EXPERT ENHANCEMENT OF SPATIAL PERCEPTION

IN THE FACE OF UNCERTAINTY

by

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Abstract

The current study expands upon previous research that has demonstrated transfer of training from action video games (AVGs) to laboratory tasks that require visual selective attention (Green, Li & Bavelier, 2009 for review). Here, the potential of AVG training was further examined by measuring visuo-spatial discrimination performance and auditory-spatial discrimination performance under varying conditions of stimulus uncertainty. To this end, 46 participants (23 expert AVG players, 23 novices) completed a visual and an auditory discrimination task, and accuracy and reaction times were recorded. Expert participants were expected to possess superior discrimination skills overall and were expected to be less affected by stimulus ambiguity. Neither mean error rate nor mean reaction time differed due to group expertise level, and both experts and novices were equally slowed and made less accurate when stimulus ambiguity was increased. Despite the lack of mean group differences, experts demonstrated faster reaction times during the visual discrimination task than during the auditory discrimination task, whereas novices did not. This interaction suggests that AVG training results in enhancement to spatial discrimination skills selectively in the visual modality, while spatial auditory processes are unaffected.

List of Abbreviations and Symbols

AVG Action Video Game

β Probability of a Type-II error

ESA Entertainment Software Association

f Cohen’s f : A measure of effect size

F Fisher’s F ratio: Ratio of variance explained and error variance

fMRI Functional Magnetic Resonance Imaging

ICI Inter-Click Interval, time between the preceding and trailing auditory click in each click pair

ISI Inter-Stimulus Interval, time between reference and comparison stimuli

ITD Inter-aural time difference, onset asynchrony between left and right ears

M Mean

ms Milliseconds

p Probability of obtaining a test statistic as extreme as the observed value due to chance

RT Reaction Times

SD Standard deviation of the mean

SE Standard error of the mean

TMS Transcranial Magnetic Stimulation

= Equal to

> Greater than

< Less than

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Introduction

Experience-dependent plasticity is the capacity of the adult brain that allows modification of neural structure and function so that specific demands of an environment can be handled successfully (Huttenlocher, 2002). This ability permits the individual to train their brain in order to overcome challenges unique to a particular environment. Extant literature focusing on the neural plasticity of sensory and perceptual mechanisms and related psychophysical benefit are of particular relevance to the primary question addressed in the current study. That is, does experience within a complex virtual environment alter human perception of spatial visual and auditory sensory information?

Related questions probing the plastic nature of the adult brain have been examined using animal models such as the rat. For example, studies investigating the relationship between "environmental enrichment," associated behavioral improvements, and neuroplasticity have reported enhanced spatial memory and spatial learning as well as neurogenesis in the adult rat (Bernstein, 1973; Fordyce & Farrar, 1991; Kempermann, Gast, & Gage, 2002). The type of anatomical change involved in experience-dependent plasticity varies due to the specific nature of environmental change or novel task being performed, but the mechanisms include synaptogenesis, neurogenesis, gliogenesis, and angiogenesis (Isaacs, Anderson, Alcantara, Black, & Greenough, 1992; Kleim et al., 1996; Markham & Greenough, 2004; Van Praag, Kempermann, & Gage, 2000). These mechanisms of plasticity are consistently associated with perceptual learning, which is the increase in performance during training or exposure to novel stimuli. Examination of these anatomical changes and their psychophysical counterparts has revealed much about experience-dependent plasticity of auditory and visual circuits.

Plasticity in Auditory Systems

Animal models of auditory plasticity.

The nature of experience-dependent plasticity in the auditory system has been elucidated through the use of animal models. Knudson and colleagues have investigated auditory learning and underlying neurology within the owl (Knudson, 1999 for review). They have revealed that the avian homologue of the inferior colliculus contains a spatial map for auditory information, and that this map reacts plastically to suit environmental regularities. Indeed, this spatial map for auditory localization is reorganized when unusual, persistent environmental changes are presented (Brainard & Knudson, 1993; Knudson, 1983). Tonotopic maps are also malleable (Recanzone, Schreiner, & Merzenich, 1993). Monkeys trained to discriminate between similar tonal frequencies demonstrated improved performance, and electrophysiological recording revealed increased cortical allotment and sensitivity for trained tones. It seems that context plays a crucial role in determining experience-dependent plasticity in the auditory domain. Research has shown that rewarding attention to one type of auditory cue (e.g. intensity) but not others (e.g. frequency) results in plasticity for the neural resources associated to the rewarded cue but not for others (Polley, Steinberg, & Merzenich, 2006). Also, general improvements in auditory perception are observed in rats housed in an environment enriched with auditory stimuli (Engineer et al., 2004).

Auditory plasticity in humans.

Much of the research examining plasticity in the auditory systems of adult humans has focused on experience-dependent changes in auditory localization performance (Wright &

Zhang, 2006 for review). Saberi and Perrott (1990) examined one example of this perceptual learning, the elimination of the precedence effect. The precedence effect describes a perceptual phenomenon that occurs when two binaural stimuli are presented in rapid succession (<10ms apart). The two stimuli are identical in terms of pitch, duration and loudness, but they have different localization cues. Typically, these localization cues are interaural time differences (ITDs), which are simply differences in time of stimulus onset between the listener's two ears that relate to the perception of sound location in space. For example, if a sound reaches the left ear first, and then reaches the right ear 200 microseconds later, the listener would perceive the sound's source to be somewhere to their left. The precedence effect occurs when two sounds are paired closely in time, and the results are as follows.

First, because these two auditory stimuli are presented so closely in time, they actually become perceptually fused into a single sound or auditory event. Second, and most critically, the localization of this perceived auditory event is biased heavily towards the location information contained within the preceding stimulus (Zurek, 1987). This means that if two stimuli are presented within this 10ms time window they are likely to become perceptually fused, and any judgments about the location of this perceived auditory event are likely to be based upon the localization cues (i.e. ITDs) contained within the preceding auditory stimulus. So, if a centrally located stimulus is presented just prior to a left localized stimulus, these two stimuli will be perceived as one, and the precedence effect will lead listeners to judge the fused event as centrally located. Essentially, the precedence effect is the ignorance of spatial information contained within a second stimulus, when it is preceded immediately by another stimulus.

While the example above describes the basic scenario in which a precedence effect occurs, precisely recording localization performance in such a situation is an arduous task that requires personalized measurement calibration for each listener. However, the precedence effect can be measured more simply using a spatial discrimination paradigm in which two pairs of precedence stimuli are presented in a single trial. This discrimination procedure is illustrated in Figure 1 and it requires the presentation of four auditory stimuli in a single trial (Saberi & Perrott, 1990). All four stimuli are brief 1ms clicks of equal pitch and intensity that are presented to both ears (binaurally). The first click and the second click are paired very closely in time (<10ms) so that they become perceptually fused into a single auditory event. After this first click pair there is a fixed 300ms inter-stimulus interval (ISI). Then the third and fourth clicks are presented with the same temporal spacing used to fuse the first pair of clicks, in order to also perceptually fuse the third and fourth click into a single auditory event. This spacing within click-pairs (between click 1 and click 2, or between click 3 and click 4) is referred to as an inter-click interval (ICI); and short ICIs (<10ms) in this paradigm result in the perception of two distinct auditory events, with each event consisting of two auditory stimuli that are perceptually unified. The first click-pair is referred to as the referent event, and the second click pair is called the comparison event.

Again, all clicks are identical in terms of duration, intensity, and pitch. The clicks within the referent event are also identical in terms of spatial information (i.e. their ITDs are the same). This means that any bias toward the first click rather than the second click will not affect the localization of the referent event, because both clicks comprising this event are spatially identical. In contrast, click 3 and click 4 differ in terms of spatial information. Click 3 is identical to click 1 and click 2, but click 4 has inter-aural time differences that are unlike the other stimuli. Conceptually, this means that if these stimuli were presented independently, outside of this precedence paradigm, the first 3 clicks would be localized to the same place, but click 4 would be localized slightly to the left or right of the others. However, within this paradigm, click 3 and click 4 become perceptually fused and the precedence effect leads listeners to base their localization of this fused event on the spatial information contained in click 3. This is demonstrated by asking listeners to determine whether the second, comparison event (2nd click-pair) is located to the right or to the left of the first, referent event (1st click-pair). If the precedence effect occurs, the perceived location of each event is based upon the spatial information contained within the preceding click of each event (click 1 and click 3 for the referent and comparison events, respectively). Because the spatial information in click 1 and click 3 are identical, the precedence effect (and resulting ignorance of the spatial information in click 4), leads to the perception of two auditory events that are located at the same place. Without perception of the spatial information in click 4 of the comparison event, listeners will be forced to guess randomly whether the comparison event was to the right or to the left of the referent event; so response accuracy would be at chance.

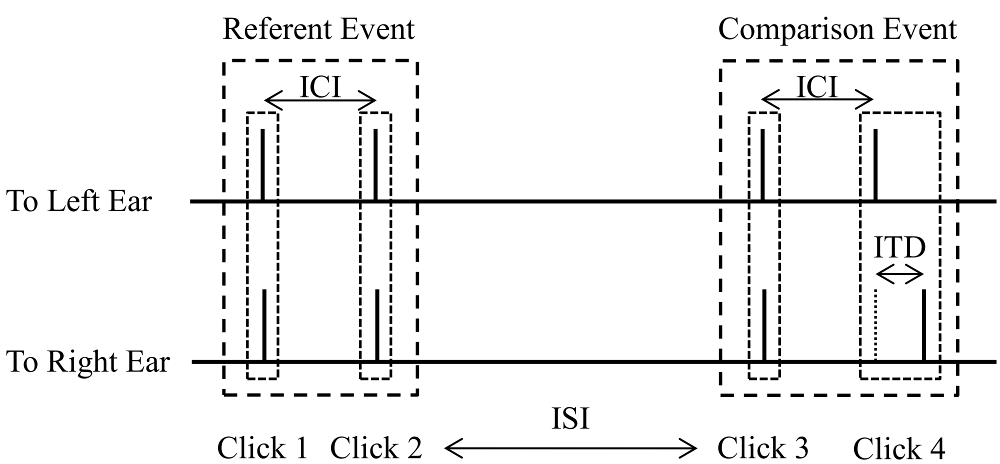

Figure 1. Spatial discrimination paradigm used to examine the precedence effect. Adapted from "Lateralization thresholds obtained under conditions in which the precedence effect is assumed to operate," by K. Saberi and D. R. Perrott (1990). *J. Acoust. Soc. Am., 87(4),* 1733.

