consisted of 180 different colors with each color covering 2° of the wheel. These colors were equal in lightness and differed in saturation and hue. The list of color values used in the color wheel can be found in Appendix A. Each colored square extended to 2x2° of the visual field and appeared randomly on one of the eight possible locations determined on an invisible circle. This invisible circle had a radius extending to 4.5° of the visual field. Therefore, the locations where the colored squares appeared corresponded to the area inside the color wheel. The colors of the squares were randomly selected from the 180 colors that make up the color wheel.

The trials started with the display of a fixation point centered on the screen. Participants then started each trial by pressing a key on the keyboard when they were ready. When a key was pressed the three colored squares appeared for 100ms. A blank delay of 900ms followed the presentation of the colored squares. Then the response display which consisted of the color wheel and three frames outlining the positions of the previously shown colored squares appeared. One of these frames was distinguishably thicker than the other two and marked the target square. The participants were required to recall the color of the target square and report it by clicking it on the color wheel. The coordinates for these mouse clicks were recorded. There were ten practice and 150 experimental trials. Only the data from the 150 trials were included in the analysis. The progression of the CW task can be seen in Figure 3.

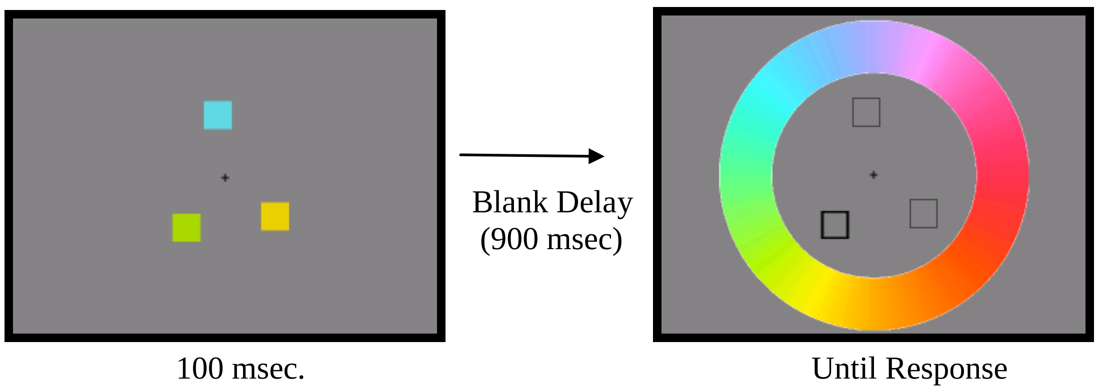


Fig. 3 Progression of the CW task. Three squares appear for 100 msec. After a 900 msec. of blank delay, the color wheel appears along with the frames marking the locations of the previously presented colored squares. One of these frames is thicker and the participants need to click the color of the square marked by the thick frame from the color wheel.

Apparatus

All stimuli were presented on a Intel Core 2 Duo Processor computer with an 17-inch color CRT Philips 107S6 monitor with ASUS Extreme AX550 series graphics card.

For the UFOV task screen resolution was set to 640 X 480. MIT task was presented with 1024 X 768 pixels resolution and 75 Hz refresh rate. CW task was presented with 640 X 480 resolution using 16 bit color. The programming, presentation and data collection for the UFOV and CW tasks were done with E-Prime Software (Psychology Software Tools, Inc). For the MIT task, MATLAB programming language (The MathWorks Inc., Natick, MA) running the Psychophysics Toolbox add-on (Brainard, 1997; Pelli, 1997) (http://psychtoolbox.org) was used.

Procedure

At the beginning of the experiments participants provided demographic information and informed consent. Participants completed the previously explained tasks in one session as described above. The order of tasks was counterbalanced across participants. The UFOV task took around ten to fifteen minutes, while MIT and CW tasks took approximately thirty minutes and twenty to twenty-five minutes to complete respectively. Participants were told they can rest for a few minutes between tasks if they felt tired. Participants binocularly viewed the displays from 57 cm distance at which 1 cm on the screen corresponds to 1° of visual angle. All tasks were administered under the supervision of the same experimenter. After completion of all three tasks participants were debriefed.

CHAPTER 3

RESULTS

UFOV Task

VGPs and NVGPs were compared on the accuracy and mean RT of responses across three eccentricity (10°, 20° and 30°) conditions. To compare VGPs and NVGPs' accuracy on the UFOV task, I conducted a 2x3 ANOVA with Group (VGP, NVGP) as the between subjects variable and Eccentricity (10°, 20° and 30°) as the within factor. Results yielded a main effect of Group $F(1,55)=18.34$, MSE= .073 $p= <.001$, $\eta^2_p=.25$ (VGP: *M*=93.2%, *SD*=.03; NVGP: *M*=75.3%, *SD*=.27). A main effect of Eccentricity was also observed on accuracy of the responses, $F(2,110)=25.87$, MSE=.007, $p=.000$, $\eta^2_p=.32$. This main effect was driven by higher accuracy in the 10° (*M*=88.3%, *SD*=.022), and 20° eccentricity conditions (*M*=86.8%, *SD*=.021), than in the 30° eccentricity condition (*M*=77.7%, *SD*=.026, $p= <.001$ Bonferroni corrected). The Group and Eccentricity interaction (depicted in Figure 4) was also significant, $F(2,110)=13,31$, MSE=.007, $\eta^2_p=.19$. This interaction was due to the fact that NVGP performance showed a significant drop in the 30° eccentricity which was not a case for VGPs. I calculated this by firstly collapsing the accuracy scores for the 10° and 20° eccentricities and calculating a single average accuracy score for these two conditions. Then I compared this score with the average accuracy scores for 30° eccentricity. When the decrease in accuracy between 10° + 20° and 30° eccentricities was compared for VGPs and NVGPs the results showed that this difference did not reach significance in the VGP group (Mean Accuracy in 10°+20°: *M*=.94, *SD*=.06

and Mean Accuracy in 30°: *M*=.91, *SD*=.08; *t*(23)=-1.9, *p*=.071, Cohen's *d*=.42). However, the decrease in accuracy between the 10°+20° and the 30° eccentricities was significant for the NVGP group (10°+20°: *M*=.81, *SD*=.2; 30°: *M*=.64, *SD*=.24; *t*(32)=-6.46, *p*=.000, Cohen's *d*=.77). These results showed that while VGP's accuracy stayed similar in all three eccentricities, accuracy for NVGPs dropped significantly in the 30° eccentricity.

