PERCEPTUAL TRAINING YIELDS RAPID IMPROVEMENTS

IN VISUALLY IMPAIRED YOUTH

By

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I dedicate this dissertation to my parents Bruce and Cindy Nyquist, who have given me vast amounts of Love and opportunity throughout my life. Thank you Mom and Pop!

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CHAPTER I

INTRODUCTION

Researchers, practitioners and organizations have long been interested in the extent to which visual functioning can be improved for low vision (LV) individuals (Barraga, 1964; 1970; Smith and O'Donnell, 1991; National Eye Institute; Association for Education and Rehabilitation of the Blind and Visually Impaired). One central effort of practitioners and organizations has been to train the basic skills that are essential to independent daily living, thereby enhancing the quality of life for individuals with low-vision (American Optometric Association, 2006).

An essential component of effective visual functioning is our visual attention processes. Studies have provided multiple examples how visual attention affects our ability to perform everyday activities. Research now shows that visual attention can be altered or enhanced through experience and training. The current study investigates whether visual attention and visual functioning across a wide field of view can be enhanced through training for individuals with impaired vision.

Visual Functioning

When you ask someone how good their vision is you will usually get a response such as their score on a vision test or that they have trouble driving at night. In contrast, people will not usually answer that they have trouble driving in hectic situations like big city freeways or that they do not always notice things that others do. Such difficulties are not usually associated with vision. These examples, however, rely on processing of visual information and represent an emerging view that vision is more than a score on simple tests such as visual acuity or contrast sensitivity. Instead, the eye is now considered as a part of a system working together with the brain to acquire and process information.

Visual Attention

Acquiring and processing visual information is largely the domain of visual attention. Our visual system is constantly bombarded with more information than we can process with our limited resources. It has been proposed that attention involves separable networks that perform different functions to effectively process this wealth of information (Fan & Posner, 2004; Fan et al., 2002). These include alerting, orienting, and executive control. These three functions encompass the current use of the term visual attention. These functions keep us vigilant to react to stimuli (alerting), allow us to select the most relevant or important subset of information for further processing (orienting), and control our strategies and goal-directed behaviors (executive control) (Posner & Raichle, 1994; Posner, 1995; Ruede, et al., 2005).

The act of selectively focusing on a small number of attributes, objects, or locations out of many candidate inputs is perhaps the most common function addressed by visual attention research. Studies have documented myriad ways that visual selection (orienting) facilitates processing of visual information. Observers can better detect stimuli and respond faster at an attended location (Handy et al., 1996, Hawkins et al. 1990; Yeshurun and Carrasco, 1999), can better discriminate properties of an attended stimulus (Yeshurun and Carrasco, 2000; Treue and Martinez-Trujillo, 1999), and have greater sensitivity to fine changes to stimuli (Reynolds and Chelazzi, 2004; Gobel and Carrasco, 2005). Performance enhancements are found at attended locations even when the eyes are looking elsewhere (Yeshurun & Carrasco, 1998; Pestilli & Carrasco, 2005). These results exemplify that visual functioning clearly involves more than just the optics of the eye.

Low Vision

This shift in how vision is construed has reshaped the way visual impairments are described as well. It has been understood for quite some time now that performance on basic visual tasks which require detection and identification of simple visual stimuli do not adequately describe the variety of visual impairments. Moreover, performance measures on these tasks do not predict well an individual's visual functioning on real-life tasks in various environments (e.g., Ball et al., 1988). The International Council for Education of the Visually Handicapped (ICEVH) formally embraced this functional perspective in the 1970's and called for a new definition that would account for individuals who were mislabeled as blind, but still had useful visual functioning. This new term would not be based on medical acuity alone, but instead put emphasis on visual functioning (Barraga, 1993). The term low vision (LV) embodies this functional perspective. Although there is no one universally accepted definition and no legal definition is established, the definition for LV used for the current work is:

> “a person who has difficulty accomplishing visual tasks, even with prescribed corrective lenses, but who can enhance his or her ability to accomplish these tasks with the use of compensatory visual strategies, low vision and other devices, and environmental modifications. (From Corn & Koenig’s “Foundations of Low Vision”)

More than 5 million Americans have visual impairments that affect their everyday life (Oberdorfer, 2004) and between 50,000 to 100,000 school age children in the U.S. have visual impairments that require special education services (Nelson and Demetrova, 1993; Corn and Koenig, 1996).

Our earlier pilot work has indicated that LV youth have a pronounced decrement with their peripheral attention in particular. Informal observations suggest that children with LV are not using peripheral vision effectively or in ways similar to those of children with normal vision. Even children whose etiologies do not indicate involvement of the peripheral retina often appear not to attend to or locate objects effectively outside the central field of view. Ambrose and Corn (1997) found that orientation skills of children with LV were inconsistent with the performance expected for their measured acuities and visual field extents. These functional failures may be caused by a simple strategy to over-attend to the central field, or from other hindrances of normal development of their peripheral functioning.

LV children and adolescents have several important differences in their peripheral abilities, as compared to typically-sighted individuals. For one, they have markedly better peripheral acuity than would be expected from typically-sighted abilities. Compared to typically-sighted acuities, LV children have less drop-off in peripheral acuity, (Nyquist et al, 2005). Relatively speaking, their peripheral vision has an elevated resolution and therefore may be an important resource to better utilize.

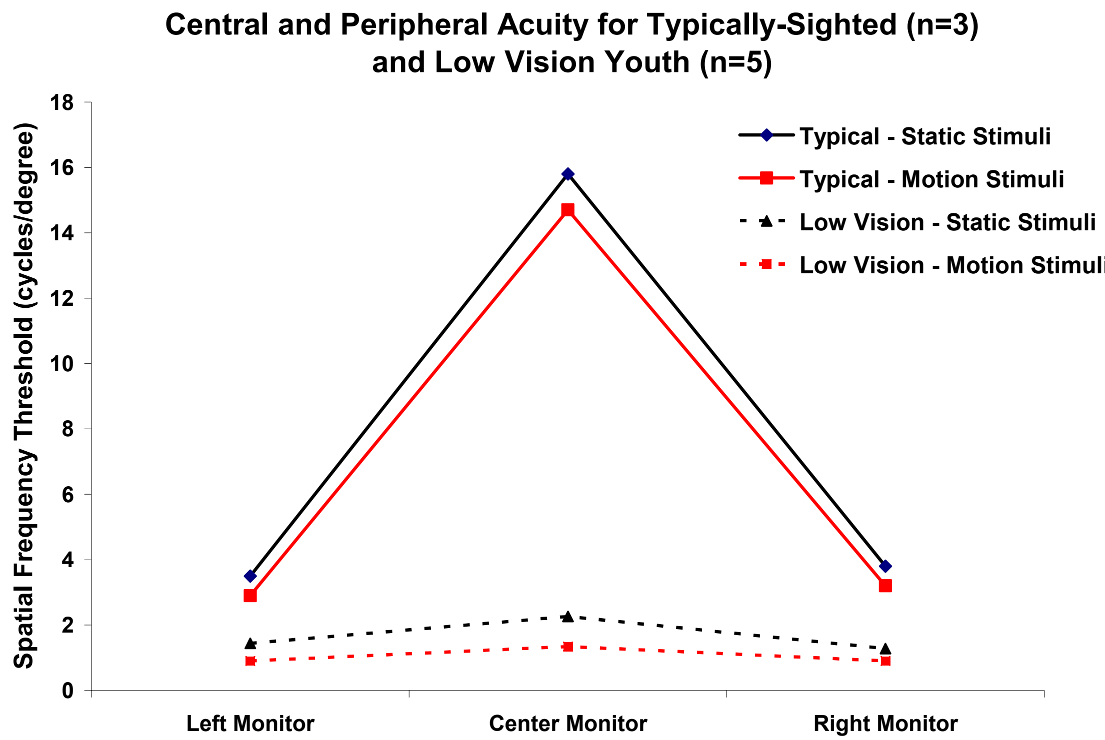

Figure 1. Average spatial frequency thresholds of typically-sighted and LV youth for foveal and peripheral locations.