Saberi and Perrot (1990) demonstrated using this paradigm that the point at which localization accuracy exceeds chance performance is dependent upon a number of factors. Of these factors, the two that are most important for the current study are the length of the inter-click interval (ICI) and the magnitude of the inter-aural time difference (ITD) contained in click 4 compared to that of click 3 (perceptual distance between click 4 and click 3). These researchers found that as the duration of the interclick-interval is lengthened the potential for greater than chance accuracy is increased. Also, as the magnitude of click 4's inter-aural time difference is increased relative to click 3, the potential for exceeding chance performance is increased. These two factors were also shown to interact. When the interclick-interval was short, a large relative ITD was needed between click 3 and click 4 in order to exceed chance accuracy. In contrast, the relative ITD threshold for above-chance accuracy was lower when longer interclick-intervals were used. Further, practice with this task decreased the relative ITD threshold for accurate performance even when brief ICIs were used. Essentially, this indicated the elimination of the precedence effect through training. Participants learned to detect the spatial information contained within click 4 that was initially unperceived due to the precedence effect (Saberi & Perrott, 1990).

With training, humans are also able to compensate for newly introduced relationships between interaural cues (i.e. intensity difference, time delay), which indicates perceptual learning similar to that described above in animal studies (Butler, 1987; Shinn-Cunningham, Durlach, & Held, 1998; Javer & Schwartz, 1995). An interesting series of studies placed divers underwater and tasked them with localizing sound sources (Feinstein, 1973; Feinstein, 1975; Stouffer, Doherty, & Holien, 1975). Sound travels faster in water reducing the magnitude of interaural onset delay for auditory stimuli, which leads to inaccurate localization judgments that are too near midline (Wright & Zhang, 2006). With training, divers became able to more accurately localize the sound source under water, but when removed from the water sound localization was again erroneous. Divers perceived the sound source to be further from midline than it actually was (Wells & Ross, 1980). This indicates a highly plastic system for auditory spatial perception, one that can be rapidly tuned to more accurately interpret novel environments. Other research has shown that localization performance with normal cues can also be improved with training suggesting that there is not only the potential to remap auditory processes in the face of the unusual, but also a capacity to refine them in the face of the mundane (Abel & Paik, 2004; Shinn-Cunningham, 2000; Zahorik, Bangayan, Sundareswaran, Wang, & Tam, 2006).

Plasticity in Visual Systems

Animal models of visual plasticity.

Much like those examining auditory plasticity, comparative studies have provided evidence for enhanced visual perception resulting from alterations of the structure and function of the visual cortex in the face of novel visual tasks and stimuli. However, investigations of plasticity of the visual modality have focused on the perception of features, and little research has tied neural plasticity to perceptual learning that leads to improved processing of spatial information. Examples of this feature-focused research have involved adult monkeys trained using an orientation discrimination paradigm. Improved performance following training was associated with increased sensitivity about the trained angle of orientation for neurons in the primary visual cortex (V1) and secondary visual cortex (V4) (Schoups, Vogels, Qian, & Orban, 2001; Yang & Maunsell, 2004). The neuronal activity in V1 has also been shown to be affected by non-visual information. Shuler and Bear (2006) found that the firing patterns of neurons within the visual cortex (V1) of the adult rat became synchronized with the trained timings between stimulus and reward. Similarly, Crist, Wu Li, and Gilbert (2001) argued that plasticity in local circuits can be affected by top-down feedback as well as attentional processes. Based on these and similar studies using adult animal models, experience-dependent plasticity is evident at a basic level of visual processing.

Visual plasticity in humans.

While cellular psychophysiological evidence such as micro-electrode recording is largely the domain of animal study, there is also neurological evidence indicating that plasticity occurs within the visual cortices of adult humans during perceptual learning. For instance, Maertens and Pollmann (2005) tasked participants with determining whether illusory contours were concave or convex. Using functional magnetic resonance imaging (fMRI), they observed increased performance and increased activation of regions in V1 previously associated with detection of “real” contours. These effects were present ten months after training, but were specific to the trained location in the visual field. Research by Neary, Anand and Hotson (2005) showed that perceptual learning resulting from a line orientation discrimination task not only improved behavioral performance, but it also decreased the magnitude of detrimental performance effects observed when transcranial magnetic stimulation (TMS) was applied to occipital cortex.

In addition to alterations of the basic, “lower” level cortical faculties of vision, experience dependent plasticity of structures involving “higher” level visual processing has also been found. For example, Kourtzi, Betts, Sarkheil and Welchman (2005) showed that training led to perceptual learning evidenced by improved ability to accurately detect a target visual stimulus within a field of distractors, and this improvement was correlated with “distributed” plasticity of visual cortex. Specifically, they found that training to detect low salience stimuli among distractors led to increased performance and intensified neural activation in both the lower visual areas (e.g. V1, V2, V3) and the higher processing lateral occipital complex (Kourtzi et al., 2005).

Although most of the reported cases of visual plasticity are feature-focused, accounts of prism adaptation describe visual plasticity in spatial processing. Individuals looking though prismatic lenses initially perform with increased errors when asked to point towards locations or objects. Prolonged experience with the prisms leads to the ability to point accurately. Further, when the prisms are removed, pointing behavior again becomes temporarily inaccurate (Redding & Wallace, 2005). This shows that perceptual learning within the visual system, like that of the auditory system, can facilitate adaptation to dramatic changes in one's environment.

Cases of perceptual learning have repeatedly been correlated with plasticity of underlying neurological resources (Kourtzi, 2005; Polley et al., 2006; Recanzone et al., 1993; Walsh, Ashbridge, & Cowey, 1998). In addition, many purely psychophysical studies have provided examples of perceptual learning of the visual system (Ball, Beard, Roenker, Miller, & Griggs, 1988; Sireteanu & Rettenbach, 1995).While these methods do not pinpoint the mechanisms of neural plasticity, the resulting behavioral benefits are apparent. Further, many examples of these benefits are particularly relevant to the current study, because the observed perceptual enhancements are spatial in nature and include: increased useful field of view (Ball et al., 1988) and improved visual search performance (Sireteanu & Rettenbach, 1995).

Action Video Games as a Platform for Perceptual Learning

A multitude of recent studies have demonstrated that action video game play facilitates perceptual learning (Green, Li, & Bavelier, 2009 for review). Action video games (AVGs) are video games that are extremely fast paced, require rapid processing, accurate action, and precise localization and tracking of multiple targets that can appear and behave unpredictably within chaotic environments cluttered with distractors. Examples of games that are considered action video games include first-person shooters, games played from the perspective of the controlled character (e.g. Call of Duty, Halo); and third-person shooters, games played from an over-the-shoulder or from-behind perspective (e.g. Gears of War, Grand Theft Auto). Training on AVGs has been shown to result in enhanced attentional (Dye, Green, & Bavelier, 2009; Green & Bavelier, 2006b), visuospatial (Feng, Spence, & Pratt, 2007; Green & Bavelier, 2007; West et al., 2008), and visuotemporal processing (Green & Bavelier, 2003; Li et al., 2009). The benefits to visuospatial processes are especially relevant to the proposed study. These benefits include increased ability to accurately pinpoint the location at which a visual stimulus briefly appears among a field of distractor stimuli (Feng et al., 2007; Green & Bavelier, 2006a). Also, AVG players are better able to detect the presence of occasional “oddball” stimuli (West, Stevens, Pun, & Pratt, 2008). Training on AVGs also appears to increase the spatial resolution of vision, especially within the periphery (Green & Bavelier, 2007).

Past research demonstrating perceptual learning resulting from AVG experience has focused almost exclusively on the visual modality. While vision is the primary medium of information delivery within video game environments, sound is also used to deliver task-relevant information to players. Much like visual information, salient sounds such as approaching footsteps are often amongst a background of distracting and chaotic noise such as booming explosions and gunfire. The use of this auditory information can signal the presence or location of an important object, and successfully deciphering these auditory cues increases the likelihood of success within the game. Thus in the AVG, the complexity of these auditory tasks and the utility of accurate interpretation of auditory cues are comparable to that of the visually presented information.

The lion's share of the perceptual learning effects depicted within these AVG studies is explained as a product of the complex and challenging nature of the training environment such as the demand to rapidly acquire targets that are presented amongst distractors (Green et al., 2009; Spence & Feng, 2010). Perhaps due to these qualities of the action video game environment, AVG expertise leads to a decrease in the detrimental impact of spatially and temporally proximate stimuli (Feng et al., 2007; Green & Bavelier, 2003; Green & Bavelier, 2006a, Green & Bavelier, 2007). Indeed, enhanced ability to separate the target signal from the surrounding noise seems to be attained from AVG training. This phenomenon has primarily been examined using visually presented stimuli. Further investigation with the inclusion of the auditory modality is needed to better understand the mechanisms of perceptual learning that underlie this increased ability to parse meaningful information from distracting environments.

Proposed Study

Does experience within a complex virtual environment alter human perception of spatial visual and auditory sensory information? The importance of this question can be highlighted by the pervasiveness of video games in modern American society. According to the Entertainment Software Association [ESA], 72 percent of American households report video game play, and the average video game player is 37 years old and has been playing video games for 12 years (2011). Further, the majority of video game players (82%) are age 18 years or older (ESA, 2011). Because video games have become a popular, enduring pastime for so many adults it is critical to understand the specific nature and extent of the effects induced by long term experience with video games. A wealth of previous research indicates that such experience leads to performance benefits on a number of spatial processes that have been examined (Green & Bavelier, 2009; Spence & Feng, 2010). This research has centered primarily on the popular "action" game genre which accounted for approximately 16 to 37 percent of all videogame sales in 2010 (ESA, 2011). In addition to increased performance on laboratory tasks, the improvements in spatial processing granted by action video game experience can also benefit one's everyday function. This is especially true of seniors, who as a result of normal cognitive aging show decreased visuospatial and visual attentional resources including decreased functional field of view (Ball & Owsley, 1991) and a decreased ability to suppress irrelevant visual information (Gazzaley & D'Esposito, 2007; Gazzaley et al., 2008). Such deficits have been implicated in an increased likelihood of vehicular crashes (Ball, Owsley, Sloane, Rowenker, & Bruni, 1993) and falls (Di Fabio et al., 2005) in seniors. Since improvements to spatial processing are granted through experience with action video games, training regimens involving these games could perhaps be implemented to counter some of the negative consequences of aging.

The current study investigates whether AVG experience can reduce the detrimental effect of conflicting stimulus information presented in the visual and auditory modalities. This is one of many research questions that may help to elucidate the specific nature of perceptual learning affected by action video games. Auditory conflict was manipulated using temporal crowding that has been shown to hinder auditory spatial localization due to the precedence effect (Saberi & Perrott, 1990). Visual conflict was modeled upon a study by Heron, Whitaker and McGraw (2004) who varied the size and consequent spatial certainty of visual targets and found that localization performance was poorer when the target size was increased. Using these paradigms it was hypothesized that localization performance would be decreased (increased reaction time, decreased accuracy) when conflicting stimulus information is presented. However, performance of AVG experts was hypothesized to be less affected by the presence of the auditory precedence effect or visual conflict than that of AVG novices. So, although detriments to reaction times and accuracy were expected for both groups, a smaller detriment was expected for AVG experts compared to novices. This is based on the previously cited research which implicates AVGs as tool for reducing detrimental effects of conflicting stimuli during visual tasks (Feng et al., 2007; Green & Bavelier, 2003; Green & Bavelier, 2006a, Green & Bavelier, 2007).