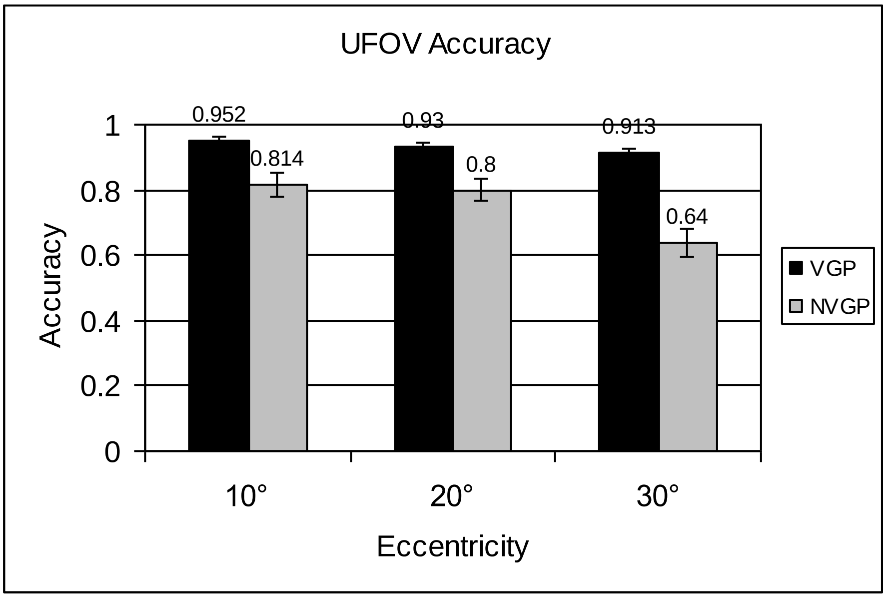


Fig. 4 Interaction of Accuracy scores and Eccentricity on the UFOV task. VGPs have significantly higher accuracy in all three eccentricities. NVGPs' performance decreases significantly more in the 30° eccentricity than VGPs' performance.

For the RT data, I also conducted A 2x3 ANOVA with Group (VGP, NVGP) as the between subjects variables and Eccentricity (10°, 20° and 30°) as the within factors. There was a main effect of Group, *F*(1,55)=10.3, MSE=73547, *p*=.002, η^2_p=.158, which resulted from overall faster response times for VGPs (VGP: *M*=649.2, *SD*=87.1 and NVGP: *M*=784, *SD*=191.8). A main effect for Eccentricity was also observed for reaction times, *F*(2,110)=13.1, MSE=5360, *p*=.000, η^2_p =.192. This was due to slower reaction times at the 30° eccentricity (*M*=756, *SD*=27.2) compared to faster reaction times of 10° (*M*=687, S*D*=20.8) and 20° eccentricities (*M*=705, *SD*=18.5, *p*=.00, Bonferroni corrected).Group and Eccentricity interaction did not reach significance, *F*(2,110)=2.37, MSE=5360, *p*=.098, η^2_p =.041 VGPs were significantly faster than NVGPs in all three eccentricities. 10° condition: (VGP: *M*=618 *SD*=105; NVGP: *M*=756, *SD*=182; *t*(55)=3.315, *p*=. 002, Cohen's *d*=0.92). 20° condition: (VGP: *M*=654, *SD*=89; NVGP: *M*=757, *SD*=164; *t*(55)=2.779, *p*=.007, Cohen's *d*=0.78) and 30° condition: (VGP: *M*=674, *SD*=81; NVGP: *M*=837, *SD* =256; *t*(55)=3.001, *p*=.004, Cohen's *d*= 0.85)

Neighborhood Analyses

In the UFOV task, the nature of the incorrect responses made by the participants was also investigated. I reasoned that some errors on this task may be due to cases in which participants detected the target and yet formed poor resolution representations of its location. In such cases, participants would be expected to select one of the nearby neighboring locations of where the target had actually appeared more often than a random location. On the other hand, on trials where the target was not encoded, responses should be random, meaning that they would be equally distributed among all twenty-four possible locations. Therefore, each incorrect response was coded as either a "neighbor" or a "random" error to gain understanding of the resolution of the spatial representations (see Figure 5).

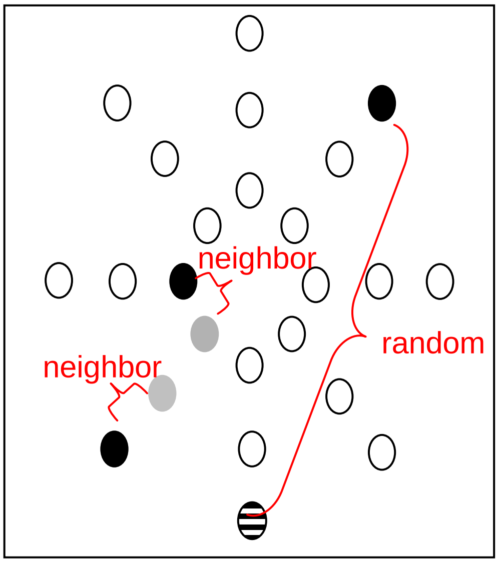


Fig. 5 Neighbor and random errors were grouped as shown.

If the incorrect response was to a response point close (to immediately neighboring options) to the correct response, then we categorized this as a “neighbor error”. However, if the incorrect response was placed in any other locations, then this type of error was categorized as a “random” error. . After grouping the errors I calculated the neighborhood error value (N.E) according to the following formula:

$$\text{N.E} = \frac{\text{\% of Random Errors - \% of Neighbor Errors}}{\text{\% of Random Errors + \% of Neighbor Errors}}$$

According to this formula a score close to -1 indicates high percent of neighbor errors whereas, a score close to 1 means most of the incorrect responses were random errors. I expected VGPs to have higher spatial resolution, and a higher proportion of “neighbor” errors. As predicted and as can be seen in Figure 6, VGPs had made significantly more "neighbor" errors than NVGPs (VGP: *M*=-.067 *SD*=.604; NVGP: *M*=.312, *SD*=.377; *t*(52)*[5]=2.838, *p*=.006, Cohen's *d*= 0.75).