Other pilot studies performed in our lab indicate that the peripheral functioning of LV youth is different than the peripheral functioning for typically-sighted individuals. For one, peripheral motion discrimination appears to be worse for LV youth, whereas central motion discrimination is surprisingly equal between LV and typically-sighted individuals. LV youth, however, do show a deficit for central motion discrimination when motion speed becomes very slow. A deficit in peripheral motion perception may be one important cause of this population's difficulties in performing certain everyday tasks.

Peripheral Attention and Visual Functioning

Peripheral vision and peripheral visual attention are essential skills needed during common everyday tasks. Studies show that measures of visual attention, particularly peripheral visual attention, correlate well with tasks and assessments of independent mobility (Geruschat & Smith, 1997; Ludt & Goodrich, 2002; Turano et al. 1996, 2002; Patel et al., 2006; Owsley & McGwin, 2004; Dodds & Davis, 1989). Broman and colleagues (2004) used a measure of visual attention to predict number of falls, trouble with balance, physical activity, and bumping into objects during a mobility task. Such correlations remain after adjusting for visual acuity and contrast sensitivity. In addition to correlational evidence, attentional training has resulted in enhanced coordination and fewer minor mishaps in the home (Drew and Waters, 1986). Similar effects appear for typically-sighted children as well. Dunbar and colleagues (2001) tested the ability of children of various ages to switch attention and concentrate. Children, who were more able to effectively switch attention, were more likely to show awareness of traffic when about to cross a road and crossed the road in an overall safer manner.

Peripheral attention has also been linked to driver performance. Statistics from driving accidents indicate significant correlations between difficulty in processing peripheral information and likelihood of causing an accident (Ball et al., 1988; Ball & Owsley, 2003; Owsley et al., 1998, 2001; Goode et al., 1998).

Enhancement of Visual Attention from Experience

Some visual attention processes and capacities seem to change from certain experiences and normal development. Research from training studies, anatomical and behavioral studies of special populations, and developmental studies all document changes to visual attention due to experience. In the developmental literature, for example, several aspects of attention appear to improve over the course of childhood. The alerting function of attention, or the ability to remain vigilant while waiting for a target to appear, is found to be worse in children compared to adults. Specifically, children's alertness function slows down after repeated exposure to a particular stimulus (Kraut, 1976). It is well documented that children's visual selection (orienting) improves over the course of normal development. As they get older, children are able to orient to a target location faster and to filter competing information better (Akhtar & Enns, 1989; Enns & Cameron, 1987), make better use of cues to guide their attention, are less distracted by invalid cues (Schul et al., 2003), and able to direct attention to a larger visual region (Enns & Girgus, 1985). Studies also suggest that higher forms of attention (executive control) develop through childhood. Age-related improvements are found on tasks involving resolution of conflict among stimulus elements. For example, one study required children and adults to respond to a stimulus by pressing a key with the identical figure as the target while suppressing information on whether the response key is on the same side of the display as the target (Gerardi-Caulton, 2000). Another study gave a child version of the stroop task to young children ages 2 – 4 (Gerstadt, Hong, & Diamond, 1994). Both studies showed strong evidence of development on these tasks.

Neuroplasticity

Several pilot studies were presented earlier that revealed unexpected differences for peripheral motion processing performances of LV youth. Another special population, in this case congenitally deaf individuals, also presents unusual visual abilities for tasks that require peripheral visual functions. This group, however, shows enhanced performance. Attentional selection, for one, appears to be more rapid for the congenitally deaf. Loke and Song (1991) showed that deaf participants were significantly faster to detect a peripheral target (25° eccentricity) compared to hearing individuals, while both groups did not differ in their reaction times to central targets. Attentional capacity over a wide field of view is also enhanced for deaf individuals. Proksch and Bavelier (2002) demonstrated greater capacity of peripheral attention for deaf individuals. Both hearing and deaf participants performed a flanker interference task, in which both a central target and a peripheral distractor stimulus (flanker) are presented simultaneously. It is believed that this distractor will attenuate performance only if peripheral attentional resources are available. In accordance with the view of greater peripheral attention in the deaf, peripheral flankers were more distracting in deaf than hearing individuals.

Anatomical evidence indicates plasticity of the peripheral visual system for congenitally deaf individuals. Psychophysical studies measuring event-related potentials (Neville and Lawson, 1987a; 1987b) have compared deaf and hearing adults on motion detection tasks for central and peripheral targets. Not only do deaf adults perform better and faster for detecting peripheral motion, but they also display much larger attention-related ERP amplitudes (indexed by the early negativity – N1) for peripheral targets.

Such differences did not occur when these individuals detected central targets. fMRI studies find greater activation levels of MT/MST for a congenitally deaf group than hearing individuals when attending to peripheral motion stimuli at 15 º eccentricities (Bavelier et al., 2001; Fine et al., 2005). Both groups, however, have comparable recruitment to MT/MST when visible peripheral stimuli are not attended to.

Although LV youth demonstrate the opposite effect by performing worse on peripheral tasks, these two special populations have unique visual functioning in their peripheral fields. These results, taken together with developmental studies showing attentional increases during typical development, suggest that peripheral visual functioning may be malleable during some point in childhood.

Children are still learning what information their environments afford and are still developing visual strategies and abilities for acquiring that information. Little is now known regarding whether visual skills and processes may be restricted to a particular developmental window or time span, but the best opportunities for visual and attentional development may be during childhood. If so, then childhood may be an opportune time for training such skills. Training studies with typically sighted adults have already enhanced visual attention. This research is reviewed next.

Training Visual Attention

For two decades now, researchers have examined whether playing video games results in improved visual attention (Gopher, Weil, & Bareket, 1994; Green & Bavelier, 2003; 2006a; 2006b; 2007; Greenfield, DeWinstanley, Kilpatrick, & Kaye, 1994; Trick, Jaspers-Fayer, & Sethi, 2005). These studies reveal improvements in spatial and temporal aspects of attention, capacity to track multiple moving objects, more efficient attentional monitoring, and even changes in peripheral acuity. Although it is not known what exactly about video game training causes such enhancements, there are certain qualities that are good candidates. Action video games are quite demanding on visual processing: multiple moving items must be selected, processed and tracked simultaneously, attention must be distributed across space and switched quickly among multiple locations while rewarding vigilance to unexpected peripheral targets, and irrelevant information must be actively suppressed. This topic will be discussed further in the next section.

Green and Bavelier (2003; 2006a; 2006b; 2007) have included both correlational and experimental studies of action video game playing. The correlational studies compare the performance of non-video game players (NVGP) to video game players (VGP), as defined by previous video game exposure. VGP groups consistently perform significantly better than the NVGP group on several attention-based visual tasks (described later). Experimental studies start with all NVGP individuals and train half with action video games and the other half with a control video game. This training lasts between 10, 1-hour sessions (2003; 2006a) and 30, 1-hour sessions (2006b; 2007). VGP groups perform significantly better than NVGP groups on several measures. For example, using an enumeration task, which provides an estimate for the number of items that can be attended at once, Green and Bavelier (2003, 2006a) showed that trained participants could attend to approximately 50% more items at once than untrained participants.

Enhancement of spatial distribution of attention

Green and Bavelier (2003, 2006b) found training effects with the useful field of view (UFOV) task, which has been defined as a measure of the total visual field area in which useful information can be acquired within one eye fixation (Ball et. al., 1988). The general structure of the UFOV measure includes an array of possible stimulus locations, where the locations form "spokes" emanating from a central fixation point. Each spoke has several locations in which a distractor or target stimulus may appear. These locations are fixed at 10, 20, and 30 degrees of eccentricity, making a total of 24 possible spatial locations. Briefly presented stimuli appear at one or more of these locations, and an observer must locate the radial position of a peripherally presented target while simultaneously performing a central task of varying complexity.

This measure does not correlate well with standard tests of visual acuity but rather provides a measure of attentional resources and their spatial distribution (Ball et al., 1988). Green and Bavelier (2003, 2006b) found that trained participants far outperformed their untrained counterparts at all locations in the visual field, sometimes approaching twice the accuracy for correctly locating a target. There was also a slight, but non-significant trend for greater improvement for targets located further in the periphery. A similar measure to this will be included in the current study.

