Video Games Modulate Visuo-Spatial Problem Solving Ability

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Author Note:

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Abstract

In 2000, Hodgson and his colleagues used eye-tracking measures to determine patterns in how participants solved visual puzzles. When analyzing the results of this study, Hodgson et al. found a reliable pattern in attention allocation for users, which predicted their efficiency in solving the puzzle. The study used the eye-gaze data to classify participants into “efficient planners” and “error makers” based on their allocation of attention. Independent of this problem solving research, studies have investigated the effects of video game play on cognitive performance. Research has demonstrated that playing video games decreases reaction time in many situations (Dye 2009), decreases the time needed for spatial visualization (Okagaki & Frensch 1994), and improves spatial attention allocation (Chisholm et al. 2010). The project presented here bridges these two lines of research. We hypothesized that expert video game players will represent and solve visuo-spatial problems more efficiently than novice video game players. Specifically we hypothesized that this would occur on account of either: augmented visuo-spatial working memory (VSWM) capacity; or enhanced perceptual/attentional mechanism. Our results demonstrated that video game players did indeed perform better than non-game players. These results were best accounted for by an augmentation of VSWM, rather than enhancements perceptual or attentive processes.

Keywords: video games, problem solving, visuo-spatial working memory

Introduction

What distinguishes a novice from an expert? Expertise is seen in almost every domain imaginable, but there is a dearth of literature on what separates an expert from their less experienced peers. The primary goal of this research is to examine processes which may underlie expertise in the visual spatial domain. The empirical studies that *do* exist show some important differences between experts and novices. Taken from a broad range of tasks, experts: take less time to solve problems (Chi, Glaser, Rees 1981); exhibit different patterns of attention allocation (Jarodzka 2010); and are capable of abstracting their knowledge to progress through novel problems in their domain of expertise (Carbonell 1985). Unfortunately, these studies only shed light on how experts solve problems in their area of expertise. This study instead seeks to see the effect of expertise specifically in the domain of visual problem solving.

What does visual problem solving entail? For the purposes of this study, visual problem solving was defined as the successful navigation through a problem whose primary representation was in the visual domain. Visual problems can be solved purely through the manipulation of their components. Examples include: mental rotation (Shepard and Metzler 1971), the Orcs and Hobbits problem (Thomas 1974), Block copying (Hayhoe, Bensinger & Ballard 1998), and the Tower of Hanoi (as seen in this paper). This study seeks to examine the role of visuo-spatial problem solving with regards to a well-defined problem space, namely the tower of Hanoi puzzle task.

Hodgson, Bajwa, Owen, and Kennard (2000) sought to record and analyze detailed gaze pattern data from participants solving a visual problem. In their experiment, they employed the Tower of London task (a variant of the Tower of Hanoi). The goal of both these puzzles is to orient the pieces from the original configuration to some other configuration, known as the goal-state or goal-configuration, without breaking any of the game's rules. Hodgson et al. asked participants to try and decipher the shortest (fewest moves involved) route to complete the puzzle. They discovered two interesting patterns in the problem solving tendencies of their participants.

First, regardless of a participant's relative skill in completing the puzzle, a consistent pattern of gaze direction was found. In the early stages of solving the problem participants focused on the "goal-space", alternatively conceptualized as the desired outcome. This can be thought of as the puzzle configuration which was the over-arching goal of the problem solving process (Simon 1978). Next, participants biased their gaze towards the "work-space", or the area that held the configuration that was to be altered. The work-space can be thought of as similar to the "problem space" as defined in Simon's information processing theory (Simon 1978). Relevant to this study, the problem-space has two hypothesized roles in visual problem solving. The first is its use as a directional guide. The problem solver uses the work space as a baseline, judging their progress towards the current goal or sub-goal, by comparing their current position to the initial state (Newell 1979). Secondly, the problem space reduces of the amount of short term memory needed to solve a problem. It does this by functioning as a kind of "base-condition", which the problem solver can return to in the event they pursue an incorrect solution path (Simon 1978). This is especially important in conditions where the number of possible solutions causes congestion of working memory (Pass, Renkl, & Sweller 2003). In the final stages of the problem solving process found by Hodgson et al, participants would again bias their gaze towards the goal-state. This according to the researchers indicated the participant's desire to ensure they had made the correct permutations.

Hodgson et al. (2000) also found that participants could be classified into two groups based on their gaze patterns. Participants were either classified as "efficient planners" or "error makers". The distinction between the groups was not built into the design of the study, but rather made on the basis of the gaze pattern results. The study lists three factors which separated the two groups. These factors were: the direction of gaze towards problem critical items, the ability to ignore previously effective strategies when non-applicable, and the ability to selectively avoid irrelevant items. However, while Hodgson et al. delineates the two groups, they do not try and explain *why* participants might display these differing gaze patterns. Rather, they simply note their existence, and that there is a difference between them.

The hypothesis of this paper is that practice with complex visuo-spatial tasks will result in more efficient gaze patterns across different visuo-spatial tasks. Video-game players represent a population that has extensive experience with a wide variety of complex visuo-spatial tasks. Additionally, the characteristics that Hodgson et al. labels as the core tenets of "efficient planners" are similar to those displayed by experienced video game players (Chisholm et al. 2010; Bavelier & Green 2006). Thus, the present study seeks to investigate the impact of experience with complex visuo-spatial tasks (i.e. video game experience) and its' effect on gaze patterns when solving visuo-spatial problems. By replacing the "efficient planners" with experienced video-game players, this study seeks to replicate the results, and discern specific differences in the problem solving strategies employed by expert video game players, compared to their non-playing counterparts.

Research suggests that video game play influences a number of cognitive, attentional, and behavioral aspects. These effects range from increasing sensitivity to salient sensory events (West, Stevens, Pun, & Pratt 2008), to positive engagement in academic settings (Durkin & Barber 2002). While video game play seems to influence a wide variety of factors which could be associated with visual problem solving, there are two theoretical routes in particular which are of interest. These theoretical approaches are: (A) video game play imparts superior perceptual/attentional mechanisms; or (B) augmented visuo-spatial working memory (VSWM) capacity cultivated through experience in video games.

The first hypothesis is biased towards a bottom-up approach to problem solving. In other words, low-level processes such as gaze direction, attention allocation, and endogenous unconscious processes, play the most important role when attempting to solve a problem. Video-game play shows effects in all of these areas. A concise measure combining all of these aspects is the ability to orient to new or “important” stimuli (i.e. stimuli which have just appeared within the field of vision, and stimuli that are critical to the problem at hand). The ability to orient involves the interplay of biasing gaze, focusing attention, and unconscious processing of problem relevant stimuli. Enhanced orientation capabilities have been demonstrated in video game populations (Green & Bavelier 2006; Green & Bavelier 2003) and represent one of the major distinctions of between video game players and non-players.

Two aspects of video game play seem to impart the largest benefit to orientation in visuo-spatial problem solving. These are: video game players ability to cast attention over a wide visual area, combined with endogenous cues about where to orient attention. Evidence for the first benefit comes from the fact that expert video game players have demonstrated the capacity to allocate their attention to areas that are not necessarily within their foveal field. An example of this would be the ability to cast an “attentional net” on a larger visual space. Greenfield (1994) found that video game experts (VGE) reaction times suffer significantly less from divided attention tasks than non-expert video gamers (NVG). Expertise in this experiment was based on the both the number of video games played (lifetime) and skill at a novel video game directly related to the task. The crux of the task involved attentional cues which were either misleading or not misleading. These cues directed attention either to an area where the target would appear (beneficial), or would not appear (misleading). Video game players did not show the normal pattern of increasing reaction times to the misleading cue. The lack of a significant difference between the misleading and beneficial trials indicates that they were capable of orienting more quickly to targets in a large visual field. Additionally, VGE with extensive experience in action video games have been shown to be better able to discern occluded target objects from within a highly detailed, and crowded visual space (Bavelier & Green 2007). Occlusion refers to the obfuscation of relevant visual information within a problem space. The Bavelier and Green experiment used extraneous distractors to hinder participant’s ability to quickly identify the target. The fact that video game players reliably demonstrated less distractor influence implies an increased capacity to overcome the problem of occlusion. Therefore, not only are video game players better at taking information in from a larger field of view, they are also capable of discerning relevant stimuli which are placed in close proximity to unimportant, yet distracting items.