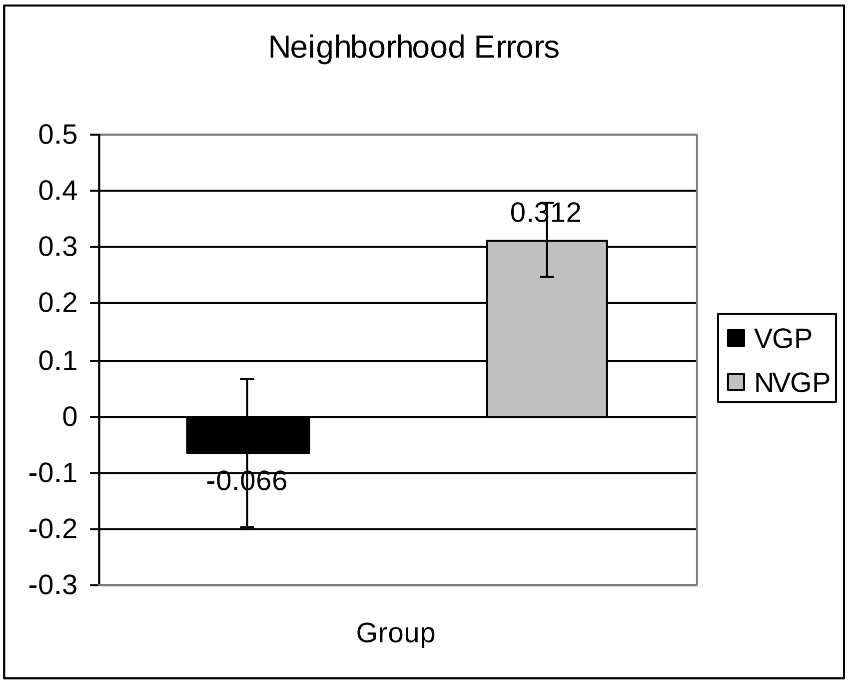


Fig. 6 Comparison of neighbor error ratios for VGPs and NVGPs on the UFOV task. Scores closer to 1 indicates more number of random errors and scores closer to -1 indicates more number of neighbor errors. VGPs did significantly more neighbor errors than NVGPs.

MIT Task

For the MIT task the dependent variable was the average number of correctly tracked items for both the Standard and Specific conditions. Results showed that VGPs could accurately track more number of items than NVGPs for both conditions of the MIT task.

In the Standard condition four items were tracked and reported. Therefore, someone who could track and report all four items would get the maximum score of four. On the other hand, in the Specific condition only one item among the four

[5] Three VGPs had no incorrect trials and therefore VGP group had twenty-three participants.

tracked items was asked, therefore making the maximum score on this condition one. To be able to compare the scores from both conditions, scores from the Standard condition were proportioned to have a maximum value of one.

Standard Condition

The average number of correctly tracked objects was calculated. VGPs accurately tracked more objects than NVGPs, $t(57) = -3.695$, $p = .000$, Cohen's $d = 1.03$ (VGP: $M = .973$, $SD = .022$; NVGP: $M = .944$, $SD = .033$).

Specific Condition

A similar advantage was observed in the Specific condition with VGPs displaying a better performance in reporting a specific object among the tracked items than NVGPs $t(49) = -4.098$, $p = .000$, Cohen's $d = 1.18$ (VGP: $M = .89$, $SD = .085$; NVGP: $M = .761$, $SD = .12$).

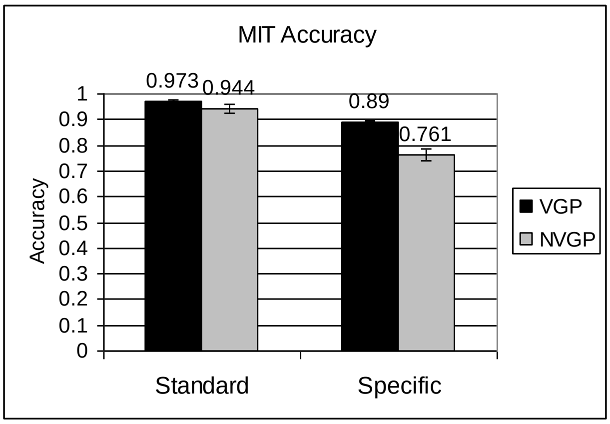


Fig. 7 Interaction for Group and Condition on MIT Accuracy. VGPs have significantly higher accuracy scores in the Standard and Specific conditions of the MIT task. The drop in accuracy for the NVGP group in the Specific condition is significantly higher than VGPs.

To determine whether VGPS had disproportionate gains in the Specific condition, a 2x2 ANOVA with Group (VGP, NVGP) as the between subject variables and Condition (Standard and Specific) as within factor was conducted for accuracy of tracking. This analysis revealed a main effect of Group, $F(1,49)=21.31$, MSE=.007, $p=.000$, $\eta^2_p=.303$. This was due to better performance of VGPs (*M*=93.1%) than the NVGPs (*M*=85.2%). A main effect of Condition was also observed. $F(1,49)=75.53$, MSE=.006, $p=.000$, $\eta^2_p=.607$. This difference resulted from higher performance in the Standard condition (*M*=95.7%) than the Specific condition (*M*=82.5%).

There was a significant interaction effect between Group and Condition $F(1,49)=10.41$, MSE=.006, $p=.002$, $\eta^2_p=.175$ (See Figure 7).This interaction was driven by the larger drop seen in NVGP performance than in the VGP performance. I calculated the accuracy drop between the Standard and Specific conditions and compared VGPs and NVGPs on this change. It was found that NVGPs' performance suffered significantly more in the Specific condition (*M*=.18, *SD*=.12) compared to VGPs (*M*=.08, *SD*=.08; $t(49)=3.23$, $p=.002$, Cohen's $d=.93$) which lead to the interaction effect observed between effect of condition and group.

Color Wheel Task

For the color wheel task, for each trial, the difference between the color the participant chose and the actual correct color was calculated. Participants clicked on the color wheel to indicate the color in the cued location. I calculated how far off this response color was from the actual correct color.

For each response, the X and Y coordinates of mouse click response was taken and from that it was possible to determine which one of the 180 colors the participant chose (The algorithm used to calculate this is presented in Appendix B). Any responses made outside of the color wheel were excluded (on average 6 % of all responses). Then, for each response, I calculated the difference between the color value of the response and the correct color (comparing the corresponding RGB values for the chosen and the actual correct color) by finding the distance between these two colors in a 3D space. A maximum difference between two colors can be 441 units (RGB Black: 0,0,0 and RGB White: 255,255,255) in this color space. After determining the error at each trial an average error for each participant was calculated.

As can be seen in Figure 8, VGPs were more accurate at remembering the colors than NVGPs, $t(25.32)=2.057$, $p=.05$, Cohen's $d=.7$ (when equal variances was not assumed); they displayed less average error than NVGPs (VGP: $M=70.8$, $SD=7.07$ and NVGP: $M=79.29$, $SD=15.39$). Given that error patterns displayed a skewed distribution (see Figure 9), I compared the median errors across two groups, and once again a marginally significant difference pointing to a better performance of VGPs (VGP: $M=46.18$, $SD=6.64$., NVGP: $M=52.56$, $SD=10.26$; $t(29)=1.961$, $p=.06$) was found.