Previous research has shown AVG training does indeed lead to increased visuospatial performance. Because spatial auditory information within AVGs is similar to the presented visual spatial information in both presentation and context, and there is a wealth of research demonstrating perceptual learning and experience dependent plasticity on similar auditory and visual localization tasks; it was hypothesized that both visual and auditory localization performance would be superior in AVG experts to that of novices. Thus, faster RTs and fewer errors were expected of AVG experts.

Method

Participants

Participants were 46 (18 female, 28 male) undergraduates (mean age = 19.67 years) who were enrolled in an introductory psychology course at a large southeastern University. Students were compensated for their participation with credit towards a research requirement of the introductory psychology course. Participants must not have had a head cold or congestion and were required to have normal hearing and normal or corrected to normal vision. Participants were placed in one of two groups depending on whether they are action video game players (Experts) or non-action video game players (Novices).

Assignment between these two groups was determined by the results of a questionnaire comparable to that used by Green and Bavelier (2007), which probed the nature, frequency and time investment of video game play in the 12 months prior to participation. Assignment to the expert player group (N = 23, 9 female) required that at least five hours a week had been spent playing action video games for the previous six months. On average, experts reported playing video games for 15.54 (SD = 8.52) hours per week and AVGs for an average of 12.89 (SD = 9.26) hours per week. Individuals were selected as novices (N = 23, 9 female) if they reported playing no action video games within the six months prior to the proposed study. Novices reported playing an average of 0.76 (SD = 1.43) hours per week of non-action video games.

Materials

During the initial recruitment session participants were asked to complete the above-described video game experience survey which was embedded in a larger questionnaire that asked similar questions about experience with athletics and musical instruments. The inclusion of these other domains of experience was intended to mask the hypotheses of the current study in order to prevent potential demand characteristics from emerging. Otherwise, any significant expertise-driven result would have been shrouded in uncertainty, and could be attributed to the predicted perceptual learning or to the participants' beliefs that they are expected to do well or poorly.

The survey itself consisted of approximately 60 items (20 items per domain: video games, athletics, musical). Each of the three sections began by asking whether the participants had practiced the skill of interest in the last six months, and participants were only required to complete the related questions if they had practiced in the last six months. The critical questions for the current study asked whether and how often participants had played any action (shooter-type) video games in the last 6 months. Again, participants who reported playing action video games for an average of five hours a week or more were deemed expert, and participants who reported playing no video games or at least no action video games were considered novices for the current study.

Apparatus

All visual stimuli were presented using a 14'' Optiquest Q51 display attached to a Dell Optiplex 745 PC running E-prime 2.0. All auditory stimuli were designed using Audacity and were presented using Logitech Clearchat headphones.

Stimuli

Visual stimuli.

Visual stimuli were modeled on those used by Heron, Whitaker, and McGraw (2004) and consisted of white circular "blobs" that were designed using the Gaussian formula

$L_{mean} + A * \exp(-(d^2) / 2\sigma_v^2)$. "$L_{mean}$ is the mean luminance of the background, A is the luminance amplitude, σ_v is the standard deviation of the Gaussian envelope", and d is the radial distance from center of the "blob" (Heron et al., 2004, p. 2877). Three visual targets, comparison stimuli of equal luminance were created using this formula. The resulting "blobs" were described as small, medium, and large; with the smallest having the smallest spread of luminance and the most spatial certainty and the largest having the greatest spread of luminance and the least spatial certainty. Visual angles of the small, medium, and large blobs were 3.57 degrees, 7.14 degrees, and 10.71 degrees respectively. The preceding, referent stimuli were identical to the small comparison blob. Visual eccentricities of the referent stimuli were 0 degrees, 10 degrees, or 25 degrees along the horizontal midline in either direction. Differences in visual eccentricity between the referent and comparison stimuli were 1, 3, 5, 8, or 11 degrees right or left along the horizontal midline.

Auditory stimuli.

Auditory stimuli utilized interaural-time difference as lateralization cues and were designed to elicit the precedence effect which is described within the literature review (Saberi & Perrott, 1990). All auditory stimuli were sinusoidal waves presented with an intensity of 60-dB, at a frequency of 40 Hz, with a duration of one millisecond. Each click (preceding, trailing) within the first, reference click pair was presented with interaural time differences (ITDs) of 0, 111, or 303 microseconds with the click leading either to the left or right ear to establish the spatial position of the referent event. The preceding click of the second, comparison click pair was presented with ITDs that matched those of the clicks within the preceding stimulus. The trailing click within the comparison click pair was presented with a interaural time difference

(ITD) that was 45, 157.5, 202.5, 247.5, or 450 microseconds greater or less than that of the preceding click.

Procedure

Preliminary and general procedure.

The initial questionnaire used to assign individuals into either the expert or novice group was given in person. Upon qualifying as either an AVG expert or a novice, individuals were asked to come back for a laboratory session lasting 60 minutes. Once in the lab, participants were instructed on the visual and auditory tasks to be undertaken, consent was obtained.

All portions of the experiment utilized a chin-rest and fixation cross in order to maintain constant observational distance and angles. Visual and auditory trials were set apart, with each making up one block. Each block lasted 25 minutes, and the order of block presentation was randomly selected prior to the start of each session; so that half of participants were presented with the visual task first, and half were presented with the auditory task first.

The fixation cross was presented at the start of each trial and participants were asked to maintain visual fixation on this dot until the target stimulus occurred and responses were to be given. A screen containing only a fixation cross was presented for 1500ms prior to the start of each trial. All trials began with an interval of 200ms. After this interval the stimuli were presented. Participants were then tasked with determining whether the second, comparison stimulus was presented to the right or left of the first, referent stimulus. Left responses were indicated using the CONTROL key on the keyboard, right responses with the ENTER key. Participants were asked to perform the task as accurately as possible, and accuracy-based feedback was given following each response given. Following the feedback, a new trial began. Both reaction times and accuracy were recorded.

Auditory procedure.

The current auditory procedures were modeled upon those used by Saberi and Perrott (1990). The only major deviation from their design is the current inclusion of off-center reference clicks. Here the ITDs of clicks 1, 2, and 3 may contain ITDs that relate to non-central locations. The precedence effect has previously been demonstrated with this manipulation (Yost & Soderquist, 1984). All auditory clicks were presented for a duration of 1ms. The fixation cross was present for the duration of each trial, which began with a 200ms ISI. Following this, the preceding click of the referent event was presented. The ITD of the preceding click was randomly selected prior to the start of each trial, and this ITD was used for the trailing click of the referent event and for the leading click of the comparison event. Only the trailing click of the comparison event differed in any way. There was then an inter-click interval (ICI) between the preceding and trailing click which lasted 2.35ms, 5ms, or 10ms (randomly selected). The trailing click of the referent event was then presented. Following this, an ISI of 300ms was presented. After this ISI, the preceding click of the comparison event was presented. An ICI equal to that presented between the clicks of the referent event was then presented, followed by the trailing click of the comparison event. The ITD of the trailing click of the comparison event was randomly selected prior to the start of each trial. Participants were instructed to indicate whether the comparison event occurred to the right or to the left of the referent event using the keyboard. Following the response feedback regarding accuracy was given.

Visual procedure.

The fixation cross was present for the duration of each trial except when the stimuli were presented at the center of the screen. For trials containing centrally presented stimuli, the fixation cross was removed during the initial ISI of 200ms, which was present in all visual trials.

Following this, the preceding, referent visual stimulus was presented for 50ms. The location of this referent stimulus was randomly selected from the five possible positions prior to the start of each trial. An ISI of 300ms was then be presented to prevent any forward masking of the comparison stimuli. The comparison “blob” was then be presented for 50ms. The size and position of the comparison “blob” was randomly selected from those described previously. Participants were instructed to indicate, using the keyboard, whether the center of the comparison blob occurred to the left or right of the center of the referent blob. Feedback regarding accuracy was then given.

Predictions

Auditory Predictions

I predicted that decreasing the ICIs between the preceding and trailing clicks would hinder performance (accuracy) for both the expert and novice groups. So, the 2.35ms ICI would lead to the worst performance, 10ms the best performance. However, we predicted that the performance detriment (reduced accuracy) for the expert players would be less than that of the novice players. This should be especially evident for the 2.35ms ICI. Statistically, this would be represented by an interaction between Expertise and Ambiguity. Finally, I predicted that mean localization accuracy would be greater for expert players than the individuals in the novice group.

Visual Predictions

I predicted that increasing the size of the comparison blob would decrease performance (accuracy) for both the expert and novice groups. So, the large blob would lead to the worst performance, and the small blob would result in the best performance. However, I again predicted an interaction between Expertise and Ambiguity in which the performance detriment (reduced accuracy) for the expert players would be less than that of the novice players. Finally, I predicted that mean localization accuracy would be greater for AVG players than the individuals in the NVG playing group

Results

Prior to any inferential analyses, descriptive statistics were used to exclude trial performance believed to be the result of participant non-compliance. A non-compliant trial was defined as any trial in which the reaction time was 150ms or less. Reaction times and accuracy data of non-compliant trials were excluded from all analyses. The justification for these exclusionary criteria is based on the distribution of the current data as well as previous reaction time research. Responses that were 150ms or faster fell more than 2.8 standard deviations from the mean (M = 653.92, SD = 179.44). Additionally, past studies have convincingly shown that the average, minimum amount of time needed to detect and respond physically to a stimulus is about 150ms (Teichner, 1954 for review); and while such ‘simple RTs’ do not require any decision, ‘choice reaction times’ such as those in the current study require additional processing time (Snodgrass, Luce, & Galanter, 1967). Thus, trials with RTs of 150ms or less were excluded because they were likely anticipatory or otherwise non-compliant. Less than 1.5 percent of trials were excluded using this conservative cut-off. Remaining trials were averaged to match the intended design, 2 Modality (Visual, Verbal) X 3 Ambiguity (Low, Moderate, High) X 5 Discrimination Distance; and the result was an average of 10 trials per participant per cell.

Preliminary data analyses revealed that the Order of task presentation did not affect response errors, $F(1, 38) = .702$, $p = .407$; or reaction time, $F(1, 38) = .026$, $p = .872$. Order was excluded from all subsequent analyses.