Enhancement of tolerance for perceptual crowding

Action video games also seem to refine the spatial resolution of peripheral vision, as measured by the crowding region. Crowding refers to the difficulty to identify a target stimulus when other stimuli (distractors) are presented in close spatial proximity to the target. These distractors, or flankers, effectively "crowd" the perceptibility of the target stimulus. The crowding region offers a measure of peripheral acuity, or resolution of visual-spatial attention (Intrilligator & Cavanaugh, 2001; Montaser-Kouhsari & Rajimehr, 2005; Tripathy & Cavanaugh, 2002). In other words, increased attention can reduce the crowding effect of flankers (Poder, 2005). Green and Bavelier (2007) have demonstrated recently that participants trained on action video games can tolerate smaller target-distractor distances. A measure of crowding will also be used in the current study.

Perhaps the most interesting finding from these training studies is that many of these improvements described above are found beyond the visual field in which training took place. For example, video game training was often displayed between +/- 10 degrees of visual angle, but improvements were found as far out as +/- 30 degrees of visual angle. This again points to the particular malleability of peripheral attention.

These training studies that use action video games demonstrate a variety of ways that our visual system, particularly visual attention, benefits. Although it is still unknown what specific qualities of these games are responsible, several possibilities include that these environments contain objects that move more quickly, peripheral processing is placed at a premium, and the number of items that need to be kept track of exceeds the circumstances in normal life. LV children may be an especially trainable group in regards to visual attention. The current study was designed to specifically investigate whether visual functioning, and peripheral visual attention in particular, can be enhanced for LV children via training.

Current Aims

Inspired by the already mentioned training studies using action video games, one aim of the current study is to investigate how similar training may affect a group of children and adolescents with LV. Based on the reviewed research, visual peripheral attention might improve particularly well for children and adolescents with LV. Training effects will be measured in both central and peripheral vision, including measures similar to earlier training studies as well as a measure of more everyday visual functioning.

A second aim attempts to flesh out the specific characteristics of video game training that cause attentional improvements. Despite the accruing evidence that video games seem to improve visual attention, there is very little understanding about which aspects of these games are causing such effects. To accomplish this, the effects of a novel (psychophysical task) training task will be included as a comparison to the traditional video game training. The psychophysical training task is designed to emulate specific task characteristics that are found in video games that may drive visual improvements. The action video games used in previous studies involve navigating through a world where numerous enemies can appear from virtually any location. More specifically, it seems to be the case that these games require players to distribute and switch their attention to many locations in rapid succession while at the same time rewarding vigilance to unexpected peripheral targets. Players must effectively ignore irrelevant stimuli and track multiple moving objects simultaneously. These task demands are emulated in the psychophysical task.

Psychophysical Training Task

This task is a modified multiple-object tracking (MOT) task. Participants must track moving targets embedded in a field of competing, and visually identical, distracting elements. Effective performance requires participants to ignore irrelevant stimuli. At the same time that participants are tracking targets, they must also be vigilant to the far periphery, where briefly presented objects appear randomly and must be discriminated for direction of motion. It is generally accepted that there is a large dynamic attentional component to the MOT task (Scholl, Pylyshyn, & Feldman, 2001). One study has demonstrated that attention is actually split between the items during tracking (Sears & Pylyshyn, 2000). This task provides a training program that includes the best candidate qualities found in action video games while eliminating the wide range of characteristics that are free to vary in action video games.

Measures of Visual Functioning

In order to quantify the effects of training, five tasks of visual attention and visual functioning are used. These measures examine both central and peripheral visual functioning, including measures of spatial acuity and attention-based performance in both fields. A measure of a more common everyday visual task (visual search) was also examined.

Foveal Tasks

To investigate training effects on central vision, two motion discrimination tasks are used. Each task presents stimuli at central fixation and measures temporal thresholds and spatial frequency thresholds, respectively. These tasks will be used as comparisons to the peripheral tasks of motion discrimination and spatial acuity.

Peripheral Motion Discrimination

Of fundamental importance to the current study are performance and training effects for peripheral motion perception and peripheral visual attention. To this end, two forms of a motion discrimination task are included in the current study, called the simple and complex peripheral motion discrimination tasks. These tasks were inspired by the UFOV task (Ball, et. al., 1988), which was described earlier as a stimulus localization task thought to provide an index of the distribution of visual attention across a large field of view (Ball et al., 1990; Owsley et al., 1995).

Similar to the UFOV task, both tasks present stimuli at several locations throughout a wide visual field (12° and 25° eccentricity). The current tasks, however, require motion discrimination and measure temporal thresholds for stimuli presentation. The simple peripheral motion discrimination task briefly displays a single moving stimulus in one of many potential spatial locations. An observer must discriminate the direction of motion (up or down). The complex peripheral motion discrimination task briefly presents three moving stimuli simultaneously and an observer must indicate whether all three motions are unidirectional (same) or have different directions of motion. These stimuli are spread throughout the visual field and require observers to process all three motion directions in order to correctly respond.

Perceptual Crowding

A crowding task is included to measure peripheral attention and spatial resolution. Crowding refers to the difficulty to identify a target stimulus when other stimuli (distractors) are presented in close spatial proximity to the target. These distractors, or flankers, effectively "crowd" the perceptibility of the target stimulus. As mentioned earlier, the crowding region offers a measure of the resolution of visual-spatial attention (Intrilligator & Cavanaugh, 2001; Montaser-Kouhsari & Rajimehr, 2005; Tripathy & Cavanaugh, 2002). Consequently, increased attention can reduce the crowding effect of flankers (Poder, 2005). Tolerance for perceptual crowding has important implications for reading and is a common problem for visually impaired individuals, such as in the cases of amblyopia or normal aging (Ball et al., 1988; Ball & Owsley, 1992). Crowding tolerance has already been shown to improve for typically-sighted subjects after training with action video games (Green and Bavelier, 2006b).

Visual Search of Natural Scenes

A visual search task of naturalistic scenes is included in the current study as well to provide a more ecologically valid measure of visual functioning. Children commonly report difficulties in everyday tasks that rely on visual search skills, expressing problems with distracting objects and events, cluttered visual scenes, and not enough time to locate task relevant objects. Visual search relies on a host of visual functions including selective visual attention, executive control, visual memory and well-coordinated eye movements.

CHAPTER II

DESIGN AND METHOD

Overview of Study

The sequence of tasks and measures is displayed below in Table 1. Participants were first screened on basic vision criteria and given a questionnaire about visually relevant activities they participate in. Next participants were given a set of computer-based tasks (pre-test measures) which typically took two or three sessions. Subjects were then assigned to a training condition which lasted for the next 2-3 weeks. After training, participants performed the same computer-based tasks again (post-tests measures).

Table 1: Sequence of study: tasks and measures.

Screening Measurements	Pre-Test Measurements	Training Conditions	Post-Test Measurements
Acuity	Foveal Spatial Sensitivity	Action Video Game	Foveal Spatial Sensitivity
Visual Field	Foveal Temporal Sensitivity	Psychophysical	Foveal Temporal Sensitivity
Questionnaire	Simple Peripheral Motion Discrimination	Control Game	Simple Peripheral Motion Discrimination
	Complex Peripheral Motion Discrimination		Complex Peripheral Motion Discrimination
	Peripheral Crowding		Peripheral Crowding
	Visual Search		Visual Search

Participants

LV participants were recruited through the Tennessee and Oklahoma Schools for the Blind. Participants are low-vision children and adolescents, ranging between 10 and 18 years old, with no cognitive impairments, acuities between 20/60 and 20/800, and visual fields of at least 35 degrees in both the left and right visual hemifields. These criteria were first screened by appropriate staff at the schools, and confirmed by the researcher using vision reports provided by the school. A group of typically-sighted children and adolescents were recruited to perform the same pre-training tasks. This group's performance thresholds provided a baseline comparison to the low-vision participants' measures. This group ranges in ages from 10 to 17 years old and have normal visual acuity and peripheral fields. A summary table of all participants is provided below (Table 2).