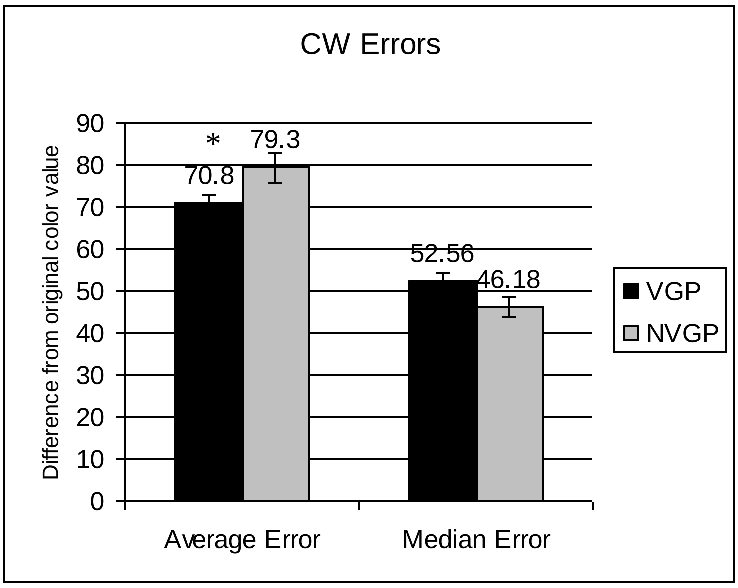


Fig. 8 Comparison of mean errors of VGPs and NVGPs on CW task. VGPs have significantly lower mean error than NVGPs (when equality of variance was not assumed). The difference between the two groups on median error was marginal.

Comparison of VGPs and NVGPs on Error Distributions

To compare the error distributions of VGPs and NVGPs, I first needed to create histograms or error distributions for each group. Therefore, responses were binned by dividing error values on each trial by 5 and 10 units. For each participant the percent of trials which fell in specific number of bins were calculated. Only 1.3 % of all responses had error values of larger than 300 units with a maximum error value of 350. Therefore, firstly I decided to divide the error values by 10 to get a reasonable number of bin groups (35 in this case) since dividing with a smaller number would result in many empty bin groups. Figure 9 depicts the histogram derived by dividing the error values with 10. Secondly, I divided the error values by 5 and created a more sensitive distribution of errors to be able to compare the number of responses falling in the smallest error / highest resolution bins. When error values were divided by 10, the maximum number of bins was 35 (350 units of error), and consequently when divided by 5, the maximum number of bins was 70 (I will refer to these as bin size 10 and bin size 5 conditions for the sake of ease). Trials grouped under the “0” bin, reflected trials in which participants reported the color value with no error. As the number of the bins increased, so did the error values.

In order to compare whether the error distributions of VGP and NVGPs were similar, I calculated the skewness and kurtosis values of each subject’s binned error distribution. Skewness can have negative and positive values. Positive values indicate that the distribution is positively skewed. Positively skewed distributions have their tails towards to right of the abscissa and most of the scores are concentrated on the left side and these scores are likely to be lower than the mean score. Kurtosis, on the other hand summarizes the “peakedness” of a distribution as well as how long and flat the tails of the distribution are (Jaccard & Becker, 2002). A high kurtosis index suggests that the distribution is more peaked and the tails of the distribution is long. In high kurtosis distributions most of the variability stems from infrequent extreme scores.

I first investigated the distribution of the error values for each participant by calculating the skewness and kurtosis for their responses (from the binned data) and compared VGPs and NVGPs on these measures. Results showed that for both groups the error values in responses were distributed similarly. There was no significant difference between groups for Skewness (NVGP: M=1.754, SD=.33 and VGP: M=1.82, SD=.33; $t(29)$= -.565, p=.576) and for Kurtosis (NVGP: M= 2.77, SD=1.62 and VGP: M=3.1, SD= 1.69; $t(29)$= -.545, p=.59). This meant that there were similar numbers of low and high error responses or responses below and above the mean for both the VGP and NVGP groups.

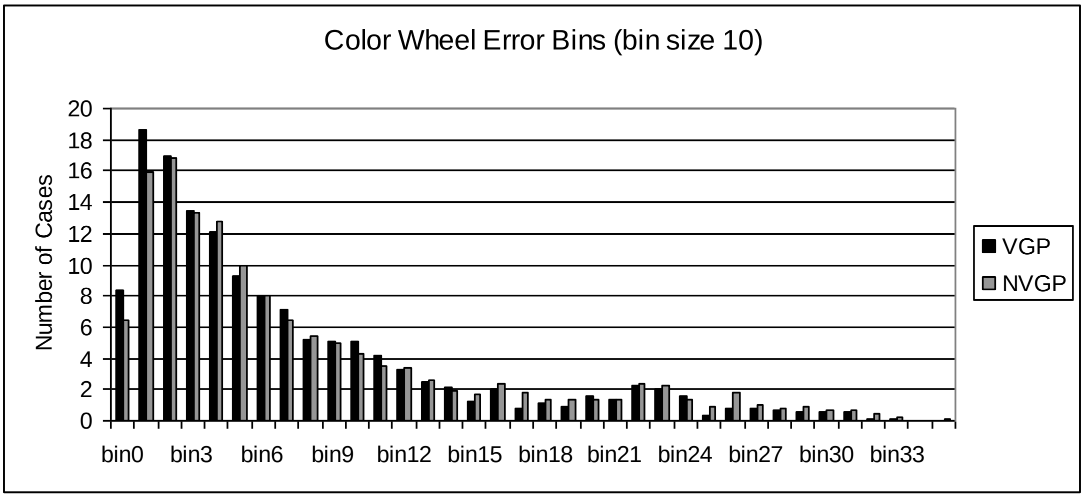


Fig. 9 Histogram for distribution of errors on the CW task for the bin size 10 condition. In order to create this histogram firstly, each response was divided by 10. Then the number of responses that fall inside each error bin for all participants was calculated from these divided error values. After that this histogram was generated by averaging the number of trials in each bin for all VGPs and NVGPs. This histogram depicts those values.

After establishing that the general distributions were similar, I further examined the distribution of errors by comparing percent of trials each group had in specific bins.

Bin size 10 Condition:

The error data was converted into a frequency distribution by grouping errors by dividing them with 10. Inspection of Figure 9 suggests that there may be a difference between VGPs and NVGPs with the number of trials in the first 3 bin groups which reflects the least error/highest resolution trials. To determine whether VGPs had a greater proportion of high resolution responses than NVGPs, I compared the percentage of trials that were grouped in the first 3 bins (corresponding to bin0= 0, bin1= 0-10 and bin2=10-20 units of error). Even though the visual inspection of the histogram indicated that there might be a difference between VGPs and NVGPs in the amount of trials in the first 3 bins, statistical analyses revealed an effect reaching marginal levels of significance *t*(29)= -1.755, *p*=.09, Cohen's *d*= .64 (VGP: *M*= 31.22%, *SD*=5.36 and NVGP: *M*=27.61%, *SD*=5.84). Secondly, I compared VGPs and NVGPs on the percentage of errors that fall in the first 6 bins (corresponding to bin0= 0, bin1= 0-10, bin2=10-20, bin3=20-30, bin4= 30-40, and bin5=40-50 units of error) because majority of all given responses (54 %) were gathered in these first 6 bins. However, there was no significant difference in the number of responses gathered in these 6 bins, *t*(29)= -1.232, *p*=.228 (VGP: *M*=56%, *SD*=.05 and NVGP: *M*=53%, *SD*=.07).