The data collected from the visual and auditory tasks were analyzed together using repeated measures ANOVAs using the design: 2 Expertise Level (Expert, Novice) X 2 Sex

(Male, Female) X 2 Modality (Visual, Verbal) X 3 Ambiguity (Low, Moderate, High) X 5 Discrimination Distance. Separate analyses were conducted for reaction time (RT) and for error data. All analyses used a 95 percent confidence interval with a conservative Bonferroni correction in order to ensure that our effects were not artifacts of multiple comparisons. The assumption of sphericity was not violated unless otherwise noted

Reaction Time Analyses

Within subject factors

Discrimination Distance significantly affected reaction times, F (4, 168) = 3.32, p = .012; but pairwise comparisons of RT for Huge (M = 639.29, SE = 25.62), Large (M = 642.07, SE = 29.29), Medium (M = 650.95, SE = 27.63), Small (M = 672.54, SE = 28.71), and Tiny distances (M = 668.27, SE = 30.02) showed that there were no significant simple effects of Discrimination Distance on RT. However, contrast analyses revealed that the increases in RT affected by Discrimination Distance represent a significant linear trend, F (1, 42) = 11.75, p = .001

There was also a main effect of stimulus Ambiguity on RT, F (2, 84) = 10.38, p < .001. Pairwise comparisons revealed that RTs to High Ambiguity stimuli (M = 669.98, SE = 27.96) were slower than RTs to Moderate Ambiguity stimuli (M = 634.82, SE = 26.69), p < .001. There was no significant RT difference between Low (M = 659.08, SE = 28.37) and High levels of Ambiguity (p = .583), and RTs actually decreased when Ambiguity was increased from Low to Moderate (p = .015). The ANOVA showed there was no significant interaction between Discrimination Distance and stimulus Ambiguity, F (8, 336) = 1.24, p = .277.

There was a main effect of task Modality in which reaction times to auditory stimuli were significantly slower (M = 687.75, SE = 30.75) than reaction times to visual stimuli (M = 621.49, SE = 28.50), F(1, 42) = 8.24, p = .006. Modality did not interact with within-subject factors:

neither stimulus Ambiguity, $F(2, 84) = 2.97$, $p = .057$; nor Discrimination Distance, $F(4, 168) = 1.03$, $p = .392$.

Between subject factors

Overall, the average reaction times of males ($M = 685.74$, $SE = 34.162$) did not differ significantly from that of females ($M = 623.50$, $SE = 42.61$), $F(1,42) = 1.30$, $p = .261$. However, participant Sex did interact with task Modality, $F(1, 42) = 8.07$, $p = .007$. Reaction times of female participants were unaffected by task modality, $p = .987$. In contrast, males' RTs were significantly faster in the visual Modality ($M = 619.83$, $SE = 37.25$) than in the auditory Modality ($M = 751.66$, $SE = 41.10$), $p < .001$. This interaction is shown in Figure 2.

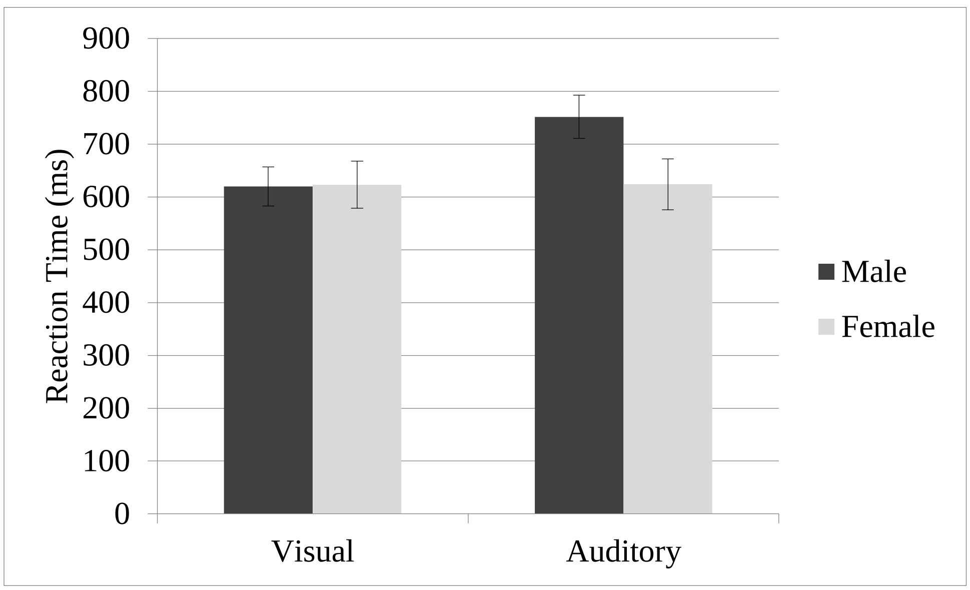

Figure 2. The interaction of Modality and Sex on reaction time.

There was also a 2-way interaction between Modality and Expertise, $F(1, 42) = 5.31$, $p = .026$. For novices, reaction times to the visual Modality ($M = 640.49$, $SE = 49.96$) were no different than RTs to the auditory Modality ($M = 653.56$, $SE = 50.08$), $p = .720$. Experts reacted more quickly to visual stimuli ($M = 602.49$, $SE = 27.44$) than to auditory stimuli ($M = 721.95$, $SE = 35.69$), $p < .001$ (see Figure 3).

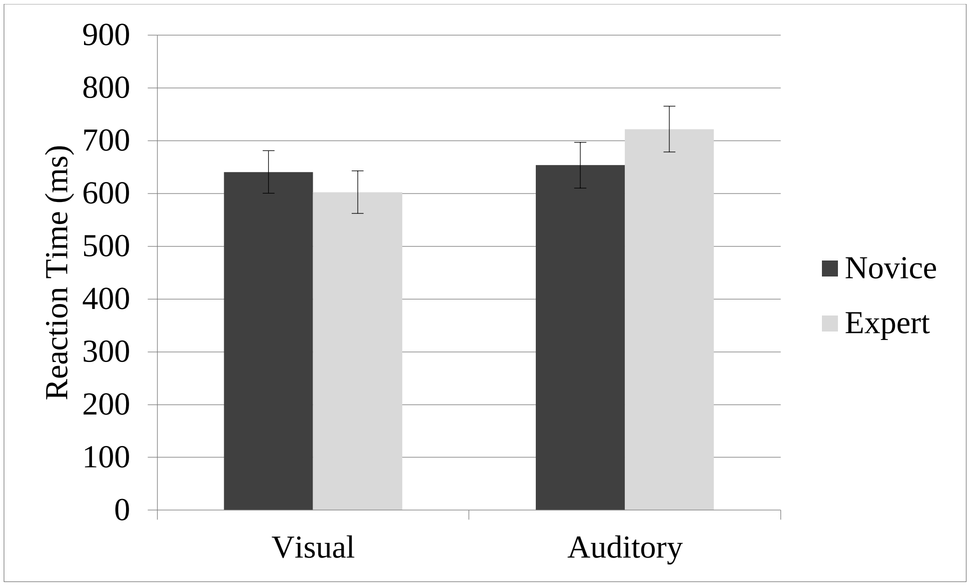

Figure 3. The interaction of Modality and Expertise on reaction time.

Expertise and Sex did not interact, $F(1, 42) = 0.15$, $p = .704$. Likewise, the main effect for Sex was not significant, $F(1, 42) = 1.30$, $p = .261$. The effect of Expertise on RT was also not significant, $F(1, 42) = 0.08$, $p = .782$. There was also no 3-way interaction of Modality, Sex and Expertise, $F(1, 42) = 0.425$, $p = .518$.

There was a significant 4-way interaction effect of Expertise, Modality, Stimulus Ambiguity and Discrimination Distance, $F(8, 336) = 3.00$, $p = .003$. This interaction was deconstructed and analyzed using simple interactions. I first analyzed the 3 way interaction of Expertise, task Modality and stimulus Ambiguity at each level of Discrimination Distance. These analyses revealed this 3 way interaction was significant only when Discrimination Distance was Medium, $F(1, 84) = 3.75$, $p = .028$; or Small, $F(1, 84) = 3.20$, $p = .046$. These interactions were each further decomposed by examining the 2 way interaction of Expertise and Ambiguity separately within the visual Modality and auditory Modality. When a medium Discrimination Distance was used Expertise and Ambiguity interacted significantly in the auditory Modality, $F(1.87, 78.65) = 3.64$, $p = .033$; but not in the visual Modality ($p = .346$). This interaction of Expertise and Ambiguity is explained by the presence of a main effect of auditory Ambiguity for experts, $F(2, 42) = 7.95$, $p = .001$; but not novices ($p = .083$). Figure 4 depicts the interaction of Expertise and auditory Ambiguity and also shows that the main effect of auditory ambiguity in experts is due to the increase in RTs observed when auditory Ambiguity is increased from Moderate (*M* = 662.85, *SD* = 41.06) to High (*M* = 788.45, *SD* = 49.73), $p = .001$. Other pairwise comparisons of auditory Ambiguity were not significant ($p > .05$). Likewise, this decomposition revealed no significant interaction effects below the 3-way described above for the small Discrimination Distance condition.

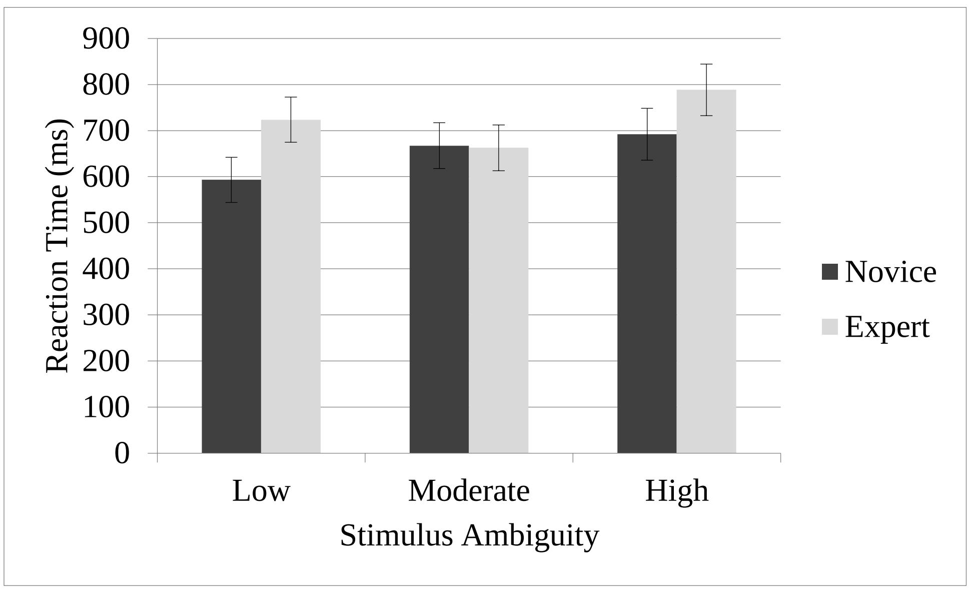

Figure 4. The interaction effect on RTs of Expertise and auditory Ambiguity at the medium Discrimination Distance.