Table 2: Ages and Visual Characteristics of Study Participants.
* indicates glasses were worn during study

School	Age	Etiology	Right Eye Acuity	Left Eye Acuity	Visual Field	Visually-Demanding Activities	Action Video Games
Control Group	**13.1 (Avg)**						
TSB	16	Nystagmus	20/800	20/400	normal	Weekly	None
TSB	9	Nystagmus, Oculocutaneous Albinism	20/800	20/800	normal	Monthly	None
TSB	16	Stargardt's Disease	20/60	20/80	normal	Weekly	Weekly
OSB	10	Stargardt's Disease	20/200	20/100	normal	Monthly	Daily
OSB	11	ROP	20/200*	20/200*	-40°, +35°	Weekly	None
OSB	14	Nystagmus, Oculocutaneous Albinism	20/300	20/200	normal	None	Daily
OSB	14	Nystagmus, Oculocutaneous Albinism	20/200	20/200	normal	Weekly	Weekly
OSB	14	ROP	20/400	20/400	normal	Once	Once
OSB	14	Nystagmus	20/200	20/200	normal	Never	Daily
Video Game	**15.3 (Avg)**						
TSB	14	Aphakia	20/200*	20/200*	normal	Once	Once
TSB	17	Retinitis Pigmentosa	20/400	NLP	?	Weekly	Never
OSB	18	Stargardt's Disease	20/400	20/400	8° central	Monthly	Weekly
OSB	15	Stargardt's Disease	20/200	20/200	normal	Daily	Daily
OSB	13	Nystagmus, Septo-optic Dysplasia	20/200	20/200	+/- 45°	Daily	Weekly
OSB	16	Coloboma	20/400	20/400	unknown	Weekly	Monthly
OSB	17	Aphakia, Cataracts, Nystagmus	20/200*	20/200*	-42°, +37°	Daily	Weekly
OSB	12	Nystagmus, OD Esotropia	20/400*	20/400*	normal	Monthly	Never
Psychophysical	**15.6 (Avg)**						
TSB	14	ROP	20/800	cf 1'	normal	Daily	Daily
TSB	16	Nystagmus, Oculocutaneous Albinism	20/400	20/400	normal	None	Monthly
OSB	14	Aphakia, Cataracts, Nystagmus	20/200*	20/200*	normal	Weekly	Weekly
OSB	16	Nystagmus	20/200*	20/200*	normal	Daily	Once
OSB	16	Nystagmus, Amblyopia	20/70	20/100	normal	Monthly	Once
OSB	15	Nystagmus	20/400	20/400	normal	Never	Never
OSB	17	Nystagmus, Oculocutaneous Albinism	20/200	20/200	normal	Daily	Weekly
Typically-sighted	**14.6 (Avg)**						

Before the study began, a power analysis was performed in order to make informed choices about the number of subjects needed to detect training effects. Effect sizes were calculated from Green and Bavelier (2002; 2006), because these studies used training and dependent measures that were similar to the current study. Beta calculations, or probabilities of detecting a significant result, are based on Lipsey (1990) with one-tailed tests and alpha = .05. Based on these calculations, between 6 and 9 subjects per condition are needed for these studies to have more than 80% power. The current study attempted to have at least 8 subjects per condition.

Assignment

Previous pilot work suggested that participant's prior experience with visually demanding activities (e.g., action video games, certain ball-based sports, biking) can have an important effect on study measures. In order to control the influence of this factor on outcome measures, a randomized block design was incorporated into the assignment process. Participants were first assessed on previous relevant experiences with a questionnaire (appendix A). Based on their answers, participants were stratified, or blocked, into three levels of this factor (see appendix B for details of this process). Participants in each block level were then randomly assigned to a training condition without replacement. This means that a participant was randomly assigned to one of the three conditions, and the next participant from the same block was randomly assigned to one of the remaining two conditions, and finally the next participant was placed in the remaining condition. This process continued until all participants within a block had been assigned. This form of assignment ensures that each experience level has equal representation in each training condition.

Apparatus

To present stimuli and collect response data, computer programs were run on a Macintosh G4 and a G5. The program that ran the central motion discrimination task (2) used the Matlab computer language, version 5.2 (The Math Works Inc., Natick, MA) and the Psychophysical Toolbox routines, version 2.44 for the apple OS9 operating system (Brainard and Pelli, 2000 - http://psychtoolbox.org). This program was only run on the G4 computer. Stimuli for this program were presented on a LCD monitor (ViewSonic VX924, 37.5 cm horizontal x 30 cm vertical area, with 1024 x 768 resolution, 85 Hz, with linearized grey-scale). Each pixel was 1.635 $arcmin^2$. Viewing distance was binocular at 77 cm. Contrast was 99.8%, with minimum ambient background luminance of .13 cd/m^2 and maximum luminance at 67 cd/m^2.

All other vision assessment tasks were run on a Macintosh G5 using the Matlab computer language, version 7.1 (The Math Works Inc., Natick, MA) and the Psychophysical Toolbox routines, version 1.0.6 for the apple OSX operating system (Brainard and Ingling, 2005- http://psychtoolbox.org). The stimuli were displayed on a matte finish projection screen using a NEC WT610 projector (174 cm horizontal x 130 cm vertical area, with resolution of 1028 X 768, 120 Hz, with linearized grey-scale). Each pixel was 3.745 $arcmin^2$. Viewing distance was 156 cm. Minimum ambient background luminance was .04 cd/m^2 across the entire screen. Maximum luminance varied from 98 cd/m^2 on the left side to 87 cd/m^2 on the right side. Contrast, however, was greater than 99.9% on the entire screen.

The psychophysical training program was run with both Macintosh computers. The G5 again used the same projector and display parameters as described above. The G4 now ran the identical operating system and programs as the G5 computer. The G4 used a Panasonic AE-9000U projector (198 cm horizontal x 149 cm vertical area, with resolution of 1028 X 768, 85 Hz, with linearized grey-scale). Each pixel was 3.755 arcmin^2. Viewing distance was approximately 177 cm. This distance was not strictly enforced for training sessions. Contrast and luminance was made as similar as possible to the NEC projector. Minimum ambient background luminance was .7 cd/m^2 across the entire screen. Maximum luminance was 56 cd/m^2 on the left side to 61 cd/m^2 on the right side. Contrast was 98.8% on the entire screen.

A Playstation 2 video game console was used for the control and action video game conditions. These training tasks were displayed on the same projectors with equivalent display sizes (28° wide X 21°high effective game area).

Vision Measures

Pre- and post-test measures were always given in the following order: complex peripheral motion discrimination, crowding, visual search, foveal motion discrimination (temporal thresholds) and simple peripheral motion discrimination, and foveal motion discrimination (spatial frequency threshold). These tasks were always given in this order to reduce the confusability of response mappings that were observed during pilot work. All computer-based training tasks and measures incorporate adaptive QUEST staircases

(Watson & Pelli, 1983). This procedure enables computer programs to efficiently adjust a task parameter based on a participant's performance in order to quickly estimate their threshold performance. Thresholds (80%) were estimated with blocks of 25 trials per threshold estimate. Each participant performed practice blocks until thresholds did not vary by more than 15% from the previous block. Three to five more blocks were then run for data collection. Auditory feedback was provided after each trial.

Foveal and Peripheral Motion Discrimination (Temporal Thresholds)

Stimuli were Gabor patches: moving sine wave gratings presented in a stationary spatial Gaussian envelope. The motion occurred in two alternative directions: up or down. Gabor size was 4° diameter, with spatial frequency (SF) of .75 cycles/° and temporal frequency (TF) was 10 °/second. Gabors were presented in a temporal Gaussian envelope, whose duration was adjusted by a QUEST staircase in order to measure temporal thresholds.

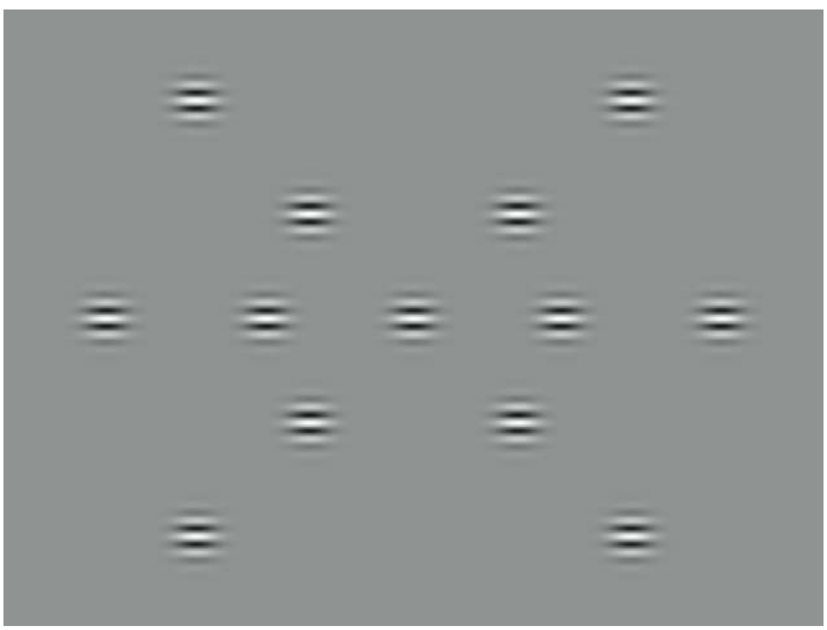

Figure 2. Display of all possible Gabor locations for the simple motion discrimination task.