Bin Size 5 Condition:

The bin size 5 condition (where the error values were divided by 5) groups the errors twice as sensitive as the bin size 10 condition therefore, to see possible differences on the proportion of lesser error/higher resolution responses between VGPs and NVGPs, I calculated the percent of errors in the first 3 (bin0= 0, bin1= 0-5 and bin2= 5-10 units of error) and 6 bins (bin0= 0, bin1= 0-5, bin2= 5-10, bin3= 10-15, bin4=15-20 and bin5= 20-25 units of error). A marginally significant percent of VGPs error fell inside the first 6 (VGP: *M*= 33.78%, *SD*=5.19 and NVGP: *M*=30.12%, *SD*=5.88; *t*(29)= -1.791, *p*=.08, Cohen's *d*= .65) and 3 bins (VGP: *M*= 16.66%, *SD*=3.25 and NVGP: *M*=13.75%, *SD*=4.48; *t*(29)= -1.984, *p*=.057, Cohen's *d*=.74).

Examining Target-Response Consistency:

In every trial three colored squares were displayed and only one of them was cued. This required participants to remember the color of the correct square and pick the most suitable color from the color wheel. However, there might have been cases in which the participant remembered and reported the color of one of the uncued squares due to a binding mistake[6]. Therefore, I calculated the percent of trials in which participants' response color was closest in value to the cued color. I reasoned that if the number of trials in which the response color is closest to the cued color is high then this would reflect higher attentional resources. Results showed that VGPs were more likely to respond with a color which was closest to the cued color, $t(29)= -2.53$, $p=.017$, Cohen's $d= 0.95$ (VGP: M=79.59%, SD=.4.33; NVGP: M=74.24%, SD=6.65).

This result implied that VGPs were less likely to make binding errors and had higher capacity for maintaining target colors and their locations. The nature of the distribution of errors is further discussed in the discussion section.

Effects of Gender Difference on the Findings

While the NVGP group had both male and female participants, the VGP group consisted of male participants only. If female participants had lower abilities on the above described tasks, then their inclusion in the NVGP group could have lowered

[6] A binding mistake refers to the failure of maintaining information about the different features of a stimuli. For example in the CW task, a blue square may appear in Location 1 and a red square may appear in Location 2. A participant can perceive both of these colors and also the locations however, can fail to maintain the appropriate binding between the two. Therefore, if Location 1 is cued then this participant may remember the color to be red confusing the color-location combination.

group performance and exaggerated the difference between these two groups. To ensure that this was not the case, we compared the performance of male with female NVGPs in all the tasks, and compared the male NVGP group with the all-male VGP group. I found that females were marginally slower in average RT measure in the UFOV task. This marginal difference was stemming from females' significantly slower RTs in the 20° eccentricity. No difference was observed in the MIT task. And contrary to the expectations female participants were found to be more accurate in their responses in the CW task than males. Female participants had significantly more number of trials falling inside the first 6 bins of the bin size 10 condition pointing to more number of high resolution responses. Below I described these differences in detail and also reported results comparing only male VGPs and NVGPs.

UFOV Task:

Female and male NVGPs were compared in all the variables and no significant difference was found between the two groups except for a significant RT difference for the 20° eccentricity, with males responding faster than female participants. There was also a marginally significant difference between overall RTs between male and females which is likely to rise from the faster reaction times of males on the 20° eccentricity. I excluded the female participants' data and did the previously reported analyses with only male participants.

Comparison of male NVG and VGP revealed that the data pattern did not differ. VGPs (*M*=.93, *SD*=.05) were significantly better then NVGPs (*M*=.77, *SD*=.21) in average accuracy of locating targets [$t(42)=-3.517$, $p=.001$, Cohen's *d*=1.02]. The average RT scores were also significantly faster for the VGP group (VGP: *M*=649.2, *SD*=87.15 and NVGP: *M*=732.9, *SD*=165.4; *t*(42)= 2.15, *p*=.037, Cohen's *d*=.63). Male VGPs were significantly better than male NVGPs in accuracy at 10°, 20° and 30°'s , RTs at 10° and 30°, and neighbor error ratios. The only measure that a significant difference could not be observed was the RT for the 20° eccentricity between VGP and NVGPs when only male participants were compared.

MIT Task:

No significant difference was found between female and male NVGPs on the standard and specific MIT measures. The pattern of findings between VGPs and NVGPs did not change when only male NVGPs were included in the group analyses. VGPs (*M*=.973, *SD*=.022) showed significantly better performance than NVGPs (*M*=.95, *SD*=.031; *t*(40)=-2.725, *p*=.009, Cohen's *d*= .83) in the Standard condition of the task. For the specific condition VGPs (*M*=.89, *SD*=.085) also demonstrated improved performance compared to NVGPs (*M*= .79, *SD*=.11; *t*(38)=-3.068, *p*=.004, Cohen's *d*=.96)

CW Task:

Female NVGPs had marginally lower error values than male NVGPs in the average and median error scores. Female participants had significantly more percent of trials that fell in the first 6 bins of the bin size 10 condition than males (Females: *N*=6, *M*=58 %, *SD*=.055 and Males: *N*=12, *M*= 50%, *SD*= .062; *t*(16)= -2.59, *p*=.02, Cohen's *d*= 1. 34) pointing to a better performance of females on this task. When the analyses between VGP and NVGP groups were done with only male participants, VGPs outperformed NVGPs on all measures (Specifically: average and median error scores, percent of errors grouped in the first 3 and first 6 bins of both bin size 5 & bin size 10 conditions, and the percent of trials in which the given response was closest to the cued color). Basically, inclusion of female NVGP reduced the difference reported between NVGP and VGPs; nevertheless, even then there was a significant trend between the two groups, in the expected direction.

CHAPTER 4

DISCUSSION

The effects of action video game experience on the VSTM capacity and the representation of objects was addressed in this study. VGPs and NVGPs were compared on the Useful Field of View (UFOV), Multiple Identity Tracking (MIT) and Color wheel (CW) tasks. Improvements in spatial attention, the number of objects that can be tracked, and in visual short-term memory processes were observed for the VGP group in these tasks. Findings for each task is described and discussed further in the following sections.