Error Analyses

Within subject factors

There was a main effect of Discrimination Distance, $F(4, 168) = 51.18$, $p < .001$. Pairwise comparisons were used to examine the simple effects of level of Discrimination Distance: Huge (*M* = 30.5%, *SE* = 1.5%), Large (*M* = 34.0%, *SE* = 1.3%), Medium (*M* = 37.0%, *SE* = 1.3%), Small (*M* = 39.0%, *SE* = 1.1%), and Tiny (*M* = 46.2%, *SE* = 0.7%). The decrease in discrimination distance from Large to Medium (p = .060), and from Medium to Small (p = .864) did not significantly affect error rates, but all other pairwise comparisons were significant (p < .05). The main effect of Discrimination Distance is best described as a significant linear trend in which Discrimination Distance results in increased errors, $F(1, 42) = 3.47$, $p < .001$.

There was also a main effect of stimulus Ambiguity, $F(1.81, 76.19) = 4.40$, $p = .018$. Differences in variance among the levels of Ambiguity violated the assumption of sphericity (W = .78, p = .006) so the Huynh-Feldt correction was used. Pairwise comparisons of Low (*M* = 35.8%), Medium (*M* = 37.5%), and High (*M* = 38.7%) levels (pooled *SE* = 1.1%) of Ambiguity revealed that increasing ambiguity from Low to Moderate (p = .398) and Moderate to High (p = .303) levels had no effect on error rates, but errors were significantly increased when Ambiguity was increased from a Low to a High level (p = .030). This effect can also be described as a positive linear trend, $F(1, 42) = 7.26$, $p = .010$.

There was a significant interaction between stimulus Ambiguity and Discrimination Distance, $F(8, 336) = 2.14$, $p = .032$. As depicted in Figure 5, increased stimulus Ambiguity and decreased Discrimination Distance generally result in increased error rates; however, error rates at the most difficult levels of Discrimination Distance (Small and Very Small distances) appear to differ depending on the level of stimulus Ambiguity. Simple effects contrasts were used to interpret this 2-way interaction. These contrasts revealed that when Discrimination Distance was decreased from a huge distance to a small distance, the resulting error increase was significantly lessened when stimulus Ambiguity was Low compared to when it was Moderate, $F(1, 42)$ = 6.78, $p = .013$; or High, $F(1, 42) = 15.19$, $p < .001$.

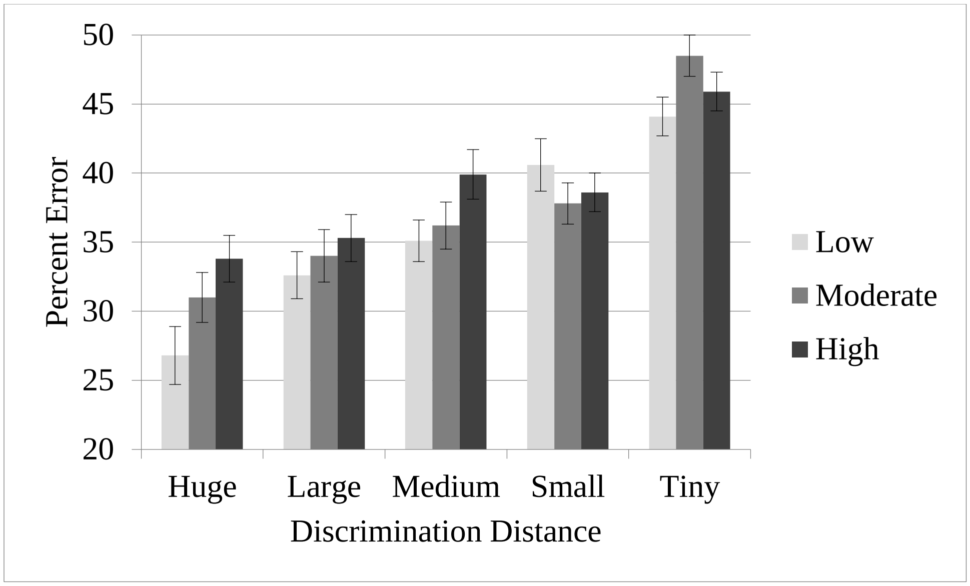

Figure 5. The interaction of Ambiguity and Discrimination Distance on error.

The effect of task Modality was investigated by comparing error rate in the visual Modality (M = 34.4%, SE = 1.1%) to the error rate in the auditory Modality (M = 40.2%, SE = 1.2%). The results of this comparison show that the errors were significantly greater with the auditory Modality, $F(1,42) = 20.93$, $p < .001$.

Modality interacted significantly with Discrimination Distance, $F(4, 168) = 3.43$, $p = .010$ (see Figure 6). Contrasts of simple effects revealed that decreasing from Huge (M = 26.0%, SE = 1.6%) to Medium Discrimination Distances (M = 35.4%, SE = 1.5%) resulted in greater errors when tasks were presented in the visual Modality, $F(1, 42) = 6.79$, $p = .013$. Likewise, decreasing Discrimination Distance from Huge to Small (M = 37.4%, SE = 1.4%) caused greater error increases in the visual Modality, $F(1, 42) = 7.10$, $p = .011$.

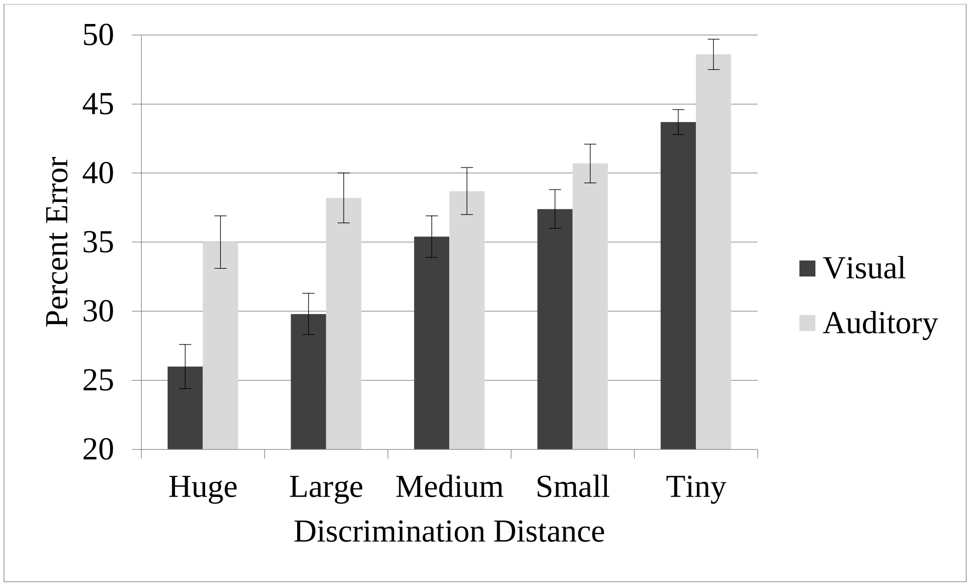

Figure 6. The interaction of Modality and Discrimination Distance on error.

Modality also interacted significantly with stimulus Ambiguity, $F(2, 84) = 3.53$, $p = .034$ (see Figure 7). Simple effects contrasts showed that increasing stimulus Ambiguity from a Low level to a High level had a greater effect on the error rates of visual trials than auditory trials, $F(1, 42) = 5.71$, $p = .021$. The effect of increasing stimulus Ambiguity from a low level to a moderate level did not differ depending on Modality ($p = .307$), neither did the effect of increasing Ambiguity from moderate to high levels depend on Modality, $F(1, 42) = 2.71$, $p = .107$. No higher order interactions were found in the error data.

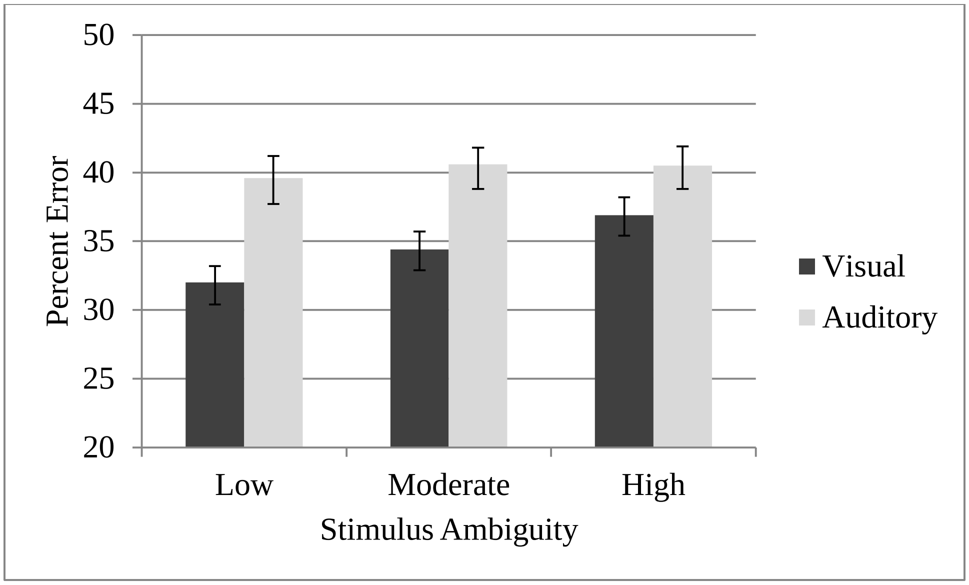

Figure 7. The interaction of Modality and Ambiguity on error.

Between subjects factors

There were no main effects on error rate for any of the between subjects factors. There was no main effect of Sex, $F(1, 42) = 0.33$, $p = .569$; or Expertise $F(1, 42) = 2.48$, $p = .123$. Sex and Expertise did not interact, $F(1, 42) = 0.24$, $p = .630$. Further, none of the between subjects factors were involved in any significant interaction effects.

Discussion

As predicted, decreasing the discrimination distance between referent and comparison stimuli decreased speed and accuracy of performance, as did increased stimulus ambiguity. Decreased discrimination distances were expected to decrease performance based upon past research that has shown that performance decreases as the discrimination threshold is neared (Woodworth & Schlosberg, 1954). These results also exemplify the detrimental impact of stimulus ambiguity on spatial discrimination performance.