The problem with this interpretation however, is the fact that, just because a person has more information to work with, does not mean that they will be more efficient in their *use* of the information. The capacity to deal with an increased volume of relevant material must also be present. It is here, that some form of top-down control must be exerted by video-game players in order to fully account for the influence of perceptual and attentive processes. In other words, perceptual capability without some regulating mechanism can't fully explain any differences that might crop up between video game players and non-video-game players. Some studies have posited that differences between video game players and non-players exist solely because video games improve stimulus-response mapping (e.g. Castel, Pratt, & Drummond 2005). Their argument is that no specific top-down mechanism exists. Rather, latencies and other measures may be a by-product of the fact that video-game play rewards speedy reactions to a situation. The ability to discern relevant stimuli from distractors (as mentioned above), however provides some evidence for top-down processes existing. Chisholm, Hickey, Theeuwes, & Kingstone (2010) demonstrated that video game players were better able to reorient away from distractors than non-video game players, suggesting the use of top-down or endogenously motivated behavior. In the experiment, the distracting images were the most salient objects on the screen. Research indicates that the saliency of an image influences the order in which it will be attended. High saliency visual objects are attended to earlier than low-saliency (Itti, Koch, & Niebur 1998; Fecteau, Bell, & Munoz 2005). Chrisholm's interpretation is supported by findings that video game players are indeed influenced by flanking distractors. In fact, the effect of flanking distractors can be *more* pronounced in video game populations (Dye, Green, & Bavelier 2009). These results seem to imply that orienting towards relevant stimuli (instead of ignoring non-relevant stimuli) is the method through which video game players manage additional information intake. This, when combined with a wider attentional net, and decreased influence of occlusion, go a long way towards explaining the difference between video game players and non-video game players.

While the Hodgson et al. study focused primarily on the attentional and perceptual differences of their participants' problem solving ability, video game experience affects other domains relevant to their task. Visuo-spatial working memory (VSWM) is also relevant to visual problem solving (Logie, Gilhooly, & Wynn 1994), and shows significant benefits from experience with video games (Green and Bavelier 2006). VSWM has a variety of different monikers (e.g. visuo-spatial sketchpad, visual working memory, etc.). It will be, for the purposes of this experiment, functionally defined as the mechanism(s) of working memory associated with maintaining visual information, as well the manipulation of said information (Baddeley 1992). Its relationship to visual attention is somewhat controversial; with VSWM reportedly having various degrees of influence on selective attention (de Fockert, Rees, Frith, & Lavie 2001; Awh & Jonides 2001; Downing 2000). An emerging trend however, seems to indicate interplay between the two.

Desimone (1996) showed that monkeys were capable of suppressing responses to non-target visual cues in a visual search task. The task measured responses from individual cells in the inferior temporal cortex (IT) in response to various stimuli in the monkey's visual array. The measures were taken during a task which required the monkeys to saccade towards a stimulus that had been recently displayed. Stimuli which were capable of inducing a strong response in the IT cell being measured were deemed "good" stimuli; those which induced a low response for the recorded cell were "bad" stimuli. "Good" stimuli induced early responses in the IT cell regardless of whether or not it was the visual search target; in cases when the "good" stimulus was not the search target however, this early response was quickly suppressed. Importantly, this effect was seen previous to the time where saccades occurred (300ms after the two-stimulus visual array was introduced). This de-activation, before shifting visual attention, indicates that information from visuo-spatial working memory was taken into account before attention was allocated. Similar results can be found in human behavior. Downing (2000) tested the robustness of VSWM effects on selective attention in humans. Participants in the experiment were asked to remember a stimulus presented on a screen in front of them for 3.5 seconds. During this time, two objects (one of which matched the presented stimulus) were then displayed on opposite sides of the screen. A secondary probe was presented after this, and reaction times to this probe were then measured. When the secondary probe was in the same location as the matched stimulus, reaction latency was significantly lower than when it appeared on the other side of the screen. This indicates the spatial component of the object in working memory was taken into account. In order to confirm this result was not due to priming effects the researchers conducted a similar experiment, without the working memory element of the task. The results from this task were not significant, signaling this effect was not solely an artifact of priming. These studies in combination seem to indicate a role for VSWM in the process of selectively attending to stimuli.

It has already been noted in this paper that VGE are capable of attending to a larger field of vision than non-players (Greenfield 1994); this may in turn affect their visual storage capacity. Green and Bavelier (2006) demonstrated enumeration differences between video game players and non-video game players, suggesting changes in capacity. Enumeration in this regard refers to the ability to process stimuli in a serial fashion. The study showed that VGE were reliably capable of storing approximately, one to two items more than their NVGP counterparts (Green & Bavelier 2006). This finding's significance comes from the fact that all stimuli were presented simultaneously, and participants were simply required to determine how many they had seen. Once more than three objects were presented simultaneously the study found that non video game players' percentage of correct responses began to drop off. While video game players displayed a similar drop in correct responses, their cutoff point was found to hover around five objects, indicating an increase in the total amount of VSWM storage space. These VSWM effects are not just limited to adults with extensive experience in the domain; children who play video games also show cognitive alterations in their VSWM capabilities. Changes occur not only in attention related features as discussed earlier (e.g. lower attention thresholds, better re-orientation), but also, with regards to enumeration (Dye & Bavelier 2009). This difference in enumeration results, present from a young age onward, provides robust evidence of increased visuo-spatial working memory capacity. This review has demonstrated that video game experience influences a large number of changes in attention, perception, and VSWM capacity for those that play them. Whether or not these changes will influence their problem solving abilities has yet to be seen.

With regards to how humans engage in problem solving, this paper will employ logic similar to that of the Information Processing System (IPS) framework as proposed by Newell and Simon (1957). Two components of this system are particularly relevant to the current study. Primarily the concepts of both: “Memories” (relating to the person's expertise and experience in a certain domain); and “Primitive Information Processes (PIPs)” (in this study, referring to the conceptual, as well as perceptual processes involved in problem solving)

(Newell & Simon 1957). In their original work, Newell and Simon conceptualize PIPs as being distinct from perceptual processes (i.e. solely operations for information stored in memory). Here, PIPs will refer to the memory manipulation mechanisms highlighted in their work, as well being associated with perceptual information uptake. This classification alteration was made due to this study's heavy reliance on perceptual and behavioral data, which cannot be accounted for as well within Newell and Simon's framework. A "Problem solving expert" will be defined in this paper as: someone who effectively incorporates data from their PIPs with previously encoded experiences ("Memories") in order to complete a task in a way which is deemed 'better' (i.e. faster, more correct, more efficient, etc.) than a non-expert problem solver. The role of memory in problem solving is well documented, however examples of PIPs relevant to the task at hand are more difficult to find.

Memory and its role with regards to visual problem solving, is at-least two-fold. It regulates: employing and managing relevant schemas, and effective temporal processing of stimuli specific knowledge (i.e. knowing when to consider problem relevant information). Sweller (1988) highlights the integral role of forming schemas to developing expertise in a particular domain. He also succinctly summarizes the importance of schemas to expertise in problem solving: "Experts are able to work forward immediately by choosing appropriate equations leading to the goal because they recognize each problem and each problem state, from experience, and know which moves are appropriate". Evidence for the phenomenon of effective temporal processing can found in Jarodzka et al (2010). Here, fish experts and non-experts were compared in regards to both attention allocation, as well other measures such as: vocalizations made by participants, accuracy, and reaction times. Results showed evidence for an interesting distinction; the timing of *when* participants considered task relevant information. The experimenters found that the fish-experts vocalized and attended to relevant task information at the beginning of problem solving, where it would be more likely to be of use. They also tended to be more vocal about their problem solving process in general. This strategy could be interpreted as a kind of “mental checking” and used for inspection of their internal processes, a pattern which was not shared by novices. The “memory” defined by Newell and Simon (1957), is a somewhat nebulous term. In order to reduce confusion, the role of memory in this study will relate specifically to previous experience in domain (i.e. the amount of interaction and knowledge the person has had with the domain).