Video Game Experience and UFOV Performance

Firstly, the UFOV paradigm (Ball et al., 1988) was employed in which participants are required to locate briefly presented targets across different eccentricities. Fast detection of enemies or resources which can appear in the periphery as well as in the center is critical for action video games. These kinds of video game requirements are similar to the requirements of the UFOV task and any video game related improvements at detection of peripheral targets was expected to manifest itself as performance gains on the UFOV task for VGP. Results were in line with this prediction.

A main effect of Group for accuracy in the UFOV task, with VGPs having an overall improvement in locating the target was observed. There was a main effect of Eccentricity also resulting from higher accuracy in the 10° and 20° eccentricities than in the 30° eccentricity. VGPs outperformed NVGPs in all three eccentricities (10°, 20° and 30°) in accuracy. An interaction effect between Group and Eccentricity in accuracy scores was also observed. While accuracy of VGP's stayed almost similar for the three eccentricities, NVGP's accuracy dropped sharply in the 30° eccentricity condition. A main effect for RT was observed for Group with VGPs having overall faster RT in giving responses. Similarly, Eccentricity had a main effect in RTs resulting from longer response times in the 30° compared to 10° and 20° eccentricities. VGPs were faster in responding in all three eccentricities compared NVGP group.

At each eccentricity VGPs outperformed NVGPs both in accuracy and RTs. However, the main improvement was observed for the 30° eccentricity. In the UFOV task, as the eccentricity increases it gets harder to detect the targets. It seems for the VGP group, increased eccentricity did not pose a difficulty and they could detect targets appearing at the periphery almost as easy as the targets appearing at the center. 30° eccentricity covers the area of the visual field outside of most of the action video game experience. Observing an improvement in the 30° eccentricity also indicated transfer of the gains to the untrained areas as pointed out by Green and Bavelier (2006a).

For the UFOV task, I also took a novel approach and characterized errors to determine whether VGPs and NVGPs made qualitatively different types of mistakes. I categorized each erroneous response as either a "neighbor" error or a "random" error. A neighbor error suggests that the target item was initially encoded but most probably a relatively lower resolution representation was formed rendering it impossible for the viewer to accurately detect the target location. On the other hand, a "random" error meant that most probably there was no accurate representation of the target in memory that can guide the performance. VGPs errors were more of the "neighbor" type than that of NVGPs. The nature of the incorrect responses also suggested that VGPs have greater spatial attentional resources, and even higher spatial representation resolution, consistent with earlier research done in this area (Green & Bavelier, 2006a, 2007).

From the results of the UFOV task it can be inferred that the VGP sample in this study was representative of the VGP samples in other studies (Green & Bavelier, 2006a). Since I was able to observe a difference between the NVGP and VGP groups in the UFOV task, any null effects on other tasks cannot be easily attributed to the lack-of-expertise in the VGP group.

Video Game Experience and MIT Performance

The MIT task developed by Horowitz et al. (2007) was used to compare VGPs and NVGPs on their ability to track multiple unique items. VGPs could track more number of objects accurately and outperformed NVGPs in both the Standard and the Specific conditions.

I had hypothesized that VGPs would show a better performance on the Standard condition of the MIT task. Indeed, as expected VGPs were more accurate in tracking target items than NVGPs on the Standard condition of the MIT task. This improvement is likely to be caused by the increased attentional resources of VGP players. Many previously mentioned studies demonstrated that VGPs have increased attentional capacity compared to NVGPs (Green & Bavelier, 2003, 2006a, 2006b, 2007; Trick et al. 2005). This increased attentional resource seems to be helping with the tracking of multiple objects by enhancing the visual short term/working memory processes. Specifically, previous research has shown MOT performance and VSTM capacity are highly related. For instance, Oksama and Hyönä (2004) showed that performance in both the visuospatial short term and attention switching tasks significantly predicted the perfomance on the MOT and MIT tasks. It had been shown that VGPs have significantly smaller task-switching costs than NVGPs (Colzato, Leeuwen, Wildenberg & Hommel, 2010; Boot, Kramer, Simons, Fabiani, & Gratton, 2008).

It has been suggested that the MOT task and the enumeration task utilize similar mechanisms (Pylyshyn, 2004). It is also known that there is a relationship between the counting aspect of enumeration task and working memory capacity (Tuholski, Engel, & Baylis, 2001). Specifically, Tuholski et al. (2001) found that participants who scored higher on a working memory task performed better on the counting aspect of the enumeration task. Green and Bavelier (2006b) had also showed that VGPs had better performance on the counting aspect of enumeration and the MOT tasks. Given the close link between the MOT and enumeration tasks, and the predictive relationship between the enumeration task and VSTM capacity, a relationship between VSTM and MOT is likely. The results of the Standard condition of the MIT task suggested that increased attentional resources of VGPs enhanced their visual short-term memory processes and helped them track more objects than NVGPs in this task.

Secondly, I expected VGPs to accurately track more items in the Specific condition of the MIT task. Results were in line with this expectation. VGPs demonstrated better accuracy than NVGPs in the Specific condition of the MIT task. Since the Specific condition of the MIT task requires tracking of both the identity and the location of the items, results indicated that VGPs could process and maintain the information regarding the objects features better than NVGPs. An interaction was observed between the effects of Group (VGP vs. NVGP) and Condition (Standard vs. Specific). While the performance in the Specific condition was lower for both groups compared to the Standard condition due to the more difficult nature of this condition; NVGPs' performance decreased more than VGPs'. This finding suggested that VGPs not only benefited from spatial attention based enhancements but also with processes that require processing of object features. The fact that NVGP's performance decreased more than VGPs suggests that there is a difference between two groups' ability to maintain the information about the objects.

To sum up, the increase in the number of accurately tracked objects by the VGPs in the Standard condition of the MIT task suggested that VGPs benefit from an overall increase in the attentional resources and visual short-term memory capacity. VGPs' better performance in the Specific condition together with the finding that NVGPs' performance decreased significantly more than VGPs' between Standard and Specific conditions pointed to specific improvements in the object processing abilities.

Video Game Experience and CW Performance

In the color wheel task, the participants were briefly shown colored squares and then were required to report the color of the probed square by selecting a color from the color wheel. Then the difference between these response colors and the actual probed colors was calculated. When compared on the average and median error scores between the response color value and the probed color value, VGPs displayed marginally lower errors in their responses than NVGPs. This marginal difference was shown to stem from the better performance of females on the CW task (Refer to the section about the effects of gender pp.39). When female participants were removed from the NVGP group and only the data from the male participants were used the marginal significance between VGPs and NVGPs reached significance. Therefore, I am going to base the discussion on the results from male only comparison of VGP and NVGP groups.