In terms of auditory ambiguity, discrimination performance was hindered when the interclick-interval (ICI) of the comparison event was reduced from 10ms to 5ms or 2.35ms. Recall that there were two pairs of two clicks in each trial, and each pair was perceived as a single sound. The first, referent pair and leading click of the comparison pair were identical, but the final, lagging click of the comparison pair differed. When the effect of ICI (Auditory Ambiguity level) is examined across all possible discrimination distances, it appears that ICI manipulations have little impact on accuracy – especially compared to visual ambiguity (see Figure 7 above). However, many of the performance trends that will be discussed here seem to be consequences of the extreme difficulty of the auditory task. In the auditory task, ICI duration and the differences in ITDs interact to determine the potential for precedence. Generally, shorter ICIs and smaller differences in ITDs increase the likelihood of a precedence effect, and localization accuracy is consequently reduced (Saberi & Perrott, 1990). The combination of ICI duration and discrimination differences used in the current study led to performance that was generally poor and near thresholds for chance accuracy for many participants. The tiny and small discrimination distances appear to have prevented any significant effect of ICI duration. Indeed, removal of the tiny and small discrimination distances and subsequent comparison of error rates for short ICIs and long ICIs at the medium, large and huge discrimination distances revealed a significant precedence effect (p = .047). Thus, the current results demonstrate that as ICIs were reduced participants were increasingly inaccurate due to ignorance of spatial information (ITDs) contained within the lagging click of the comparison sound, thus replicating the precedence effect (Saberi & Perrott, 1990).

Again, these results indicate that the auditory task was much more difficult than the visual task. Both errors and reaction times were significantly increased in the auditory Modality.

Regardless of task modality, errors increased linearly as ambiguity was increased, yet reaction times were fastest to the moderate level of ambiguity. It is unclear whether the RT decrease at moderate levels of visual and auditory ambiguity is an aberration, but the effect does not represent a speed-accuracy tradeoff. Further, error rate was the primary dependent variable; speed was described as secondary to the participants, so RTs should be interpreted hesitantly.

As expected, decreased discrimination distances had a greater effect on performance accuracy when stimulus ambiguity was increased. Together, the effects and interaction of stimulus ambiguity and discrimination distance support the validity of this experimental design.

While discrimination distance and ambiguity impacted performance, the predicted differences between expert AVG players and novice participants were not evident. Thus, the results of the current study indicate that experience within action video games does not alter visual spatial or auditory spatial perception in the face of uncertainty. Here, this finding is discussed in contrast to related studies of video game expertise while considering methodological explanations for the lack of support for training effects. But first I ask, are trained video game skills task specific?

This question is critically important for continued development of our understanding of the limits of human training. Countless studies have demonstrated that humans possess a robust capacity to improve task performance through training. This potential for skill learning is so persistent that psychologists even control for practice effects that can creep into experimental methods. Yet, despite the pervasiveness of training effects, decades of research have demonstrated that the performance benefits of training are often task-specific, narrowly limited to the stimulus conditions of training (Ball & Sekuler, 1982; Karni & Sagi, 1991). This specificity of training often prevents transfer of trained performance enhancements to seemingly similar tasks (Ball & Sekuler, 1987). While apparent task similarity does not adequately predict transfer of trained skills, consideration of the neurocognitive resources required and trained by a specific task has provided insight into the potential for skill-transfer (Boles, 1997; Dillard, Boles, & Black, 2012). Tasks that require the same underlying resources can be cross-trained, practice with one can lead to performance improvements on the other. Such resource models of training assume that a task requires specific neurocognitive resources, that behavioral practice effects are dependent on training of these resources, and that any task that requires these same trained resources will also be benefited. Theoretically, predicting transfer of trained skills should be this simple. However, even when two tasks are believed to consist of identical resources, transfer of training is not guaranteed due to additional factors that constitute hurdles on the track to far transfer. These factors include relative task difficulty, schedules of task training, and motivation to transfer skill from one task to another (Ahissar & Hochstein, 2004; Dillard, Boles, & Black, 2012).

The logic of the current study was based upon the resource-training model - chasing and shooting enemies in AVGs and the simple discrimination task used here have few obvious task similarities. However, if action video games train the resources required to perform simple perceptual discrimination in the face of uncertainty, performance improvements should have been observed. Average expert performance did not differ from that of novices, and expertise did not interact with the effects of discrimination distance or stimulus ambiguity; which may indicate that the resources trained by extensive AVG training are not those required for spatial discrimination in situations of uncertainty.

Visual Expertise

In contrast to these findings, past research has shown that action video game expertise leads to improved visuo-spatial processing even in distracting environments (Feng, Spence & Pratt, 2007; Green & Bavelier, 2006a; Green & Bavelier, 2006b). Specifically, reported performance improvements have been attributed to enhancements in selective visual-attentive processes (Hubert-Wallander, Green, Bavelier, 2010). Action video game training appears to endow an increased flexibility of attention, as experts are better able to willfully engage attentional resources across shifting demands of space and time. The discrimination task used here was similar to those used in many studies that have demonstrated improved selective attention in AVG experts, because it required attentional focus be directed quickly at targets while irrelevant, distracting information is suppressed. Specifically, the current visual task required that participants attend to the center of each "blob" while ignoring the irrelevant spread of the stimulus' luminance. Unlike previously used tasks, the irrelevant, distracting spatial information used here was within stimulus rather than within display. Previous studies have employed spatial crowding and multiple object tracking paradigms to tax selective attention, and such tasks require attention be focused on target stimuli while surrounding irrelevant stimuli are ignored (Green & Bavelier, 2006b; Green & Bavelier, 2007). In contrast, the current study required that attention be narrowed accurately to the central point within each visual stimulus, and the target point and distractors were not distinct visual objects. Therefore, feature-based spatial discrimination was not a possibility; instead, spatial magnitude (distance) estimates may have been utilized to determine where the center of a "blob" was relative to its edge. While previous research has shown that AVG expertise results in improved ability to narrow attentional focus while ignoring distractors, it is possible that without distinct target and distractor objects, the visual task was no longer supported by the trained skills obtained by AVG practice.

Auditory Expertise

Research on AVG expertise has focused primarily on the visual modality; and as a result, there is a relative shortage of findings to compare with the current auditory findings. However, Green, Pouget, and Bavelier (2010) found that expert AVGPs were faster but no more accurate than novices in an auditory localization (left ear vs right ear) task when speeded reactions were permitted, but their study was concerned with the ability to detect a tone presented to one ear against a binaural background of chaotic white noise. Perhaps AVG training does not directly influence the accuracy of auditory localization. Experts have demonstrated a faster rate of accuracy improvement in auditory localization, but this has been attributed to enhancement of modality-independent probabilistic inference (Green, Pouget, & Bavelier, 2010). These findings are not easily compared with those of the current study, because the auditory localization tasks are quite different. Unlike the aforementioned study, the current study required spatial comparison of two tones. The location of each tone was determined by inter-aural time differences, and the tones were presented extremely briefly. While it is possible that expertise does not affect auditory localization accuracy directly, another explanation for the current null result is that the precedence effect may not be diminished by AVG training.

More generally, the potential for training-based diminishment of the precedence effect has been disputed. Some studies have shown that practice and auditory expertise leads to a decrease in the precedence effect (Saberi & Antonio, 2003; Saberi & Perrott, 1990); while others have failed to produce such training effects (Litovsky, Hawley, Fligor, & Zurek, 2000). Precedence effects vary widely among novice participants in these studies, and the highest performing novices show diminished precedence effects similar to those of experts (Saberi & Antonio, 2003). It is possible that individual differences in the precedence effect contributed to lack of expertise effects in the current study. Additionally, experts who have demonstrated improved performance under precedence conditions in past studies have been extensively trained in the precedence task or other auditory localization task using discreet spatial stimuli.

In the current study, experts reported a wide variety of auditory device use; most used integrated television speakers, some used stereo headphones, and others reported playing with music in the background. With such inconsistency in auditory stimulation, no conclusions can be made regarding the potential for AVG training of auditory localization. Ideally, future studies should restrict expert participants to those who use high fidelity sound devices, such as headphones, to ensure that spatial auditory information has been available during AVG training.

Future research should also investigate whether auditory spatial discrimination thresholds in the absence of ambiguity are superior due to AVG training. There are many factors that contribute to the magnitude of the precedence effect, and one is individual differences in baseline discrimination performance. When comparing auditory experts to novices, Saberi and Antonio (2003) found that there were substantial individual differences in the precedence effect among novices. These researchers found that some novices performed nearly as well as experts and required smaller discrimination distances than the average novice to elicit the precedence effect. Similar individual differences may have contributed to the lack of observed group differences by effectively washing out mean differences with extreme within group variance. So investigating the effect of AVG expertise on a traditional auditory spatial discrimination task (no ambiguity) may help to clarify what, if any process is affected.

General Expertise Effects

The only significant effects involving expertise were interaction effects on reaction times. The interaction of task modality and expertise suggests that only experts' RTs were affected by task modality. Experts demonstrated faster reactions during visual trials than auditory trials, whereas novices did not; but RTs did not differ based on expertise in either modality. This interaction may be attributable to the essential visual nature of video games as well as individual differences in habitual auditory stimulation among experts during AVG training. Although there was no main effect of expertise in either modality, this interaction suggests that AVG training may improve visual spatial processing, but not auditory spatial processing. As the name implies, video games are inexorably visual, and success within AVGs requires attention to visual stimuli first and foremost. Also, the integrity of visual spatial information during training is maintained so long as individuals are able to see the entire screen during training; but in contrast, integrity of auditory spatial cues varies greatly depending on the sound devices used during training. For instance, the stereo speakers that are integrated within most televisions provide less spatial information than headphones. It is possible that maintaining high fidelity auditory spatial information during AVG training would lead to speeded processing of auditory spatial task, but the current results indicate that only visual spatial processing was improved.

However, even if this interaction indicates that experts possess superior visual spatial skills, no causal conclusion can be made because of the current quasi-experimental design. In such designs, any observed expertise effects may be due to skill training, but an alternate explanation is that individuals who possess superior visual spatial skills are more likely to play AVGs. This causality conundrum can be solved using pretest-posttest designs in which novices are trained using AVGs and skill increases are measured. Previous studies have used training methods to demonstrate that AVG experience does cause skill improvements in the visual domain, but this causality is not a forgone conclusion – pretest-posttest designs should be continually used to confirm suspected effects detected using extreme group quasi-experimental designs.

The 4-way interaction between expertise, modality, ambiguity, and discrimination distance in RT data produced no clear theoretical implications; but descriptively, this interaction was driven by a violation of the parabolic ambiguity trend for novices at the medium discrimination distance in the auditory modality. Complex multi-factor designs like that used in the current study have an increased potential for high-order interactions that are not meaningful or that are representative of error. Basically, as the number of factors increases, the number of statistical comparisons increases; and as the number of statistical comparisons increases, the probability of committing a Type-I error also increases. This interaction was reflected by tradeoffs in the error data, further suggesting that the observed RT interaction was spurious.