PIPs as introduced by Newell and Simon relate to the manipulation of information stored in memory (Newell & Simon 1957). Their model explicitly disregards the interplay that may occur between perceptual processes and memory. However, evidence cited earlier in this paper shows that the role of memory and visual attention may be more intertwined than was previously thought (Downing 2000; Desimone 1996). Therefore PIPs in this paper refer to both the manipulation of memory based information, as well as information gathered by perceptual processes. In respects to the second part of this definition, there is evidence that expertise effects can be demonstrated in PIPs. Noted by Reingold, Charness, Pomplun & Stampe (2001) chess experts were better than novices at both: the reproduction of previously viewed chess related scenes; as well as tending to focus on the spaces between pieces, rather than on the individual pieces themselves (Reingold et al. 2001). Interestingly, the second finding parallels results of a Greenfield (1994) study noted above. Experts in Reingold’s study cast their attention across the work-space as a whole, rather than focusing on any specific piece; similar to how video game players cast attention across an entire screen instead of focusing only on a target cue.

The modified IPS framework proposed here allows for the influence of expertise, as well as also capturing the differences found between the “efficient planners” and “error makers” categories introduced by Hodgson et al (2000). According to the Hodgson et al. (2000) the three major differences between the two groups were: the biasing of gaze towards relevant areas, selectively ignoring irrelevant areas, and ignoring inappropriate, previously employed schemas. The first two differences listed can be thought of PIPs, where explicit or implicit processes influenced expert participants’ information intake. This included both: excluding non-critical items, as well focusing on critical pieces. The final difference can be thought of as a difference in “memory” related function between the groups. Those in the “efficient planners” condition were better able to select (or in some cases) inhibit appropriate memories, which allowed them to solve the puzzle more efficiently.

Evidence has been provided in this paper of augmentations in perceptual processes & memory related capacities for video game players. These include possible increased VSWM memory capacity (Green and Bavelier 2006); the ability to attend to stimuli not in the foveal view (Greenfield 1994); an ability to discern objects from a more visually crowded space (Bavelier and Green 2007); and endogenous top-down processes which unconsciously direct attention (Chisholm et al. 2010).

Given all of this information, the current study hypothesizes that there is considerable similarity between the processes engaged in by experts as defined by Hodgson et al. (2000) and experienced video game players. We tested this hypothesis by creating measures to directly test for: measures of attention allocation, ability to disregard previously effective strategies, VSWM capacity, and spatial planning ability. We hypothesize that experienced video game players will perform similar to the “efficient planners” condition introduced in the Hodgson et al. (2000) study. Alternatively stated, experienced video game players will perform better than non-players on all of these measures. Following this, the current study is also interested in whether these differences are due to PIPs, the role of memory, or some interplay between the two.

Methods

Participants & Materials:

We tested 35 participants in this experiment (*n* = 35). Participants were pre-screened for video-game play, and based on the results were divided into two groups: practiced and novice video game players. All participants were males 18-25 years of age, and were recruited through an advertisement placed on Tufts-Life. Experimental attrition somewhat high, with five participants being unable to complete the experiment. The results from these five participants were not included in the analysis.

The tower of Hanoi is a puzzle game which requires the player to project multiple moves into the future, as well as remember patterns that they have seen before. The puzzle consists of at least three blocks (though more can added) arranged by size; within the starting (and ending) configurations, the largest piece is on the bottom and the smallest is on the top. These pieces are arranged on one of the three pegs, while the goal becomes to successfully move the pieces so that they are in the same configuration, but on a different peg. This puzzle derives its difficulty through its two major rules: 1) participants can only move one piece at a time, and 2) participants can not put a larger piece on top of a smaller one.

The stimuli used were free-trade, non-copyright protected pictures taken from Google image search. Each of the images used in the experiment (five pictures) was of the tower of Hanoi, the original image contained the 5 piece configuration; all other images were edited versions of this picture. All image editing was done through PAINT.NET software. The questionnaire was modeled after a screening measure used in the video game industry. It was used to: assess the number of hours/week the participant played video games; determine genre preference; as well as measure other related factors that could be used in follow-up studies. Programming and implementation of the experiment were completed in Experiment Center 3.0. Data related to eye-movement, eye position, and time spent by participants on each slide was collected with the iView X 500 hz eye tracking software. The various data were collected by an eye-tracker, which was mounted at the bottom of the computer displaying the stimulus. Data analysis and interpretation was done in Begaze 3.1.

Procedure:

Participants who responded to the Tufts-Life advertisement, or were recruited through SONA, were asked to fill out a brief 10 question survey which was used to determine their status as expert or non-expert. The number of hours/week that the participants played was used to determine their status as expert or non-expert; participants who responded that they played more than ten hours/week were placed in the expert group. If a participant responded that they played less than ten hours/week over the last six months, they were classified as non-experts. After receiving consent, participants were introduced to the both the eye-tracking software, and the Tower of Hanoi puzzle. First, participants were given basic training in how to solve the tower of Hanoi puzzle. The same basic training was provided for all participants, regardless of their individual skill and experience with the Tower of Hanoi. The basic rules of the game were then explained. Players can only move one piece at a time, and it could never be the case that a larger block is resting on top of a smaller block. Afterwards, the experimenter presented participants with a physical example of the tower of Hanoi, and demonstrated how to solve the puzzle. The participants were then required to solve the puzzle themselves. These steps insured that all participants, even those who had little to no familiarity with the tower puzzle, had a similar baseline level of knowledge.

Next, participants were oriented to the eye tracking procedure. Due to the complexity of the eye-tracking software used, a calibration and validation phase was required for the eye-tracker to adjust to new participants eye-movement patterns. This phase consisted of the participants following a moving circle around the screen, while the eye-tracker took measurements at certain points (when the dot stopped, a participants fixation point was compared to the middle of the dot). This phase was repeated until the software registered that it could follow the person's gaze to at least a 90% degree of certainty. Afterwards, the participants then read through instructional slides, where the rules of the experiment were explained.

The experiment consisted of five trials (not counting the instructional or end slides), each containing a different tower of Hanoi puzzle. Each trial was broken up into two pieces; the initial configuration (the work space), as well as the target configuration (the goal space). The slides were presented to the participants in ascending order of difficulty. There were two types of problems presented, ordered setup and unordered setup, hereafter referred to as “OS” and “US” respectively. OS refers to the canonical positioning of pieces at the beginning of a game. In this case, all pieces were stacked in order on the left hand side, with the challenge being to move them to an identical formation on the opposite peg. US however, represented novel configurations, where beginning orders were new, and could not possibly be known the participants, even those well-versed in the Tower of Hanoi. The initial configuration of US puzzles was the only difference present between “US” and “OS” conditions. In this experiment there were 3 OS puzzles, and 2 US puzzles.

This experiment required participants to announce each move that they made as they progressed through the puzzles. The participant’s moves were recorded by the experimenter. If participants were unable to remember their series of moves, then the experiment used the listed moves to remind participants of the current locations. The trial ended either when the participants had solved the puzzle, or had given up.

The procedure allowed for the collection of a number of different measures. Of primary concern were: 1) The number of moves, 2) The number of non-optimizations (mistakes) the participant made, 3) the number of saccades (rapid eye-movements) made per second, 4) the number of fixations made per second, 5) the number of times the participant asked for help, 6) the total time taken on each puzzle, and 7) the total number of critical targets hit (out of 2). Other measures were recorded, but these five were of primary interest.

Results and Discussion:

Of the five trials included in this experiment, data comes from only the last four. The initial trial was included to show a baseline comparison between the two groups. Data from participants who were unable complete any of the five trials were not take into account. All participants unable to complete the experiment (*n* = 5) were in the NVGP group. Additionally, due to software errors two participants eye-tracking data was not used (1 participant from each condition). A 4 (problem 2, 3, 4, 5) x 2 (expert vs. non-expert) ANOVA was conducted on all DVs, except for one. DVs were separated between behavioral results, and eye-tracking data. Behavioral results include: moves per trial, mistakes per trial, help requests per trial, time taken in each trial, and the number of critical targets identified. Eye-tracking data consisted of the number of saccades per trial, as well as the number of fixations. Data for targets was found only in the randomized trials, and were analyzed using an independent T-test between the two groups.

Behavioral measures can be further subdivided by their correspondence to specific aspects of VSWM, or relation to expertise as defined in the Hodgson et al 2000 paper. Time per trial, mistakes, and moves all relate to efficiency/planning metrics in VSWM. The less/fewer mistakes, moves, and time spent, show an increased capacity to plan into the future. The number of help requests is an index of VSWM capacity. Participants who made fewer help requests can be inferred to have had an easier time holding the current configuration in mind, compared to those who made more help requests. Finally, the number of targets (critical pieces) hit is an index of an ability of allocate attention to critical/relevant items. This variable measures both the participants' ability to bias attention to task critical information as well ignore irrelevant stimuli (similar to the Hodgson et al (2000) study). The target piece (appearing only in trials 3 & 5) when moved allowed for an expedited solving process. Participants who “hit” (moved the target piece first) were able to solve trials 3 & 5 in fewer moves than those who did not.