The first finding was that VGPs' responses showed significantly less deviations from the correct color value than NVGPs responses, revealed by the average and median error comparisons. This implied that on average VGPs could maintain the representation of the cued color better than the NVGP group. Secondly, I moved on to examining the difference between VGPs and NVGPs performances by comparing the difference between the error values throughout the distribution of errors. To do this, histograms for the errors in responses were created for each participant and then by collapsing these, group histograms were created for VGPs and NVGPs. These histograms were created by grouping the errors by dividing the error values by 5 or 10. I examined the spread of the distribution of errors for VGPs and NVGPs by comparing the skewness and kurtosis values for the binned errors. This comparison showed that the errors were distributed similarly for the VGP and NVGP groups. This meant that both VGPs and NVGPs had similar number of low error-medium error and high error trials in their own groups. When compared on the percentage of trials falling in the first bins which reflected the lowest error / highest resolution responses, VGPs had significantly more number of trials in these groups. Together, these results showed that although errors of VGPs and NVGPs were distributed similarly, VGPs responses deviated less from the actual color value than that of NVGPs responses.

The CW task firstly requires participants to maintain the color and location of the briefly shown squares. Then the participant needs to select the right color regarding the square on the cued location. As previously mentioned, this requires the binding of the color and the location features. In some cases when the location and the color information is not bound strongly, the participants might report the color for an uncued square. Participants might be remembering the colors accurately however; due to a binding error they might be reporting the color of the uncued square. Therefore, to further investigate these possibilities, I measured the error distances of given responses to the probed and to the uncued colors on each trial. Results showed that VGPs had significantly more trials in which they responded with a color closest in value to the probed item. This suggested that they were better at remembering the colors and the locations of the three squares. The fact that VGPs made fewer binding errors is consistent with the observation that they have greater VSTM resources (e.g. Wheeler & Treisman, 2002).

When I compared VGPs and NVGPs on the average error of responses for only the trials in which they responded with a color more similar to the probed item, I found that they were in general recalling items with less error. It can be argued that these trials reflect the trials in which participants were able to maintain the correct binding between the location and the color. Results showed that on these trials VGPs had on average significantly less error at recalling the colors than NVGPs, $t(23)=2.31$, $p=.03$, Cohen's $d= .94$, (VGP: $N=13$, $M= 45.8$, $SD= 5$ and NVGP: $N=12$, $M=50.7$, $SD= 5.4$). Performance on this group of trials in which there was no binding error suggested that VGPs were able to represent the colors of the objects with a higher resolution compared to NVGPs.

Next, I examined the trials in which participants responded with a color similar to the uncued squares. I calculated the difference between the response color value and the color of the uncued square in which the error was least. I compared the average error on these trials and found that VGPs and NVGPs did not differ on the error of responses on these trials (VGP: *M*=62.3, *SD*=10 and NVGPs: *M*=68.28, *SD*= 16.2; *t*(23)=1.11, *p*=.277). A difference on this measure could be expected with VGPs having less error than NVGPs if we assumed that these trials reflect the cases in which participants responded by remembering an uncued color. If that were the case, then VGPs would have been expected to have represented these uncued colors better and display less errors. However, it is also possible that some (or even all) of these trials are trials where there was no accurate representation that drives the performance. In other words, these trials may have been trials in which participants simply erred. When the average error was compared between the trials in which the response is given according to the cued square (no binding error) and in trials when the given response is most similar to the color of the uncued squares then it can be seen that the average error is smaller for the former condition (Cued: *M*=48.16, *SD*=5.7 and Uncued: *M*=65.2, *SD*=13.41; *t*(24)=7.33, *p*=.00, Cohen's *d*=1.6). This indicates that the responses which categorized as being most similar to an uncued square may also involve random responses where the response is made without any reference to the uncued square.

To sum up, CW task revealed the following results: (1) VGP's had significantly less overall (average & median) error at recalling target colors, (2) VGPs and NVGPs had similar error distributions, (3) VGPs had significantly more number of trials within the high resolution response bins, (4) VGPs significantly responded more often with a color value similar to the cued color, (5) Average error on the trials where participants responded with a color most similar to an uncued color was similar for both VGPs and NVGPs, (6)Average error for both groups was less on trials where they responded with a color similar to the cued color than on trials where their response was similar to an uncued color. These results suggested that VGPs had more attentional capacities and were better at maintaining the color and location of the briefly flashed squares. Moreover as hypothesized they can report the colors with a higher precision which points to higher resolution of the representations.

In sum all hypothesis regarding VGPs: (1) an increased number of remembered objects in the Specific condition of MIT task, (2) less errors and smaller deviations of the reported colors from the actual colors in the color wheel task, (3) increased number of remembered objects in the Standard condition of MIT task and (4) improved performance in the UFOV task were confirmed.

Counter Evidence

Not all the studies to date have revealed a similar improvement for VGPs in cognition. A study by Boot and colleagues (Boot et al, 2008) compared VGPs and NVGPs on several attention, memory and executive control tasks. They used three batteries of tasks measuring visual-attentional, spatial processing & spatial memory and executive function abilities. The visual- attentional battery involved the UFOV, Attentional Blink, Enumeration, and MOT tasks which were also used by Green and Bavelier (2003, 2006a, 2006b, 2007). Boot and colleagues were able to show improvements for VGPs only in some of these tasks.

They did not report any significant difference between VGPs and NVGPs in the UFOV, Attentional Blink and Enumeration tasks. The only difference they observed in their visual-attentional task battery was in the MOT task. They found that VGPs were better at tracking objects moving at higher speeds. One of the few differences they could observe was in Task Switching, an executive control task.. They found that VGPs had significantly lower reaction time costs while switching between tasks.

Similar to Green and Bavelier, (2003, 2006a, 2006b, 2007) they also trained novice participants with video games to investigate the casual link between video game experience and the changes in the visual system. They trained a group of participants with an action video game, a second group with a strategy based video game, and the third group with a puzzle game (Tetris). They expected to see the effects of different types of game training with specific improvements with each task batteries they used. Specifically, they expected action video game training group to show most improvement in the visual-attentional task battery, the strategy trained group in executive function task battery and finally the puzzle game group in spatial tasks battery. Contrary to Green and Bavelier's (2003, 2006a, 2006b, 2007) findings they could not observe any special improvement for action video game trained group. All three training groups improved similarly, the only increased amount of improvement that they observed was for the puzzle game (Tetris) group in the mental rotation task.. They found that the group trained with Tetris improved most in RT measures in the mental rotation task..