The simple motion discrimination task briefly presented a single Gabor in one of 13 possible spatial windows, very similar to the spatial layout of the UFOV task. Figure 2 displays an image of all possible stimuli locations for this task. Spatial locations are at 0°, +/-12°, and +/-25° in cartesian coordinates and 0° and +/- 45° in polar coordinates. Participants responded by pressing one of two keys to identify the direction. This task is thought to primarily require the alerting and orienting functions of attention over a wide region of visual space, requiring rapid deployment of selective attention to various locations.

A similar task, named the complex motion discrimination task, briefly presents three target Gabors simultaneously along the horizontal line (Figure 3). All three targets move up or down independently and have the same stimulus attributes as the simple motion task. A QUEST staircase again controls the stimulus presentation time. A two-alternative forced-choice (2AFC) is given to an observer: Participants respond "same" if all three Gabors are moving in the same direction (all up or all down), or "different" if one Gabor moves in the opposite direction from the other two. The program is constrained to produce "same" and "different" presentations equally often at 50% each. This task also requires the alerting and orienting functions of attention over a wide region of visual space, while also requiring rapid deployment of selective attention to a much larger region of space. Executive control may be recruited as well in order to compare and reject incongruent stimuli.

Two conditions are run with interspersed trials and independent threshold measurements. One condition presents stimuli at central fixation and at 12° left and right of center, and a second condition presents the three stimuli at central fixation and 25° left and right of center.

Figure 3: Example of complex motion discrimination task.

Crowding

Stimuli are landolt-type letter c's with four potential orientations: 0°, 90°, 180°, and 270°. A target stimulus is briefly presented (150 msec.) along with four identical distractor letter c's surrounding the target at 0°, 90°, 180°, and 270° polar degrees. Targets and distractors all have a diameter of 3° visual angle. Participants were asked to fixate on a central point while the target was presented randomly at either 8° or 16° left or right of central fixation. Participants discriminated the orientation of the target c. A QUEST staircase procedure adjusts the target – distractor distance. A separate threshold was measured for each eccentricity.

Similar to the previously described tasks the crowding task presents stimuli very quickly, requiring vigilance (alerting function of attention) and rapid selection of a spatial location and correct orientation of a target stimulus (orienting function of attention). Crowding also measures the spatial resolution of attention.

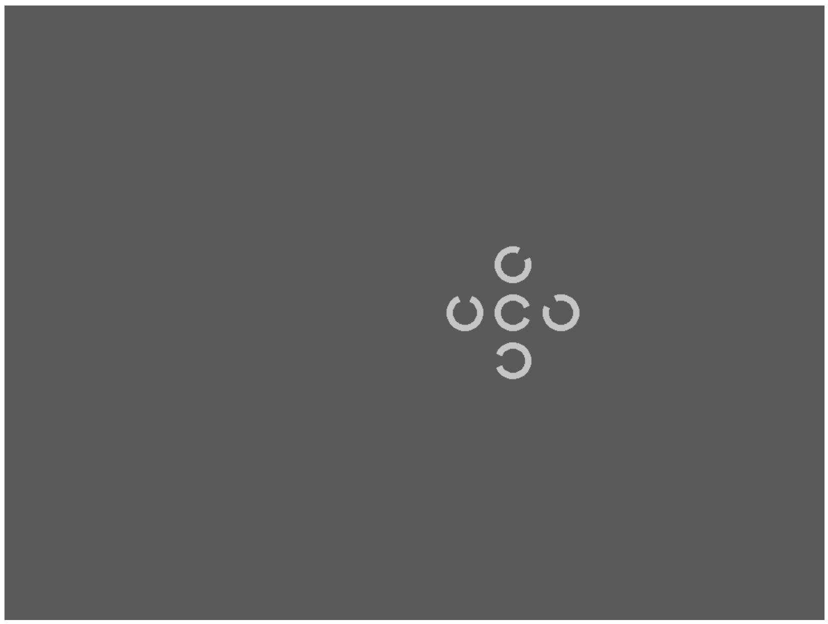

Figure 4: Example of the 8° crowding stimuli presentation just after central fixation cross disappears.

<u>Naturalistic Visual Search</u>

This task measures how quickly participants can locate and point (with a laser pointer) to a target object located in photographs of typical scenes (i.e., office rooms). Nine target objects (e.g., coffee cup, plant, bottle of Motrin) were used, with one target per trial. Each target is presented in four different scenes, for a total of 36 trials. Targets and target placement were chosen to vary the level of discriminability from background scenes. Level of discriminability was adjusted using different levels of contrast between target and background, amount of clutter, and number and similarity of distracting objects. Trials were presented on the same large projection screen used for other measures.

Before the trials began, the experimenter would explain the task and give the participant a brief test to make sure he or she could see the laser pointer and point to randomly called out corners of the screen. All subjects could do this quickly. Participants were also instructed to find the target object with their eyes first and then point to the target with the laser pointer. This reduced “fishing” for the target. Laser points were almost always direct points or quick, linear sweeps toward the participant’s answer.

Trial sequence began with a photograph of the target object alone in the center of the screen for 5 seconds. The experimenter would state out loud the name of the target. Next the scene photograph would be displayed and the participant would begin searching for the target object. The computer program began a timer at this point, which terminated once the experimenter pushed a button indicating that the target was located. If a participant pointed to an incorrect object, the experimenter simply said “no” and instruct the participant to turn the laser back off if they did not do so on their own. After 30 seconds, the experimenter would say “keep looking, you will find it”. After 60 seconds, the experimenter would state again the name of the object, repeating this every following minute. The trial would be terminated if a participant had not found the object after 5 minutes, although this did not occur.

Training Tasks

For all three groups, training consisted of playing the predetermined task for 10 total sessions (40-50 minutes per session, minimum of 3 times a week and maximum of 5 times a week). Many video games were examined in order to find a child-friendly game that would emulate similar characteristics to video games used in previous studies. The action video game chosen is Ratchet and Clank: Dreadlocked. This game controls a character from the first person perspective, provides an appropriate level of challenge for LV children, and adapts appropriately to participants' progress. Most importantly, this game includes the task demands characteristic of action video games used in previous studies. This game requires rapid visuospatial processing: multiple moving items must be attended and tracked simultaneously, vigilance to unexpected peripheral targets, and irrelevant objects must be rejected.

The control training task is a video game called Lumines. This game is similar to the well-known game Tetris, which has been used regularly in previous training studies as a control condition. This game was selected to control for the effect of improved visuomotor coordination, while putting little demand on visuospatial processing.

Psychophysical Training Condition

Generally, this task is a multiple object tracking (MOT) task, with the addition of briefly presented moving Gabors that randomly appear in the periphery during the tracking task. Participants begin their first session with a small block of trials so that the researcher can describe the task and let participants get acquainted with the task. Initial blocks are also used to discern the appropriate parameter values (e.g., number of targets and distractors, speed of balls, etc.) to fit the participant's skill level. After task parameters are adjusted to match the participant's performance, blocks of 50 trials begin. Blocks generally included two staircases of 25 trials each, with two levels of targets and distractors. This helped to reduce monotony of the task.