The number of moves made by participants can be directly related to their overall efficiency in solving the puzzle. A move in this experiment was defined as the positioning of a block on a new pillar. For example re-positioning “A” from pillar one, to pillar two would be considered a move. Participants were allowed to recall exactly one move. Meaning if their sequence of moves consisted of moving “A” from pillar 1 to 2, then pillar 2 to 3, they were allowed to recall “A” back to 2, but not back to 1. Each trial had a minimum number of moves that needed to be implemented in order to solve it. In total, the minimum number of moves needed to complete all of the puzzles was 94. Only one participant (VGP group), was able to complete the experiment in so few moves. The main effect of problem was significant *F*(1,26) = 667.131, *MSE* = 91146.30, *p* < .001. This result was expected as each problem had a different configuration and minimal number of moves required in order to solve it. A main effect was also found for group *F*(1,26) = 7.480, *MSE* = 1022.01, *p* = .01 with expert participants requiring fewer moves in order to solve each puzzle. Finally, a marginally significant interaction was found between problem and group *F*(3,78) = 3.401, *MSE* = 357.52, *p* = .11. This interaction likely reflects the effect of the final two trials. Here, experienced video game players showed the greatest distinction compared to their non-experienced peers. This is related to next measure discussed, mistakes.

Mistakes, in this experiment, refer to non-optimal moves associated with a particular train of logic. This is a somewhat nebulous phrase, but for this experiment a “logic train” can be thought of as the series of moves that a participant uses to solve a goal or sub-goal related to a problem. For instance, if a participant decides that a piece must be moved to one pillar, in order to free up space on another, the series of moves needed to execute this sub-goal would be the “logic train” formed in order to solve the task. As noted above, the minimum number of moves needed to complete all the puzzles was exactly 94, any mistakes made by the participant would be reflected (to varying degrees) in the number of moves.

This conceptualization of mistakes was implemented to capture errors in planning on the part of the participant, rather than note each sub-optimal move. This measure was conceptualized as such due to the difference in the number of moves needed to complete any one subgoal. For example, making a mistake at the beginning of trial 5, would result a series of errors that was far larger than moving the wrong piece at the beginning of trial one. However, both of these instances represent a single error in the participant’s train of logic.

There was a main effect of problem *F(*1,26) = 48.757, *MSE* = 364.583, *p* < .001, which can be explained in a similar fashion to main effect observed for the number of moves seen above. The difficulty of each puzzle increased as the experiment continued, which likely contributed to the number of mistakes the participant made in each trial. There was also a main effect of group, *F*(1,26) = 8.026, *MSE* = 60.012, *p* < .01. This main effect can likely be attributed to planning in the early stages of problem solving, which is seen more often in experts than (Jarodzka et al 2010). Experienced video game players (this experiment’s experts) made fewer mistakes, because they were more likely to plan out their moves at the beginning of each trial. There was no interaction between the two $F(3,78) = 1.743$, $MSE = 5.562$, $p = .21$.

The final behavioral measure relating to the efficiency of problem solving was the time taken for participants to complete each puzzle. This measure reflects the total time the participant spent completing each puzzle. It was measured as the time taken from the initial presentation of the trial slide, to the point at which the participant had successfully manipulated the initial configuration. There was a main effect of problem $F(1,26) = 178.46$, $MSE = 1.12 * 10^7$, $p < .001$, which was expected for reasons similar to those extrapolated on in the number of moves as well as mistakes sections above. A main effect was not found for group $F(1,26) = 1.531$, $MSE = 96402.55$, $p = .23$. There was no interaction between the two $F(3,75) = 1.161$, $MSE = 23504.15$, $p = .33$. The fact that there was no main effect for group, or interaction, has two possible explanations. The first is that, while experienced participants were more likely to plan out their moves (Jarodzka et al. 2010), non-experienced video game players, were more likely to immediately begin. This was reflected in the difference between the groups in regards to mistakes and total moves; non-experienced participants having more of both, due to a lack of initial planning. Alternatively, these results could be confounded by an error in the experiment. Due to the difficulty of the puzzles, after every trial slide there was a break slide in-between, to allow participants some time to recuperate. Time spent on these “break” slides was not factored in the analysis of total time measured. This was not the case between trials 4 & 5, as there was no a slide present. This fact may have caused some participants to take additional time between the fourth and fifth trials that was still recorded, confounding this measure.

One of the most difficult aspects of the experiment was the combination of actively planning one's moves, and holding the current configuration of pieces in mind. In the event that participants were unable to remember the configuration, they were allowed to ask the proctor, and they would be reminded. Help requests were coded as either full (1 HR) or half (.5 HR). A full help request was recorded when the participants were completely unable to remember the configuration of the pieces, and explicitly asked for help. Half requests were recorded when either: (1) the participant asked the location of a specific piece (i.e. "Where is 'C' right now?"), or (2) the participant simply asked for confirmation that their internal representation was correct (i.e. "So A is on 1, B is on 2, and C is on 3?"). A full help request was recorded, and the correct configuration was given, if the participant was incorrect in relation to one or more piece locations. In regards to this measure, there was a main effect of problem $F(1,26) = 95.269$, $MSE = 104.91$, $p < .001$. This is likely due primarily to increases in the number of pieces per slide. As the participants progressed, they encountered trials with more pieces. This required the participants to hold additional information in VSWM, while still actively planning towards the goal. A main effect was found for group as well $F(1,26) = 9.649$, $MSE = 10.63$, $p = .01$. As hypothesized, experienced video game players were better than their counterparts at actively holding current configuration in mind, while planning. This resulted in fewer help requests than in the inexperienced condition. There was no interaction between the two $F(3,78) = .64$, $MSE = .432$, $p = .592$.

The final behavioral measure recorded was the number of critical targets hit by the participant. Unlike the other measures, this variable was only present within the randomized trials (3 & 5). This measure was added to assess how well participants were able to direct their attention to critical stimuli. This is important for two reasons. The first is that, as noted in the introduction, other experiments have found VGP are able to reliably use endogenous cues to orient attention (Chrisholm 2005). Secondly, this feature provided some overlap between this experiment, and the Hodgson et al. experiment the paper is based on. In their experiment, they found experts were more likely to focus attention towards their critical item, when trying to solve the problem. Therefore, if experienced video game players are similar to "efficient planners", then the number of critical targets hit by VGE should be significantly higher.

Since this item only occurred in randomized trials, an independent T-Test analysis was performed. There was in fact a significant difference in the scores for experts (M=1.66, SD=.49) and non-experts (M=1.06, SD =.80) conditions; t(28)=2.352; p = .026*.* Experts showed an increased likelihood to hit critical targets.

The two eye-tracker based DVs in this experiment were the number of saccades per trial, and the number of fixations per trial. Both of these measures are related to attentional and perceptual characteristics of the participants. That is, they measure the approximate volume and speed of information of information intake (Finlay & Gilchrist 2001). The traditional view of the relationship between saccades and fixations is that they are complimentary. Information is recorded during fixations, while saccades are used to rapidly locate new areas relevant to whatever the situation calls for (Land, Mennie, & Rusted 1999). Given that video game players are more adept at the integration of visual information (Okagaki & Frensch 1994), we hypothesized that video game players would show more saccades and fixations than non-players.

Saccades refer to rapid movements of eye during which foveal focus does not occur on any one point (Noton & Stark 1971). Saccades do not have a specific maximum duration, but are generally defined as rapidly shifting gaze bias lasting at least 50ms (Fischer & Web 1993). This definition of saccades was used for the purposes of classification and accounting for this variable. We hypothesized a significantly different (higher) number of saccades for participants in the expert, as opposed to the non-expert condition. We found a main effect of problem on saccades $F(1,26) = 139.217$, $MSE = 5.01 * 10^8$, $p < .001$; but not for group $F(1,26) = .683$, $MSE = 2.48 * 10^6$, $p = .416$. The study did not find an interaction between the factors $F(3,75) = .51$, $MSE = 5.02 * 10^5$, $p = .676$. The lack of main effect for group is likely due to the fact that the study lacks statistical power. The number of saccades for each trial was very large as a result of the duration of each trial. This, when combined with the number of subjects lead to little statistical power for this measure.