The current lack of AVG expertise effects could be taken to mean that the resources needed for these experimental tasks are not trained by action video games. However, past training research has shown that skills sometimes fail to transfer even when the underlying resources appear to be the same (e.g. Phillips, 2006). As previously mentioned, there are a number of factors other than resource sharing that contribute to the potential for skill transfer, but the current quasi-experimental design prevents description of these training factors.

Another alternate explanation for the lack of expertise effects is that there was not enough power to detect an expertise effect in the sample, and that the current experiment lacked the sensitivity needed to detect a main effect of expertise on either reaction times or accuracy. A power analysis was conducted to determine the smallest effect size that would have been detected by the current experiment assuming adequate power ($1 - \beta$ error probability = .8). This analysis revealed that the current experiment provided only enough sensitivity to detect a large effect size ($f = .42$), but medium and small effects may not have been detected (Cohen, 1988). Knowing this effect size, and assuming that the standard deviation of the current sample is representative of the population, the minimum detectable expertise effects were calculated in terms of the current dependent variables. This calculation revealed that the smallest RT difference needed to detect a significant expertise effect was 149.44ms, and expert error rates would have needed to be at least 5.33% lower than novices to conclude that AVG experience significantly enhances discrimination accuracy. So, the current lack of observed expertise effects may be due to a type-II error. Participant recruitment was grueling, and this problem was reflected by a small sample size (N = 46) compared to the initial goal of 60 participants. To prevent this lack of statistical power, future attempts to answer the current questions should integrate procedures to determine individuals' baseline for spatial discrimination. Personalized discrimination distances could then be used to match discrimination difficulty between participants. This method would allow for independent measurement of spatial discrimination processing with and without ambiguity.

References

Abel, S.M. & Paik, S.E.J. (2004). The benefit of practice for sound localization without sight. *Applied Accoustics*, *65*(3), 229-241. doi: 10.1016/j.apacoust.2003.10.003.

Ahissar, M. & Hochstein, S. (2004). The reverse hierarchy theory of visual perceptual learning. *Trends in Cognitive Sciences*, *8*, 457-464.

Ball, K., Beard, B.L., Roenker, D.L., Miller, R. L., & Griggs, D.S. (1988). Age and visual search: Expanding the useful field of view. *Journal of the Optical Society of America, 5,* 2210–2219.

Ball, K., & Owsley, C. (1991). Identifying correlates of accident involvement for the older driver. *Human Factors, 33*, 583–595.Brainard M.S. and Knudson, E.I. (1993). Experience dependent plasticity in the inferior colliculus: A site for visual calibration of the neural representation of auditory space in the barn owl. *The Journal of Neuroscience, 13*(11), 4589-4608.

Ball, K., Owsley, C., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1993). Visual attention problems as a predictor of vehicle crashes among older drivers. *Investigative Opthamology & Visual Science*, *34*, 3110-3123.

Ball, K. & Sekuler, R. (1987). Direction-specific improvement in motion discrimination. *Vision Research, 27*, 953-965.

Ball, K. & Sekuler, R. (1982). A specific and enduring improvement in visual motion discrimination. *Science, 288*, 697-698.

Boles, D.B. (1997). Multiple resource contributions to training. *Proceedings of the Human Factors and Ergonomics Society, 41,* 1176-1179.

Butler R.A. (1987). An analysis of monaural displacement of sound in space. *Percept. Psychophys. 28*, 449-457.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.

Crist, R.E., Wu Li & Gilbert, C.D. (2001). Learning to see: Experience and attention in the primary auditory cortex. *Nature Neuroscience*, *4*(5), 519-525.

Di Fabio, R. P., Zampieri, C., Henke, J., Olson, K., Rickheim, D., & Russel, M. (2005). Influence of elderly executive cognitive function on attention in the lower visual field during step initiation. *Gerontology, 51,* 94-107.

Dillard, M.B., Boles, D.B., & Black, S.R. (2012). Bidirectional resource training of simple and complex tasks. *Proceedings of the Human Factors and Ergonomics Society, 56*, 2462-2466.

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

Electronic Software Association (2011). 2011 sales, demographic and usage data: Essential facts about the computer and video game industry. Retrieved from www.theesa.com/facts/gameplayer.asp

Engineer, N.D., Percaccio, C.R., Pandya, P.K., Moucha, R., Rathbun, D.L. & Kilgard, M.P. (2004). Environmental enrichment improves response strength, threshold, selectivity, and latency of auditory cortex neurons. *J. Neurophysiol., 92*, 73-82. Doi: 10.1152/jn.00059.2004.

Feinstein, S.H. (1973). Acuity of the human sound localization response underwater. *The Journal of the Acoustical Society of America, 53(2)*, 393-399. doi: 10.1121/1.1913335.

Feinstein, S.H. (1975). The accuracy of diver sound localization by pointing. *Undersea Biomed Research, 2*(3), 173-184.

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

Fordyce, D. E. & Farrar, R. P. (1991). Physical activity effects on hippocampal and parietal cortical cholinergic function and spatial learning in F344 rats. *Behavioral Brain Research, 43*(2), 115-123.

Gazzaley, A., Clapp, W., Kelley, J., McEvoy, K., Knight, R. T., & D'Esposito, M. (2008). Age-related top-down suppression deficit in the early stages of cortical visual memory processing. *Proceedings of the National Academy of Sciences, USA, 105*, 13122–13126.

Gazzaley, A. & D'Esposito, M. (2007). *Top-down modulation and normal aging.* Oxford, England: Blackwell Publishing.

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

Green, C.S., & Bavelier, D. (2006a). Effects of action video game playing on spatial distribution of visual selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 32*, 1465-1478.

Green, C.S., & Bavelier, D. (2006b). Enumeration versus multiple object tracking: The case of action video game players. *Cognition, 101*, 217-245.

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

Green, C. S., Li, R. & Bavelier, D. (2009). Perceptual learning during action video game playing. *Topics in Cognitive Science,* 1-15.

Green, C.S., Pouget, A., & Bavelier, D. (2010). Improved probabilistic inference as a general learning mechanism with action video games. *Current Biology, 20*(17), 1573-1579.

Heron, J., Whitaker, D., & McGraw, P.V. (2004). Sensory uncertainty governs the extent of audio-visual interaction. *Vision Research, 44,* 2875-2884. doi: 10.1016/j.visres.2004.07.001.

Hubert-Wallander, B., Green, S.C., & Bavelier, D. (2010). Stretching the limits of visual attention: The case of action video games. *WIREs Cognitive Science, Wiley, 1,* 1-9.

Huttenlocher P. R. (2002). *Neural Plasticity.* S. M. Kosslyn (Ed.) Cambridge, MA: Harvard University Press.

Isaacs, K. R., Anderson, B. J., Alcantara, A. A., Black, J. E. & Greenough, W. T. (1992). Exercise and the brain: Angiogenesis in the adult rat cerebellum after vigorous physical activity and motor skill learning. *Journal of Cerebral Blood Flow and Metabolism, 12*(3), 110-119.

Javer, A. R. & Schwartz, D. W. (1995). Plasticity in human directional hearing. *The Journal of Otolayngology, 24*(2), 111-117.

Karni, A., & Sagi, D. (1991). Where practice makes perfect in texture discrimination: Evidence for primary visual cortex plasticity. *Proceedings of the National Academy of Sciences, 88*, 4466-4470.

Kempermann, G., Gast, D. & Gage, F.H. (2002). Neuroplasticity in old age: Sustained fivefold induction of hippocampal neurogenesis by long-term environmental enrichment. *Annals of Neurology, 52*(2), 135-143.

Kleim, J. A., Lussnig, E., Schwarz, E. R., Comery, T. A. & Greenough, W. T. (1996). Synaptogenesis and *FOS* expression in the motor cortex of the adult rat after motor skill learning. *J. Neurosci.* 16, 4529–4535.

Knudson, E. I. (1983). Early auditory experience aligns the auditory map of space in the optic tectum of the barn owl. *Science, 222*(4626), 939-942.

Knudson, E. I. (1999). Mechanisms of experience-dependent plasticity in the auditory localization pathway of the barn owl. *Journal of Comparative Physiology A: Neuroethology, Sensory, Neural, and Behavioral Physiology, 185*, 305-321.

Kourtzi, Z., Betts, L. R., Sarkheil, P. & Welchman, A. E. (2005). Distributed neural plasticity for shape learning in the human visual cortex. *PLoS Biology, 3*(7), 1317-1327.

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

Litovsky, R.Y., Hawley, M.L., Fligor, B.J., & Zurek, P.M. (2000). Failure to unlearn the precedence effect. *Journal of the Acoustic Society of America, 108*(5), 2345-2352.

Maertens, M. & Pollmann, S. (2005). fMRI reveals a common neural substrate of illusory and real contous in V1 after perceptual learning. *Journal of Cognitive Neuroscience 17(10)*, 1553-1564.

Markham, J.A. & Greenough, W.T. (2004). Experience-driven brain plasticity: Beyond the Synapse. *Neuron Glia Biology, 1*, 351-363.

Neary, K., Anand, S. & Hotson, J. R. (2005). Perceptual learning of line orientation modifies the effects of transcranial magnetic stimulation of visual cortex. *Exp. Brain Res., 162*, 23-34. doi: 10.1007/s00221-004-2117-5.

Phillips, J. B. (2006). Perceptual resources: Transfer of training and individual differences. (Unpublished doctoral dissertation). The University of Alabama, Tuscaloosa, AL.

Polley, D. B., Steinberg, E. S. & Merzenich, M. M. (2006). Perceptual learning directs auditory cortical map reorganization through top-down influences. *The Journal of Neuroscience, 26*(18), 4970-4982.

Van Praag, H., Kempermann, G. & Gage, F. H. (2000). Neural consequences of environmental enrichment. *Nature Reviews Neuroscience, 1*, 191-198.

Recanzone, G. H., Schreiner, C. E. & Merzenich, M. M. (1993). Plasticity in the frequency representation of primary auditory cortex following discrimination training in adult owl monkeys. *The Journal of Neuroscience, 13*(1), 87-103.

Redding, G. M. & Wallace, B. (2005). Prism adaptation and unilateral neglet: Review and analysis. *Neuropsychologia, 44*, 1-20.

Saberi, K. & Antonio, J. V. (2003). Precenence-effect thresholds for a population of untrained listeners as a function of stimulus intensity and interclick interval. *J. Acoust. Soc. Am., 114*(1), 420-429.