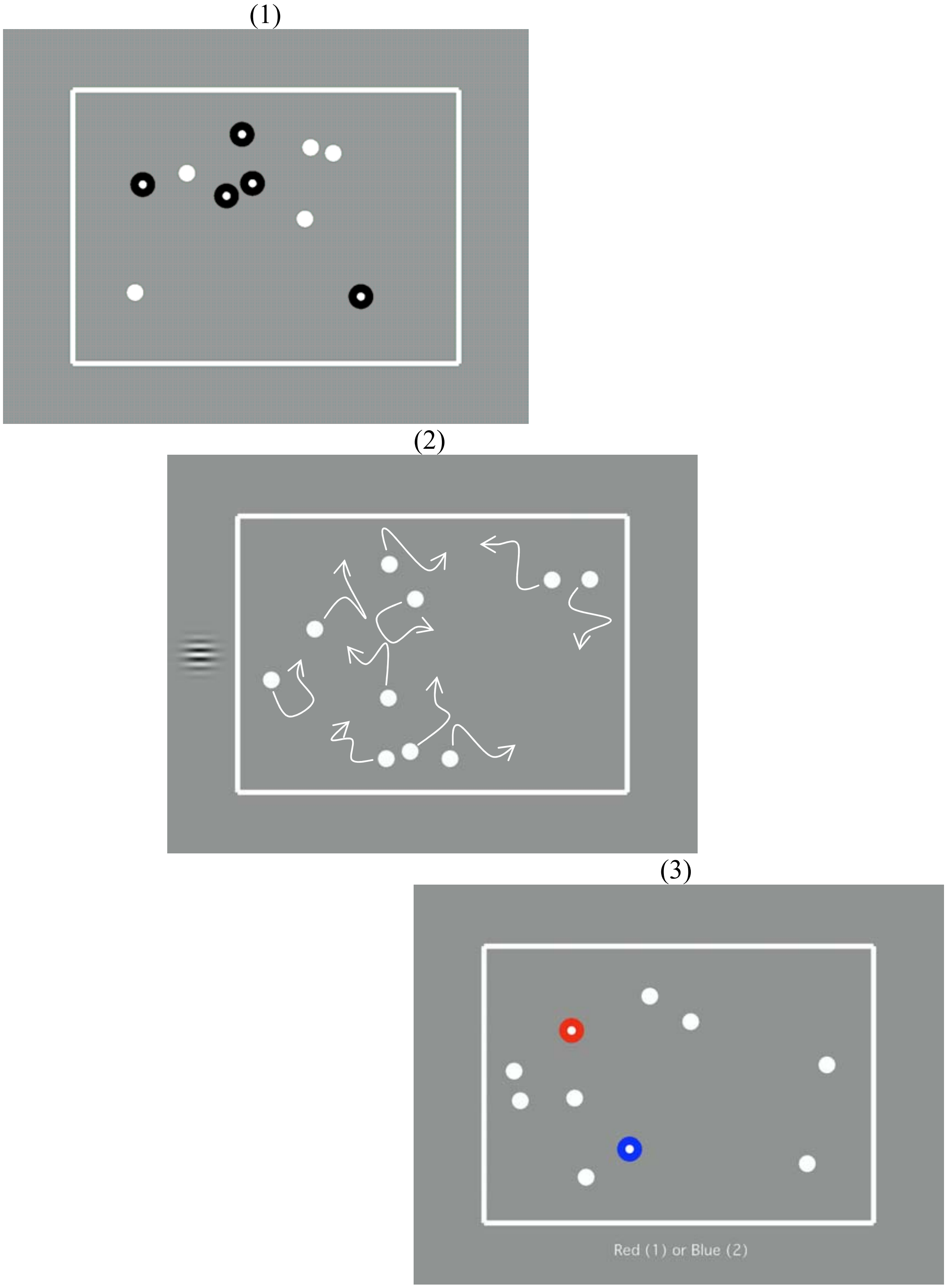

Figure 5. Sequence of psychophysical task: (1) targets are briefly identified, (2) balls move about randomly while peripheral Gabors may appear, (3) balls stop and participant chooses target from two alternatives.

The sequence for a trial is presented in Figure 5 above. Participants hit any key to initiate the trial. A number of static white balls (4 – 10) are presented for 2 seconds on the screen, appearing in random locations within a box (23° wide X 17° high). Balls were 1.5° in diameter. During this time, 2-5 balls are highlighted (circled with black) to signal their status as targets. Next, all balls become visually identical and begin moving randomly and independently of one another, avoiding each other and the edge of the box. These balls can approach but never touch each other (they repulse each other). Movement continues for 10 seconds, during which time briefly presented Gabors (same characteristics as previously described) may appear directly outside the box to the left or right (+/- 25°eccentricity). Participants make a simple up/down discrimination to these targets. Between 0 - 2 Gabor presentations may occur during a single tracking trial. Onset of first Gabor (if present) occurs between 500 msec and 3500 msec, and onset of second Gabor (if present) occurs between 500 msec and 3000 msec after the first Gabor is responded to. After the balls stop moving, two balls become highlighted (one circled with red and another circled with blue). Participants then respond to which highlighted ball is a target, “1” for red and “2” for blue. Immediate auditory feedback is provided for correct answers to both the tracking and the motion discrimination tasks.

Several QUEST procedures are used in this task. One adjusts the velocity of the targets and distractors to maintain 82% accuracy. Velocities typically ranged between 5.0°/second and 30°/second. A second QUEST procedure adjusts temporal durations of the peripheral targets – these Gabors were presented in a temporal Gaussian envelope, whose duration was adjusted by a QUEST staircase in order to measure temporal thresholds. The multiple QUEST procedures are used to keep performance adapted to participants' skill level, similar to video games. Adjustment of task difficulty with an adaptive staircase such as QUEST (especially with a conservative 82% threshold) minimizes the experience of failure, which presumably should have a positive effect on participants' motivation. The number of targets and distractors was also adjusted as participants' skill level increased. Once ball velocity surpassed approximately 25°/second then the number of targets and distractors was increased before the next block of trials. Participants usually completed two blocks of trails during each session.

CHAPTER III

RESULTS

Participants

Perhaps the most succinct way to describe the LV participants in this study is the word variable. Participants had a wide range of performance thresholds on pre-test vision measures, as well as variability on individual characteristics. For example, participants had many different types of visual impairments. The most common type was Nystagmus (involuntary eye movement) with 58% having this condition. Other impairments include Stargardt's Disease (juvenile macular dystrophy) at 17%, Retinopathy of Prematurity (abnormal retinal blood vessel growth and scarring) at 13%, Aphakia (absence of the lens) at 13%, and congenital cataracts (8%). Less frequent impairments included Retinitis Pigmentosa, Coloboma, Amblyopia, optic nerve hypoplasia, and Strabismus. Recall from Table 2 that many participants exhibit more than one of these conditions.

These sources of variability introduce noise for data analyses and complicate how results are interpreted. For one, the wide variance across participants can introduce pre-training group differences, even when random assignment is used. Such pre-existing group differences make it more difficult to attribute post-test differences to a training condition. These issues can, and will, be handled using various research methods and statistical procedures which are discussed in a later section. The following section will first take a closer look at individual-level characteristics and pre-training thresholds, in order to highlight the pre-training variability that may need to be controlled for in later analyses. LV thresholds are also compared to a typically-sighted baseline group to highlight other patterns that help describe LV performance.

Individual Pre-Training Thresholds

Individual thresholds on foveal tasks are shown below (Figures 6 and 7) for both LV and typically-sighted participants. Temporal thresholds had a wide range of thresholds for LV individuals (mean = 74.0 msec, SD = 78.5), although most performed in the same range as typically-sighted youth (mean = 48.1 msec, SD = 21.3). Importantly, group differences exist between average thresholds for the three LV training conditions (Control mean = 109.3, Video Game mean = 61.1, Psychophysical mean = 49.2). These differences are found in many of the measures presented in this section.