The final DV of this experiment was the number of fixations that participants made in each trial. A fixation is defined by focusing the fovea onto a specific area, for a duration of 300ms (Loftus & Mackworth 1978). Given that fixations are necessary for the intake of information (Grant & Spivey 2003), it was assumed that experienced video game players would display more fixation oriented behavior. A main effect for problem was found $F(1,26) = 178.46$, $MSE = 1.12 * 10^7$, $p < .001$, however one was not found for group $F(1,26) = 1.53$, $MSE = 9.64 * 10^4$, $p = .23$. There was no interaction between the two conditions $F(3,75) = 1.161$, $MSE = 2.35 * 10^4$, $p =.33$. The explanation for a lack of main effect for group is the same as for saccadic measurements. Additional participants were needed in order to gain statistical relevance.

The results for eye-tracking measures came at first as a surprise, however upon further analysis, it was determined that the problem was related to a lack of statistical power. Chart 1 shows the relative means for saccades and fixations per trial. The data is clearly trending towards a significantly larger number of saccades/fixations for experienced participants. However, the lack of available subjects created too much noise in order to achieve the statistical correlation.

Conclusions:

The results from this experiment clearly demonstrate that video game experience in some way positively impacted participant's visual problem solving ability. Video game players demonstrated an advantage over non-game players in every behavioral measure, sans the time taken per trial. VGPs completed the task in fewer moves, making fewer mistakes, requiring less assistance, and more frequently orienting to specific stimuli that were relevant to the task. In the introduction, this paper hypothesized two different possible mechanisms through which video game experience might influence visual problem solving ability. These were: superior allocation of attentional and perceptual resources, and the augmentation of capacity in the VSWM.

In light of the findings of this study, the hypothesis that experienced video game players would perform better due to attentional or perceptual changes must be discarded. This hypothesis predicts differences in behavioral measures between conditions (specifically experienced video game players allocating attention to the most integral areas of the puzzle), as well differences in the eye-tracking data for participant conditions.

The perceptual/attentional hypothesis correctly predicted the behavioral results; however it lacks an explanation as to why the two conditions did not show a difference in eye-gaze patterns. The most relevant measures for this hypothesis were: the number of problem critical targets hit (attention allocation), saccades (perceptual intake), and fixations (perceptual intake). While, the experienced video game players were significantly better at attending to critical targets they did not show a difference from non-experienced players in saccades or fixation measures.

Most crucial for this hypothesis was that participants experienced with video games would show differing patterns of saccades or fixations during the trial. This was not reflected in the results. One explanation for this is that while video game experience influences perceptual processes, this change may only be reflected in tasks associated with video games (i.e. this effect is not generalizable). For example Sims and Meyer (2002) tested differences in mental rotation abilities between experienced Tetris players (a game based around spatial manipulation of an object), and participants with no experience with the game. They found that while Tetris players had an advantage on puzzles resembling Tetris, this effect was not generalizable to other mental rotation puzzles. Relevant this study, they also found that experienced Tetris players displayed a different style of mental rotation than the other participants. This indicates that a difference was in fact present, but it showed no beneficial effects. The Tower of Hanoi puzzle used in this experiment is dissimilar to most, if not all video games. This could explain why video-game expertise did not provide a benefit; or generate differences between the groups.

The augmentation of VSWM hypothesis provides the best fit for the results of this experiment. This hypothesis correctly predicted differences between the groups in all behavioral measures. The two measures most related to VSWM were the number of help requests the participant made, and the number of mistakes made. The number of help requests was hypothesized to be a measure of difficulty on the task. With more difficult problems placing a larger burden on the participant's ability to hold multiple components in mind while planning. The results reflected this, showing a main effect for problem number, indicating that, as the difficulty of the problem increased, so did the number of help requests made by participants. Additionally, there was a main effect of group on this variable. Demonstrating increased difficulty for non-experienced participants to perform the task compared to the experienced group. It would appear that participants with video-game experience simply required less external assistance on the task. The number of mistakes made can be conceptualized as an index of the participant's ability to plan their moves into the future. Participants, who could effectively plan into the future, were less likely to make non-optimal moves when solving the problem. The main effect of group on this variable indicates an increased capacity to plan into the future for experienced participants. This is likely due to planning occurring earlier in the problem solving process for experts (Glick 1996), which is especially important for the Tower of Hanoi puzzle task.

Additionally, this theory provides an explanation for the marginal interaction found between moves x group x problem. Figure 1 demonstrates a clear point after which video game inexperienced participants' performance dropped dramatically (at the transition from trial 3 to 4). According to Sweller (1988) working memory is crucial to the development of schemas (or mental shortcuts). He also posits that schemas in turn, are necessary for the development of expertise in a field. However, solely engaging in problem solving does not actively engender the development of schemas due to the strain in places on working memory (Sweller & Cooper 1985). Given an augmentation in visuo-spatial working memory capacity, it is possible that early problems did not place a large burden on VSWM for experienced participants. This meant the video game playing group was better able to develop schemas. This explanation accounts for the smaller difference in moves for early trials. As seen in figure 1 the difference between the groups grew significantly larger in later trials. Alternatively, the discrepancy could be explained simply through a larger capacity to manage and manipulate objects in VSWM as suggested by Green & Bavelier (2006). Regardless of the specific sub-mechanisms at play, augmentation of VSWM is the best explanation for the data emanating from this study.

The two major limitations of the study are: the lack of statistical power for eye-tracking results, and the lack of a buffer slide between trials 4 & 5. The lack of statistical power is due to having too few participants, combined with a large number of saccades and fixations per trial. With a larger sample pool, it is likely that this error could be corrected. Table 1, displayed below, maps out the average number of fixations and saccades per trial as factored by subject group. There is a clear difference in the number of saccades and fixations made by each group. Given more subjects, this limitation may be overcome, at which point, the perceptual / attentional hypothesis may be revisited. The second limitation (the lack of a buffer slide between trials 4 & 5), was noted as a possible confound for the lack of a main effect for group on time taken per trial. While it is possible that adding a buffer between the trials would generate significance between the groups, it is unlikely. As noted in Jarodzka et al. (2010), experts and participants begin working on problems in fundamentally different ways. Experts were more likely to consider task relevant information before beginning the trial. Alternatively, novices did not take the additional time to consider task relevant information. Both of these explanations have merit; however the second is more convincing. All participants viewed the slides in the same order. Neither group had a break between trials 4 and 5, which would indicate that the difference between groups was negligible in this regard. Fixing this error would likely not cause a significant finding in relation to time spent per trial.

The final confound of this study is present in any experiment based around finding differences between video game populations and non-playing populations. Namely, the question of self-selection bias in video game players. That is, are differences in video game populations due to changes engendered by video games, or is it the case that people who are naturally gifted in these areas are drawn to video games? This problem can not be addressed by the current literature, however this study's position is that evidence for the first hypothesis is stronger than the second.

Some researchers argue for the self-selection bias in video game playing populations due to video-game training studies where no effect was found. In other words, some experiments have found that training people with no experience in video games does not engender the behavioral results found in other video game playing populations. The longitudinal study of Boot et al. (2008) provides evidence for a lack of performance improvement after video game training in many of the areas listed in this paper (e.g. visual short-term memory accuracy, mental rotation, etc). However, a major confound of studies seeking to test the effectiveness of video game training, is their participants age. Children with video game expertise begin showing improvements in visuo-spatial measure as young as 7 years old (Dye and Bavelier 2010). The Boot et al. study, however had a mean age of 22 years old. Age differences play a large role in how quickly we acquire new knowledge (Thomas 1980), and this confound is not addressed in their study. Additionally, evidence for improvement of skill due to video game experience is found in a broad range of domains. Tasks ranging from lacroscopic surgery (Schlickum et al. 2009) to flight skill (Gopher, Well, & Bareket 1994) have seen improvements from video game training. Given the confounds in training research, and the robust number of findings in favor of video games increasing visuo-spatial measures; this paper falls in favor of video games influencing behavior, rather than an explanation revolving around self-selection bias.