This differences between Boot et al.'s (2008) results and that of Green and Bavelier's (2003, 2006a, 2006b, 2007) might have partly arisen from the differences in several aspects of the tasks used. For instance, the duration and the color of the mask in the UFOV or the number of time lags between the first and the second targets in the AB task. These are important details that might have affected the outcome of the results. Similarly, the difference in training schedules might have prevented Boot et al. to observe a difference after training. Training in Boot et al.'s (2008) study was more condensed (Four, one and a half hour session in one week) than that of Green and Bavelier's (2003, 2006a, 2006b, 2007) in which they had a more spaced-out schedule (Ten, one hour sessions within fifteen days). As also pointed out by Boot et al. (2008) more distributed trainings tend to give better results. Finally, Boot et al. (2008) concluded that either more expertise is needed to observe differences between VGPs and NVGPs or the difference between the two groups might be due to people with higher attentional skills choosing to play video games.

Limitations

The main limitation of this thesis is that it does not show a casual relationship between the observed improvements in VGPs and the video game experience. To show such a relationship, similar to what Green and Bavelier did in their experiments (2003, 2006a, 2006b, 2007), a NVGP group should be trained either with an action video game or with another type of game that does not have similar requirements with an action game. Then, these two different training groups should be compared on the amount of improvement they displayed between pre and post-training tests. Although previous studies were able to establish that casual relationship (Green &Bavelier; 2003, 2006a, 2006b, 2007), there also exists studies that could not find such a relationship (Boot et al., 2008). Therefore, I cannot completely rule out the possibility that the improvements observed for the VGP group did not arise from of a self-selection effect which means the difference between two groups arise from the fact that individuals with better visual-attentional skills choose to play action video games more.

A second limitation stems from a more technical reason. CW task involves displaying of various colors. If not controlled it is possible that there might be slight changes in the color values for the displayed colors even though the information on the software creating these colors stays constant. These variations might occur due to functioning of the computer monitors. To prevent the occurrence of such changes a color calibration equipment is needed. However, since this equipment was not available color calibration could not be done. To decrease the possibility of alterations on the display of the color values, same computer and monitor was used.

Future research could vary the properties of the CW and MIT Tasks such as the number of targets/distractors or the speed of movement. The difference between VGPs and NVGPs could be further investigated if these tasks have more conditions. For example increasing the number of items to track in the MIT task or presenting more then 3 colored squares in the CW task could provide more information while trying to asses the capacity for the attentional resources.

APPENDICES

Appendix A

List of Colors Used in the CW Task

color no	R	G	B	color no	R	G	B
1	254	54	83	51	148	182	254
2	255	54	88	52	144	184	255
3	255	55	91	53	136	185	254
4	255	56	95	54	131	188	255
5	255	57	98	55	126	191	255
6	255	58	104	56	124	194	254
7	255	58	107	57	117	198	254
8	255	61	111	58	114	199	254
9	255	62	115	59	108	204	255
10	255	64	118	60	102	207	255
11	255	66	124	61	99	210	255
12	255	68	129	62	96	213	255
13	255	71	133	63	89	215	255
14	255	73	137	64	88	223	254
15	255	74	141	65	82	225	255
16	255	78	148	66	80	229	253
17	255	81	152	67	78	234	255
18	254	84	155	68	74	237	254
19	255	89	163	69	71	243	255
20	255	89	167	70	70	249	254
21	255	94	172	71	65	247	250
22	254	97	174	72	63	248	243
23	254	98	182	73	61	248	239
24	254	105	189	74	61	249	234
25	255	109	192	75	60	249	227
26	254	112	198	76	60	250	224
27	255	118	206	77	60	251	220
28	255	122	215	78	60	250	216
29	255	122	229	79	61	252	208
30	253	134	224	80	60	253	200
31	253	138	231	81	61	253	196
32	254	143	238	82	67	253	192
33	254	148	246	83	69	252	185
34	254	153	255	84	75	253	179
35	246	156	254	85	77	252	173
36	240	156	254	86	79	253	166
37	230	159	255	87	84	253	162
38	224	160	255	88	87	253	155
39	219	157	254	89	91	253	150
40	214	160	254	90	93	253	143
41	209	159	255	91	99	254	137
42	199	164	255	92	103	252	132
43	192	166	255	93	107	253	126
44	188	170	255	94	112	252	121
45	181	169	255	95	114	251	112
46	176	172	255	96	119	252	107
47	168	173	255	97	124	251	100
48	164	175	255	98	129	250	95
49	159	178	255	99	133	251	89
50	151	178	255	100	140	249	82

color no	R	G	B	color no	R	G	B
101	147	248	68	141	254	148	1
102	153	253	69	142	254	145	0
103	153	248	60	143	255	141	1
104	155	248	53	144	255	137	1
105	160	247	46	145	255	132	0
106	163	247	37	146	255	128	1
107	170	247	31	147	253	125	0
108	176	245	17	148	255	122	1
109	177	243	9	149	255	122	1
110	182	243	0	150	253	115	0
111	187	245	0	151	253	111	1
112	195	243	1	152	255	107	1
113	199	243	0	153	255	104	1
114	207	242	2	154	255	101	3
115	213	242	0	155	255	97	0
116	217	242	0	156	253	93	0
117	221	242	1	157	255	88	0
118	227	240	0	158	255	86	1
119	233	241	0	159	254	85	4
120	236	239	2	160	254	82	8
121	242	239	0	161	253	78	11
122	248	236	0	162	255	77	15
123	255	235	0	163	253	72	17
124	253	230	2	164	254	72	22
125	255	226	0	165	255	69	28
126	254	220	0	166	255	67	30
127	251	215	1	167	254	65	33
128	255	211	0	168	255	64	38
129	254	206	0	169	254	62	41
130	255	199	0	170	255	60	46
131	253	195	0	171	255	59	47
132	255	188	0	172	255	58	52
133	255	185	1	173	255	57	56
134	255	180	0	174	255	57	58
135	255	175	0	175	255	56	63
136	255	171	2	176	255	53	65
137	255	166	0	177	255	54	70
138	255	161	1	178	255	54	72
139	255	158	1	179	255	54	76
140	253	152	0	180	254	54	80

Appendix B

Conversion of the Mouse Click Response on CW

E-prime software saves the X, Y coordinates for the mouse click response. The angle where these coordinates corresponded to on the color wheel was determined. E-Prime assigns (X=0, Y=0) to the left-top corner of the screen. The color wheel had a center of (X=320,Y=240). In order to find which angle the mouse click corresponded to the ATAN2 formula on excel was used. This formula calculates the arctangent for the specific X and Y coordinates in radians between –Pi and Pi. For this formula to work 320 from the X, and 240 from the Y coordinate was subtracted since the formula is based on a circle with a (X=0,Y=0) center. Additionally, unlike the normal Y plane in which values increase as it goes up, on E-Prime the values on Y plane increases as it goes down. Therefore, the Y value was subtracted from the maximum Y coordinate which was 480. After calculating the arctangent 2Pi was added for negative values and the results were converted to degrees from radians. In the end of these calculations I was able to find which angle the mouse click corresponded to.

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