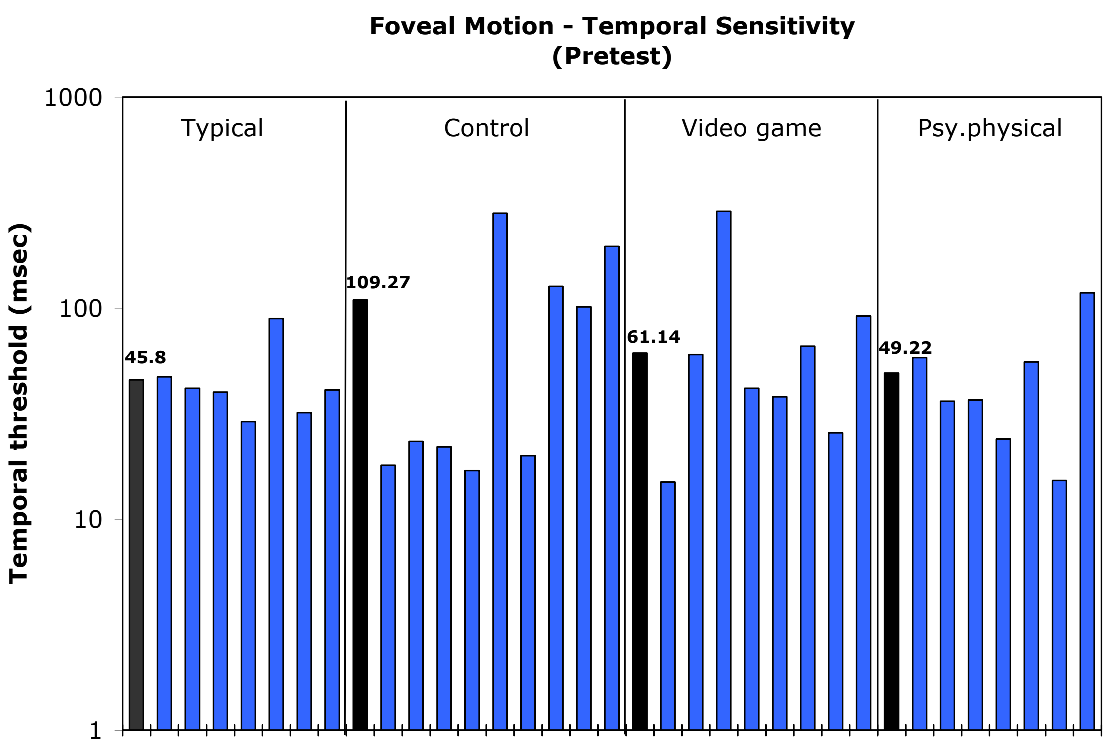

Figure 6. Average individual temporal thresholds for foveal motion discrimination. Thresholds are ordered within group by acuity, from best to worst.

Not surprising, the average foveal acuity (measured with a motion discrimination task) was much better for typically-sighted youth than for LV youth. LV performance averaged 2.99 cyc./deg. (SD = 1.78), and typically-sighted youth averaged 10.18 cyc./deg. (SD = 1.05). Potentially important group differences may be present here as well for the three LV groups (Control mean = 2.5 cyc./deg., Video Game mean = 1.8 cyc./deg., Psychophysical mean = 3.5 cyc./deg.).

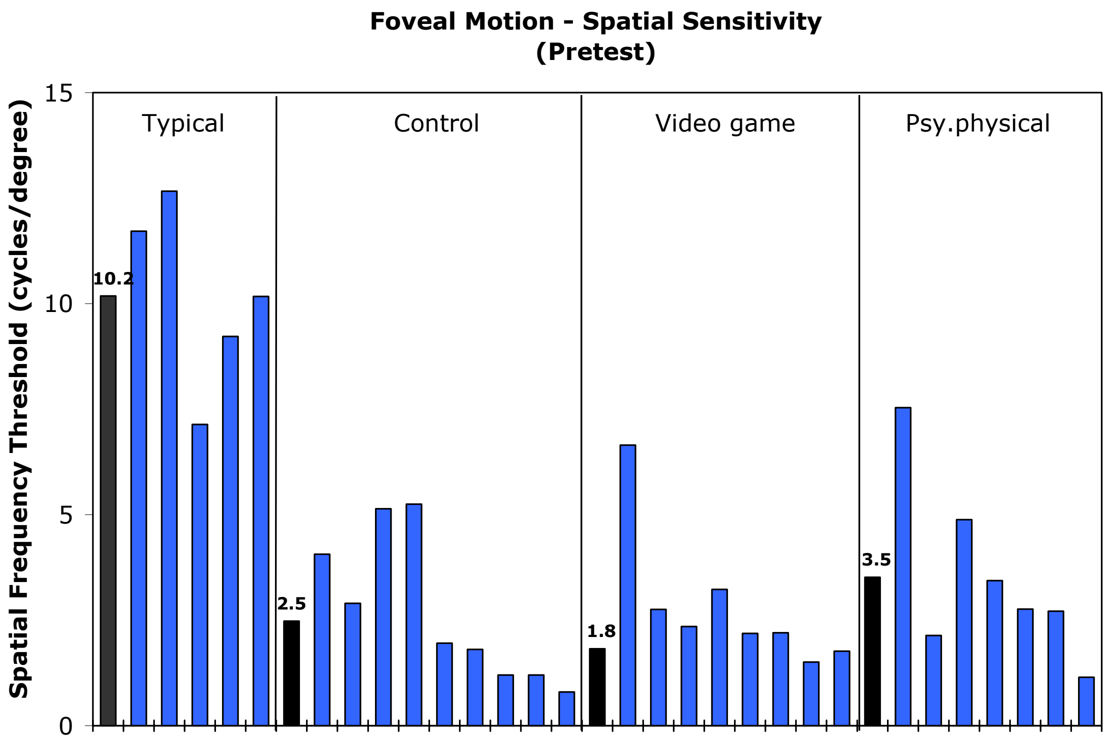

Figure 7. Average individual spatial thresholds for foveal motion discrimination. Thresholds are ordered within group by acuity, from best to worst.

Temporal thresholds for peripheral motion discrimination are shown below in Figure 8. LV performance, across all groups, was extremely variable, averaging 194.3 msec (SD = 339.2) at 12° eccentricity, and 318.4 msec (SD = 409.4) at 25° eccentricity.

Again, note the large differences between the three training groups on these pre-training thresholds (bars in black and gray with values included).

Typically-sighted youth performed much better at these tasks, with substantially less variability between individuals. This group averaged 40.3 msec (SD = 25.6) at 12° eccentricity, and 30.8 msec (SD = 11.6) at 25° eccentricity.

Interestingly, these results show a clear difference in the two groups' patterns of performance for peripheral motion processing. Typical vision is characterized by enhanced temporal thresholds in the far periphery, while LV participants have declining performance in the far periphery. This pattern held for every individual. Even LV youth who performed at similar levels to the typically-sighted group show this pattern.

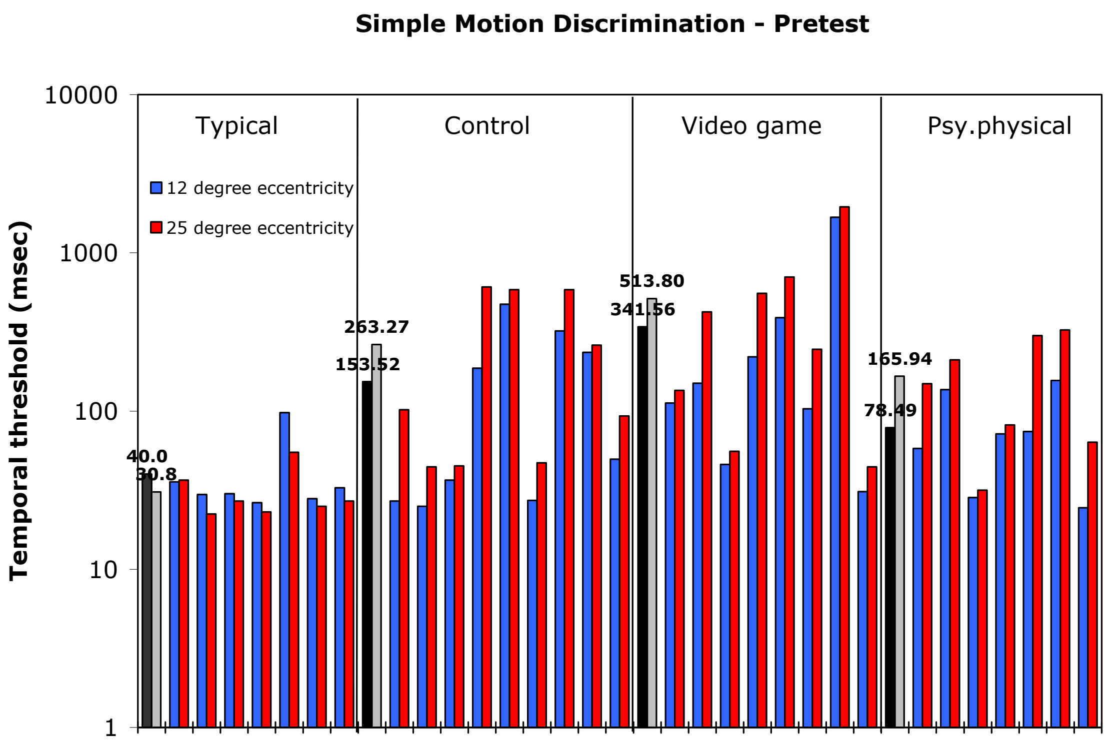

Figure 8: Average individual temporal thresholds at two eccentricities of simple peripheral motion discrimination. Participants are ordered within group by acuity from best to worst.