Assuming that video game play is what drives these changes in behavior (as we must for this experiment), invites a bevy of different training and rehabilitation programs. Some successful examples of this type of program include: improving manual dexterity in the elderly (Drew & Walters 1986); air force cadet training (Gopher, Well, & Bareket 1994); and reducing the effects of cognitive decline in elderly players (Basak, Boot, Voss, & Kramer 2008). More relevant to the study at hand, these training regimens have also managed to influence visual plasticity (promoting changes in vision). Achtmann, Green, & Bavelier (2008) have shown that engaging adults in action video game training enhances numerous visual processes. These enhancements include: faster RTs to visual stimuli, quicker recovery of attention, and the reduction of crowding effects. If video game training can improve skill sets as varied as these, this study advocates its’ use in clinical as well as other appropriate settings to improve living conditions for those with impaired VSWM.

Figures and Charts:

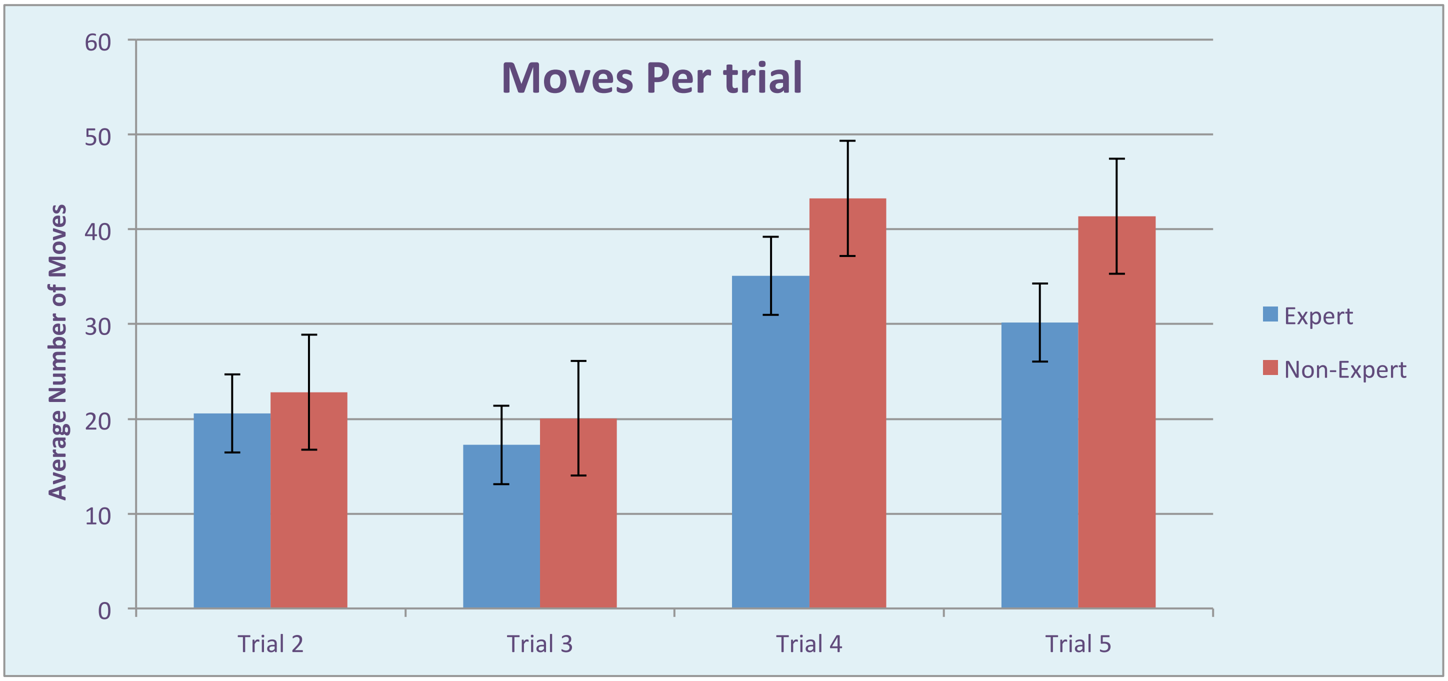

Figure 1 Mean number of moves of per trial for participants in the two conditions.

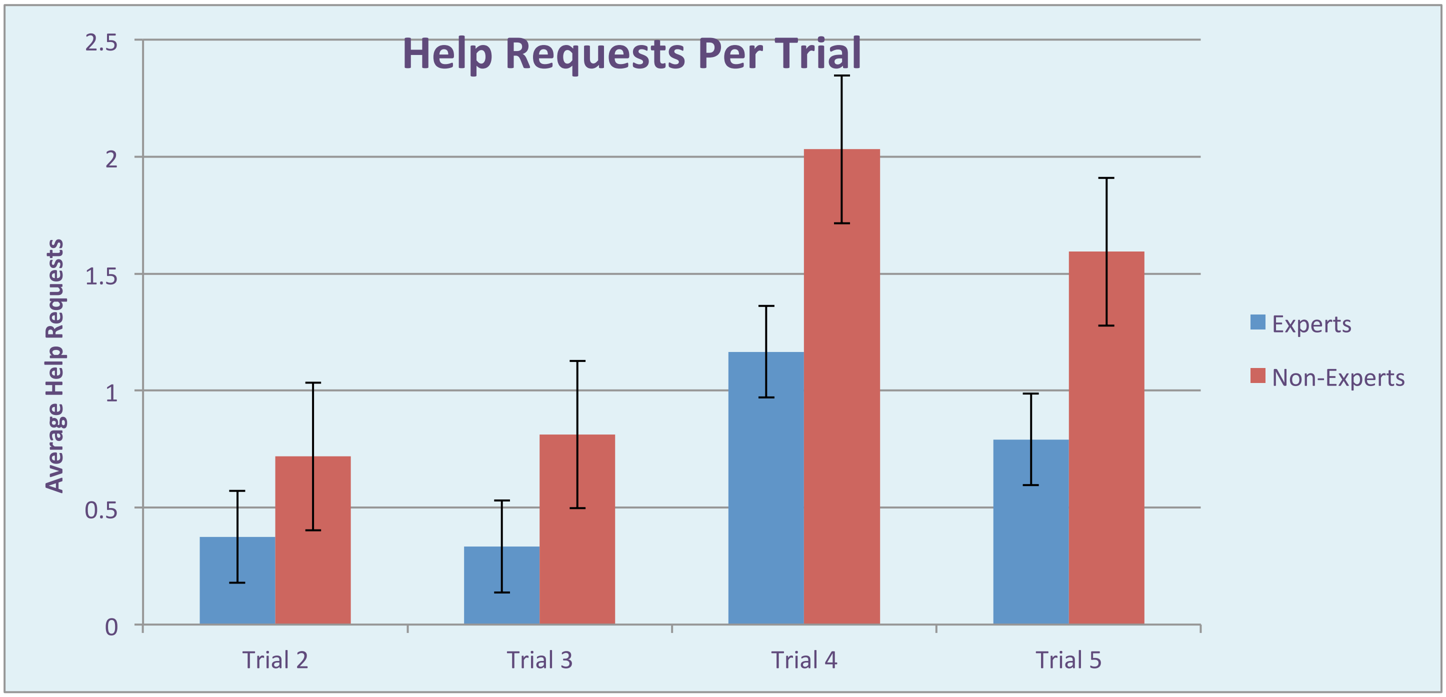

Figure 2. Mean number of help requests per trial for participants in the two conditions.