Saberi, K. & Perrott, D. R. (1990). Lateralization thresholds obtained under conditions in which the precedence effect is assumed to operate. *J. Acoust. Soc. Am., 87*(4), 1732-1737.

Shinn-Cunningham, B. G., Durlach, N. I. & Held, R. M. (1998). Adapting to supernormal auditory localization cues. I. Bias and resolution. *J. Acoust. Soc. Am., 103*, 3656-3666.

Shinn-Cunningham, B. (2000). Adapting to remapped auditory localization cues: A decision-theory model. *Perception and Psychophysics, 62*(1), 33–47.

Schoups, A., Vogels, R., Qian, N. & Orban, G. (2001). Practicing orientation identification improves orientation coding in V1 neurons. *Nature, 412*, 549-553.

Shuler, M.G. & Bear, M. F. (2006). Reward timing in the primary visual cortex. *Science, 311*, 1606-1609. doi: 10.1126/science.1123513.

Sireteanu, R. & Rettenbach, R. (1995). Perceptual learning in visual search: Fast, Enduring, but non-specific. *Vision Res., 35*(14), 2037-2043.

Spence, I. & Feng, J. (2010). Video games and spatial cognition. *Review of General Psychology, 14*(2), 92-104.

Stouffer, J. L., Doherty, E. T. & Holien, H. (1975). Effect of training on human underwater sound-localization ability. *J. Acoust. Soc. Am., 57*(5), 1212-1213.

Walsh, V., Ashbridge, E. & Cowey, A. (1998). Cortical plasticity in perceptual learning demonstrated by transcranial magnetic stimulation. *Neurophysiologia, 36*(4), 363-367.

Wells, M. J. & Ross, H. E. (1980). Distortion and adaptation in underwater sound localization. *Aviat. Space Enivron. Med., 51*, 767-774.

West, G. L., Stevens, S. A., Pun, C. & Pratt, J. (2008). Visuospatial experience modulates attentional capture: Evidence from action video game players. *Journal of Vision, 8*(16), 1-9.

Woodworth, R. S. & Schlosberg, H. (1954). *Experimental psychology*. New York; Chicago: Holt, Rinehart and Winston.

Wright, B. A. & Zhang, Y. (2006). A review of learning with normal and altered sound-localization cues in human adults. *International Journal of Audiology, 45*(1), S92-S98.

Yang, T. & Maunsell, H. R. (2004). The effect of perceptual learning on neuronal responses in monkey visual area V4. *The Journal of Neuroscience, 24*(7), 1617-1626.

Zahorik, P., Bangayan, P., Sundareswaran, V., Wang, K. & Tam, C. (2006). Perceptual recalibration in human sound localization: Learning to remediate front-back reversals. *J. Acoust. Soc. Am., 120*(1), 343-359.

Zurek, P. M. (1987). The precedence effect. In W. A. Yost & G. Gourevitch (Eds.), *Directional Hearing* (85-105). New York: Springer-Verlag.

Yost, W. A. & Soderquist, D. R. (1984). The precedence effect: Revisited. *Journal of the Acoustic Society of America*, *76*(5), 1377-1383.

Appendix

Experience, Expertise, and Hobbies Questionnaire

Instructions: *Please provide the following information regarding your hobbies and experiences. If you have any questions please ask the experimenter.*

Please specify your sex_____

Please specify your age_____

- Do you play any video games (in the last 6 months)? yes/no
  - *If yes please answer the following questions. If no, please skip to next bullet point*

1.) At what age did you begin playing video games?_____

2.) Indicate whether you agree or disagree with the following statements (*1= Strongly Disagree, 2=Disagree, 3=Neither Agree Nor Disagree, 4=Agree, 5=Strongly Agree*)

   a. Since I started playing video games, I have played continuously ever since_____

   b. I play videogames with others, either online or in-person, with the deliberate attempt to improve my performance_____

   c. I try to earn accomplishments within games that are not necessarily tied to pleasure (e.g. trophies, achievements, kill-to-death ratio) _____

3.) Estimate the average number of hours per week you have spent… *(Circle One)*

   a. playing video games during the time in your life when you played them the most
   0-1 2-4 5-7 8-10 11-13 14-16 17-19 20+

   b. playing videogames in the past 2 years
   0-1 2-4 5-7 8-10 11-13 14-16 17-19 20+

   c. Researching strategy for video game play within the last two years (e.g. watching instructional videos, reading strategy guides or articles)
   0-1 2-4 5-7 8-10 11-13 14-16 17-19 20+

d. Playing videogames in the past 6 months
   0-1 2-4 5-7 8-10 11-13 14-16 17-19 20+

e. Researching strategy for video game play within the last 6 months (e.g. watching instructional videos, reading strategy guides or articles)
   0-1 2-4 5-7 8-10 11-13 14-16 17-19 20+

f. Playing video games on a phone or other mobile device in the last 6 months
   0-1 2-4 5-7 8-10 11-13 14-16 17-19 20+

g. Playing video games on a console, PC, or MAC in the last 6 months
   0-1 2-4 5-7 8-10 11-13 14-16 17-19 20+

4.) Please consider video game-play **within the last 6 months** and fill out the chart below.

Game Categories	**How Often?** (Daily, Weekly, Monthly, Less)	**Session Length?** (Average Hours)	**How Many Games?**	**Versus Online Play?** (hours per week)	**Which Is Your Favorite Category?** (Checkmark)	**Which Are You Best At?** (Checkmark)
Adventure & Fantasy (e.g. Mario, WoW)						
Flight & Racing (Ace Combat, Need For Speed)						
Puzzle (e.g. Tetris, Bust-A-Move)						
Shooters (e.g. Call of Duty, Gears of War)						
Sports & Fighting (FIFA, Mortal Kombat)						
Real-Time Strategy (e.g. Starcraft)						
Other						

5.) Please rate the degree to which you enjoy playing videogames (0=Extremely Dislike, 4=Neither Like Nor Dislike, 8= Extremely Like)

0 1 2 3 4 5 6 7 8

6.) Please rate your level of expertise playing video games in general (0=Novice, 4=Intermediate, 8=Expert)

0 1 2 3 4 5 6 7 8

- Do you play any musical instruments (in the last 6 months)? yes/no
  - *If yes please answer the following questions. If no, please skip to next bullet point*

7.) At what age did you begin playing musical instruments?_____

8.) Indicate whether you agree or disagree with the following statements (*1= Strongly Disagree, 2=Disagree, 3=Neither Agree Nor Disagree, 4=Agree, 5=Strongly Agree*)

a. Since I started playing musical instruments, I have played continuously ever since_____

b. I play instruments with others, cooperatively or competitively, with the deliberate attempt to improve my performance_____

c. I try to earn accomplishments with music that are not necessarily tied to pleasure (e.g. awards, perfecting a musical piece) _____

9.) Estimate the average number of hours per week you have spent… *(Circle One)*

a. Playing a musical instrument during the time in your life when you played them the most
0-1 2-4 5-7 8-10 11-13 14-16 17-19 20+

b. playing musical instruments in the past 2 years
0-1 2-4 5-7 8-10 11-13 14-16 17-19 20+

c. Researching for musical instrument play within the last two years (e.g. watching instructional videos, reading about techniques, Instruction from others)
0-1 2-4 5-7 8-10 11-13 14-16 17-19 20+

d. Playing a musical instrument in the past 6 months
0-1 2-4 5-7 8-10 11-13 14-16 17-19 20+

e. Researching for musical instrument play within the last 6 months (e.g. watching instructional videos, reading about techniques, Instruction from others)
0-1 2-4 5-7 8-10 11-13 14-16 17-19 20+

10.) Please consider instrument play **within the last 6 months** and fill out the chart below.

Instrument Categories	**How Often?** (Daily, Weekly, Monthly, Less)	**Session Length?** (Average Hours)	**How Many songs played?**	**Competitive Play?** (hours per week)	**Which Is Your Favorite Category?** (Checkmark)	**Which Are You Best At?** (Checkmark)
Brass (e.g. Trumpet, Tuba)						
Keys (e.g Keyboard, Piano)						
Percussion (e.g. Drums)						
Strings (e.g. Guitar, Violin)						
Woodwinds (Clarinet, Saxophone)						
Other						

11.) Please rate the degree to which you enjoy playing musical instruments (0=Extremely Dislike, 4=Neither Like Nor Dislike, 8= Extremely Like)

0 1 2 3 4 5 6 7 8

12.) Please rate your level of expertise playing musical instruments in general (0=Novice, 4=Intermediate, 8=Expert)

0 1 2 3 4 5 6 7 8

- Do you play any sports (in the last 6 months)? yes/no
    - *If yes please answer the following questions. If no, please skip to next bullet point*

13.) At what age did you begin playing sports?_____

14.) Indicate whether you agree or disagree with the following statements (*1= Strongly Disagree, 2=Disagree, 3=Neither Agree Nor Disagree, 4=Agree, 5=Strongly Agree*)

a. Since I started playing sports, I have played continuously ever since_____

b. I play sports with others, cooperatively or competitively, with the deliberate attempt to improve my performance_____

c. I try to earn accomplishments with sports that are not necessarily tied to pleasure (e.g. awards, perfecting a technique or play) _____

15.)Estimate the average number of hours per week you have spent… *(Circle One)*

a. Playing a sport during the time in your life when you played them the most
   0-1 2-4 5-7 8-10 11-13 14-16 17-19 20+

b. playing sports in the past 2 years
   0-1 2-4 5-7 8-10 11-13 14-16 17-19 20+

c. Researching for sport play within the last two years (e.g. watching instructional videos, reading about techniques, Instruction from others)
   0-1 2-4 5-7 8-10 11-13 14-16 17-19 20+

d. Playing a sport in the past 6 months
   0-1 2-4 5-7 8-10 11-13 14-16 17-19 20+

e. Researching for sport play within the last 6 months (e.g. watching instructional videos, reading about techniques, Instruction from others)
   0-1 2-4 5-7 8-10 11-13 14-16 17-19 20+

16.)Please consider sport play **within the last 6 months** and fill out the chart below.

Sport Categories	**How Often?** (Daily, Weekly, Monthly, Less)	**Session Length?** (Average Hours)	**Organized Play?** (e.g. intramural)	**Competitive Play?** (hours per week)	**Which Is Your Favorite Category?** (Checkmark)	**Which Are You Best At?** (Checkmark)
Baseball						
Basketball						
Football						
Soccer						
Speed & Endurance (Bike, Run, Swim)						
Other (Strength, Rock Climbing)						

17.)Please rate the degree to which you enjoy playing sports (0=Extremely Dislike, 4=Neither Like Nor Dislike, 8= Extremely Like)

0 1 2 3 4 5 6 7 8

18.) Please rate your level of expertise playing sports in general (0=Novice, 4=Intermediate, 8=Expert)

0 1 2 3 4 5 6 7 8