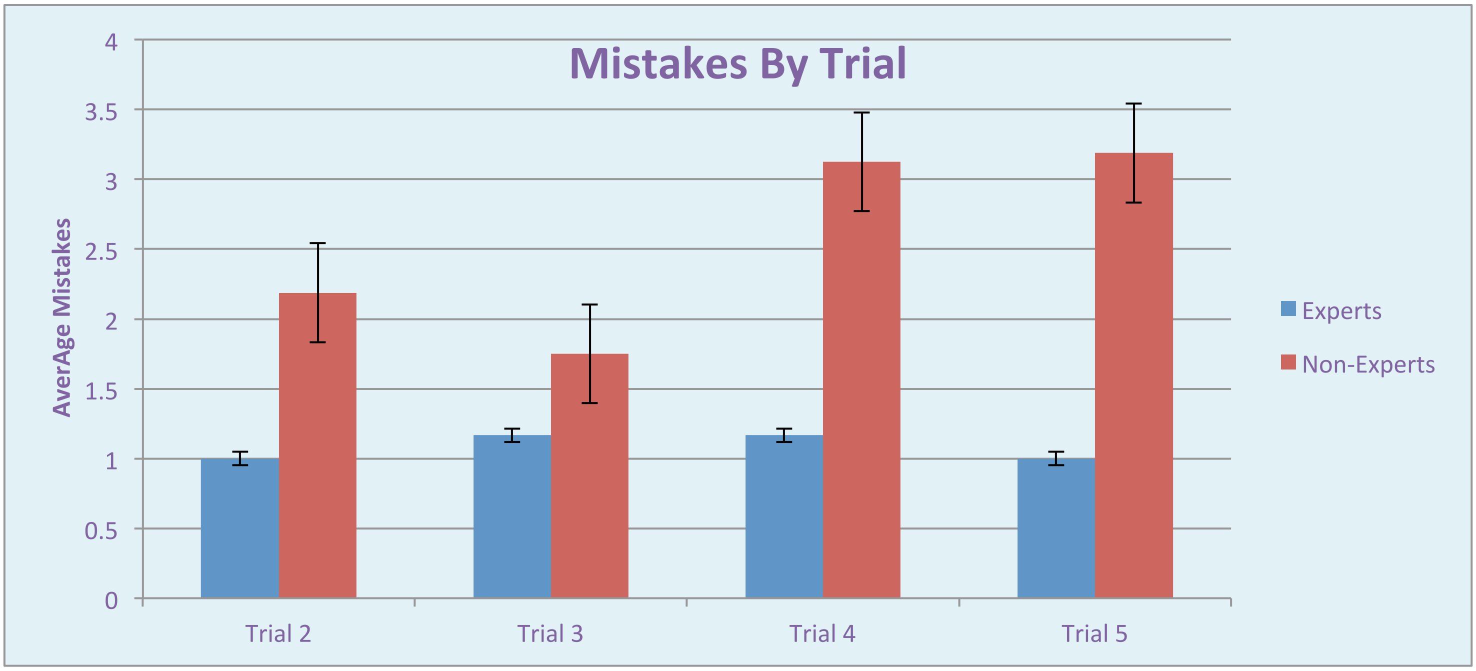

Figure 3. Mean number of help requests per trial by group

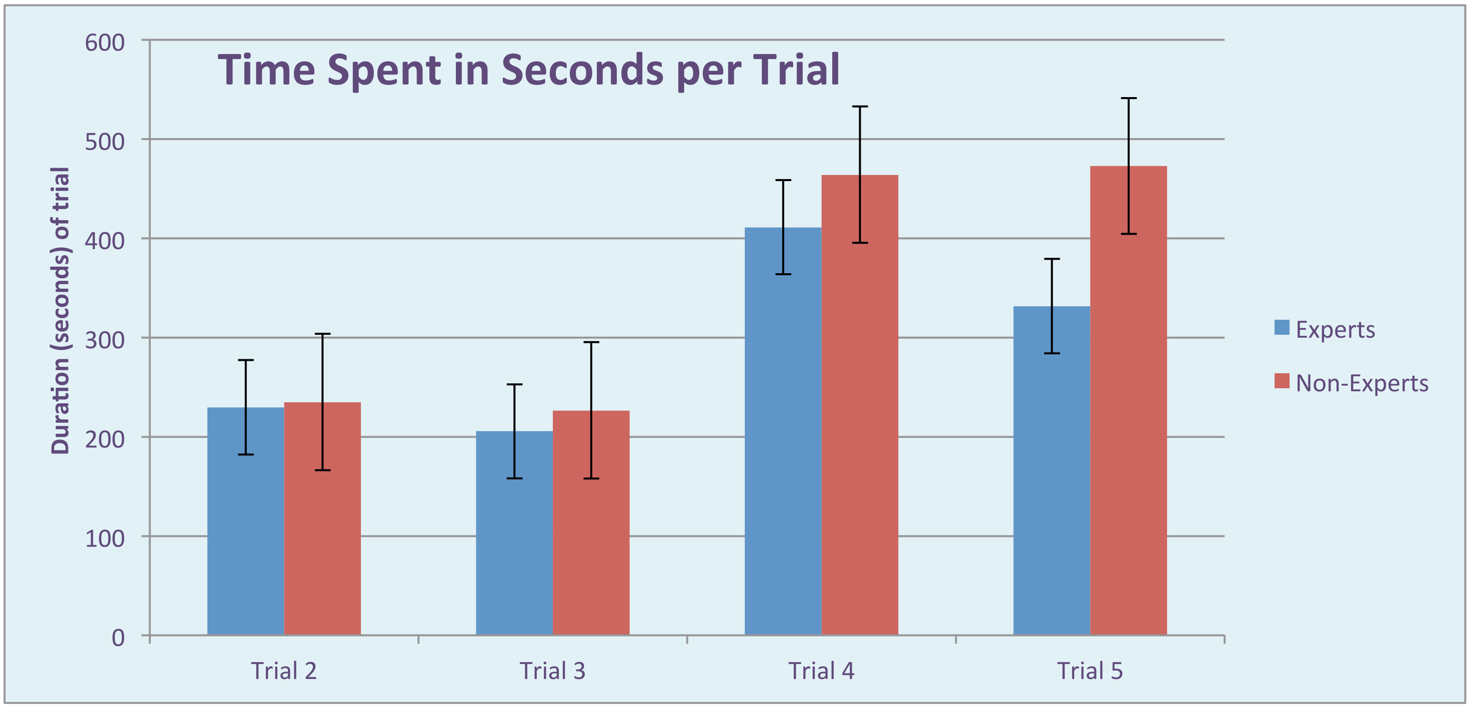

Figure 4. Average time taken per trial (in seconds). The major differentiation between groups occurs in second randomized trial (trial 5).

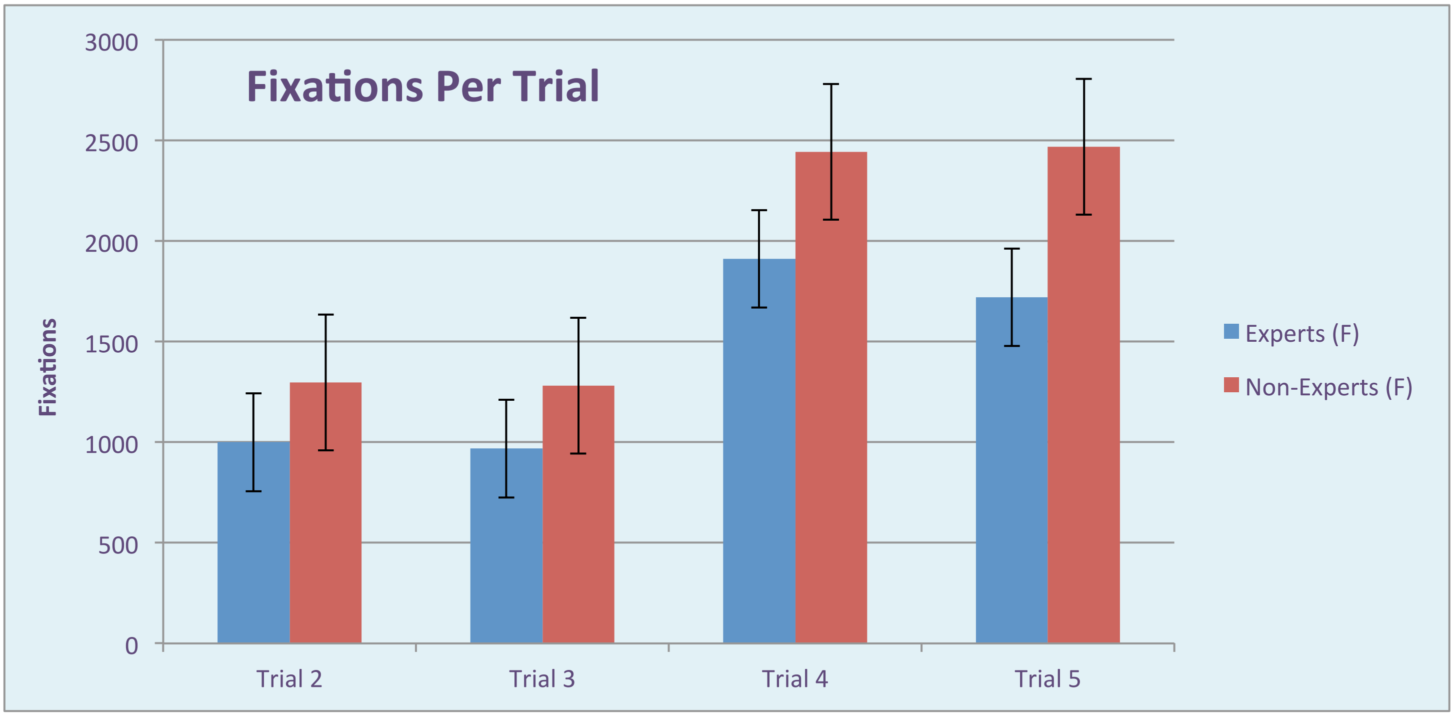

Figure 5. Number of fixations per trial by group, experts showed a clear distinction from non-experts in later trials.

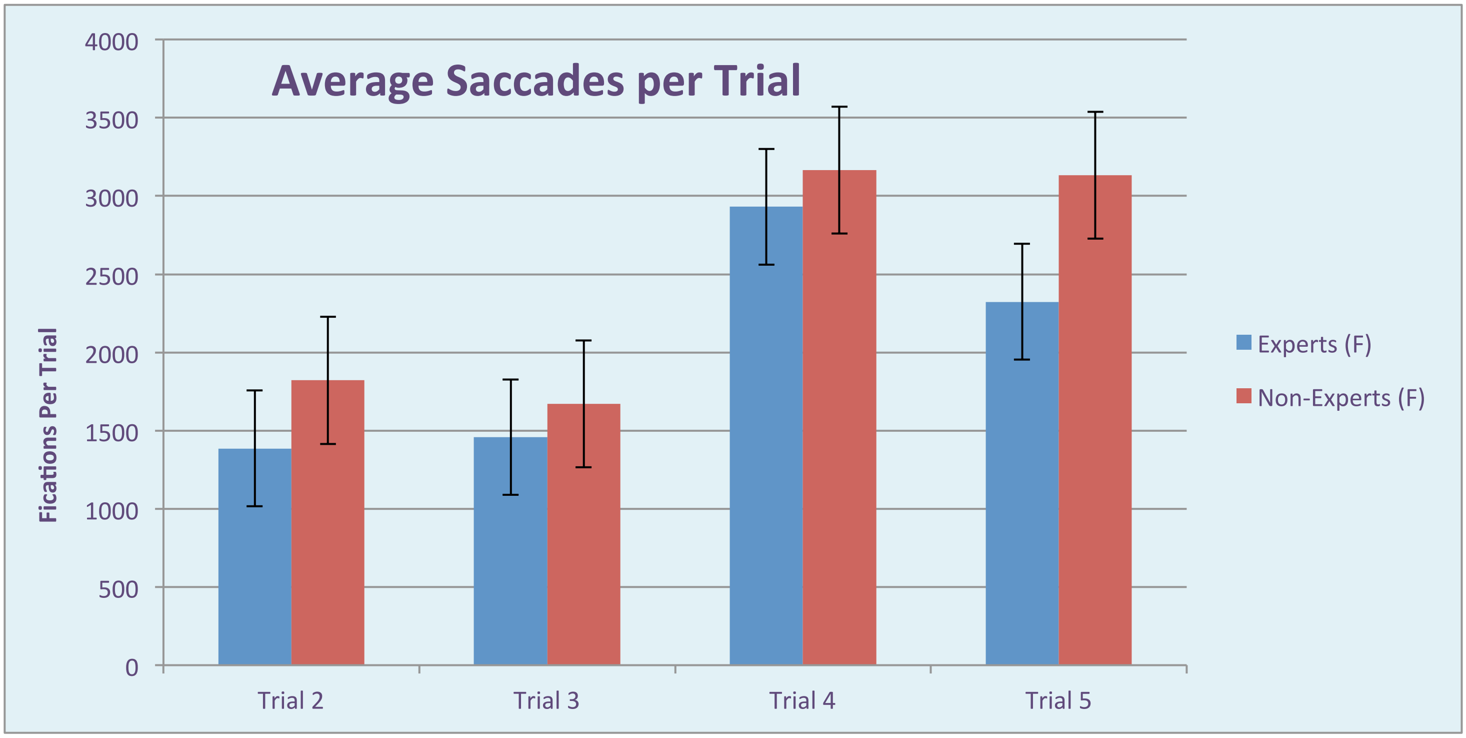

Figure 6. Average saccades per trial. The differences here were smaller than the differences between fixations.

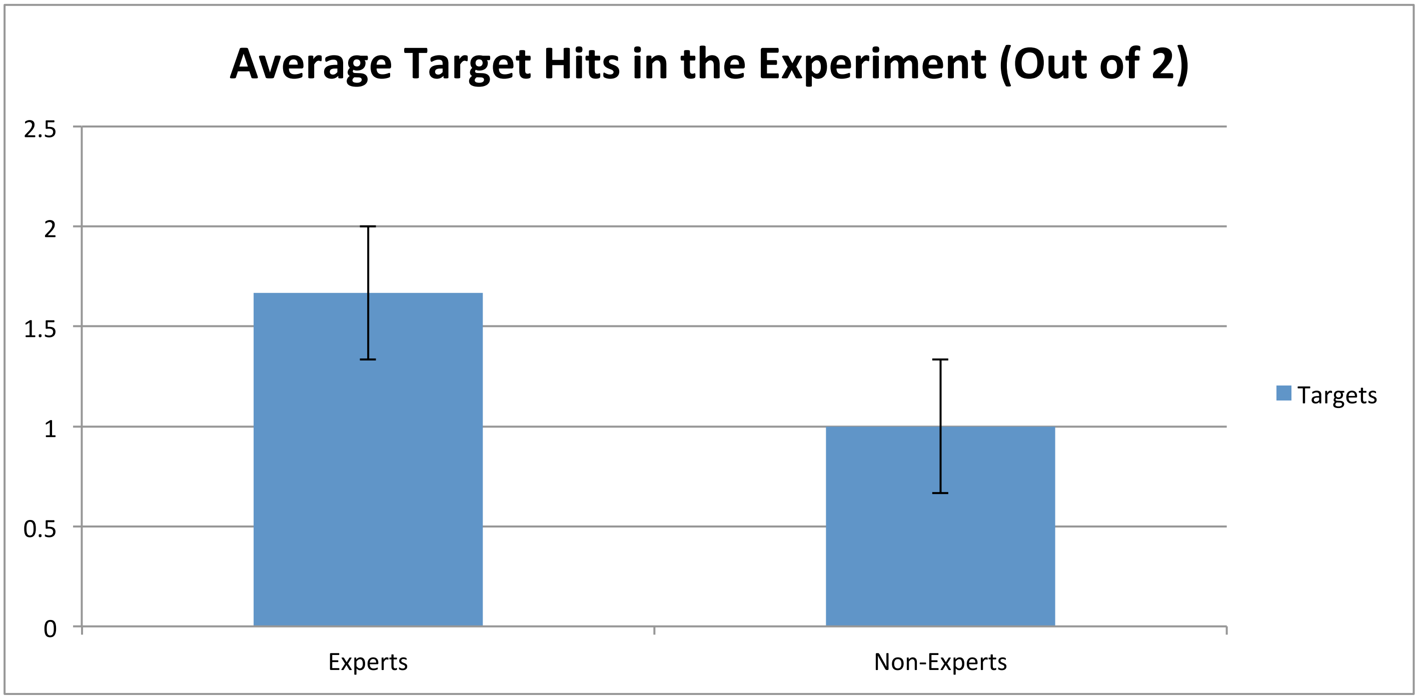

Figure 7. The number of targets hit by experienced video game players (experts) was significantly larger than the number hit by non-experts

Group (Measure)	Trial 2	Trial 3	Trial 4	Trial 5
Expert (S)	1385.75	1457.917	2930.333	2323.583
Expert (F)	999.75	968.6667	1911.667	1720.75
Non-Expert (S)	1820.563	1671.438	3165.2	3133.643
Non-Expert (F)	1296.813	1280.875	2443.533	2468.5

Table 1. The number of saccades (S) and fixations (F) made by participants. As mentioned in the results this finding, while not significant, is clearly trending.

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