Similarly, discriminating multiple moving stimuli was harder and more variable for LV youth (Figure 9). LV thresholds averaged 216.4 msec (SD = 412.8) for 25°condition and 393.4 msec (SD = 523.5) for 50° condition. Typically-sighted youth averaged 30.0 msec (SD = 5.1) at a 25° stimuli spread and 34.0 msec (SD = 5.1) for a 50° stimuli spread. LV participants again had more difficulty in the far periphery condition compared to typically-sighted performance. Group averages for the three LV experimental conditions again show important pre-training differences.

Performance on this task appeared to elicit two confounding skills. Several individuals seemed to use a strategy of sequentially examining each of the three stimuli separately with central vision. All participants were asked to keep their eyes fixated centrally and examine the two peripherally located stimuli using their peripheral vision. This change in strategy altered the meaning of these participants' thresholds. Further analyses will attempt to separate out the influences from these individuals who appeared to perform the task incorrectly.

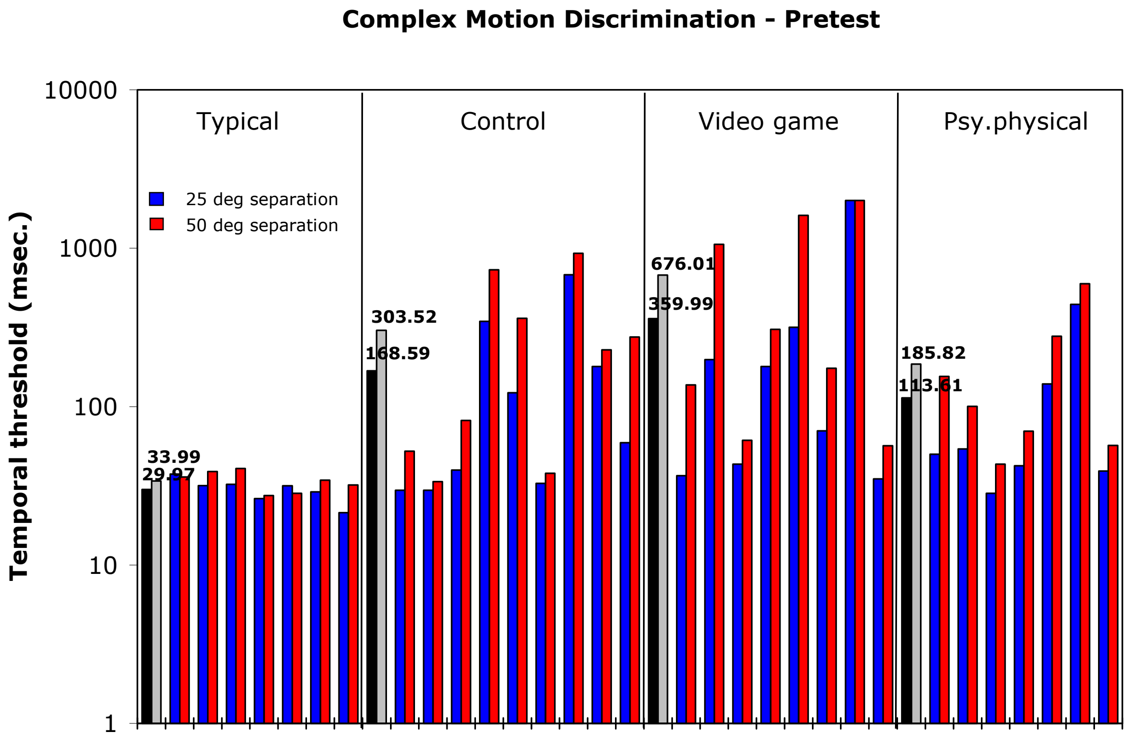

Figure 9: Average individual temporal thresholds at two eccentricities of complex peripheral motion discrimination. Participants are ordered within group by acuity from best to worst.

Crowding performance was more similar between LV and typically-sighted participants (Figure 10), although variability was still greater between low-vision individuals. This again resulted in differences between the three training groups. LV participants averaged 5.2 deg. (SD = 3.0) at 8° eccentricity, and 7.8 deg. (SD = 3.1) at 16° eccentricity, while the typically-sighted group averaged 3.5 deg. (SD = .45) at 8° eccentricity, and 7.1 deg. (SD = 1.5) at 16° eccentricity.

Notice that average performance was almost equivalent between the two groups in the far periphery. Because this task is a measure of peripheral spatial acuity, these results show a similar pattern to the study described earlier (Nyquist et al, 2005) which showed that LV youth have much less change from central to peripheral acuity compared to typically-sighted youth.

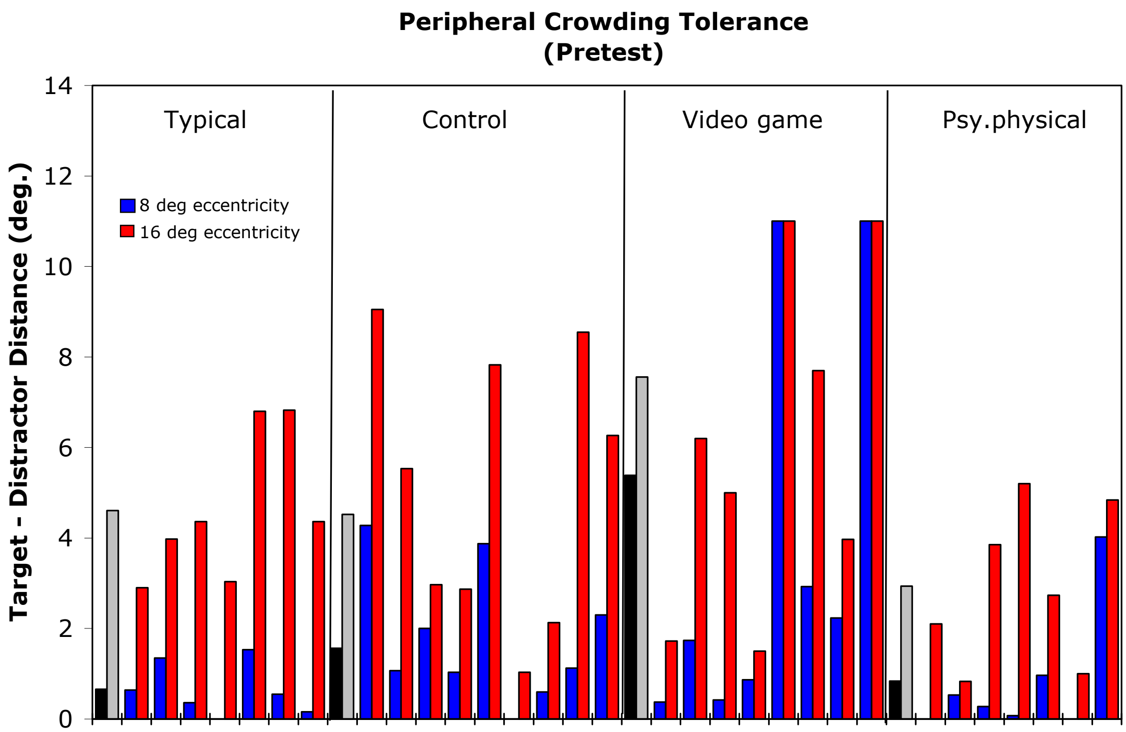

Figure 10: Average individual crowding thresholds at two eccentricities. Participants are ordered within group by acuity from best to worst.

Visual search performance was also highly variable between low-vision participants and quite consistent between typically-sighted youth (Figure 11). On average, typically sighted participants detected targets in 1.7 seconds (SD = .37), whereas LV participants took 10.1 seconds (SD = 11.3). Note that group averages for the three training conditions were again markedly different.

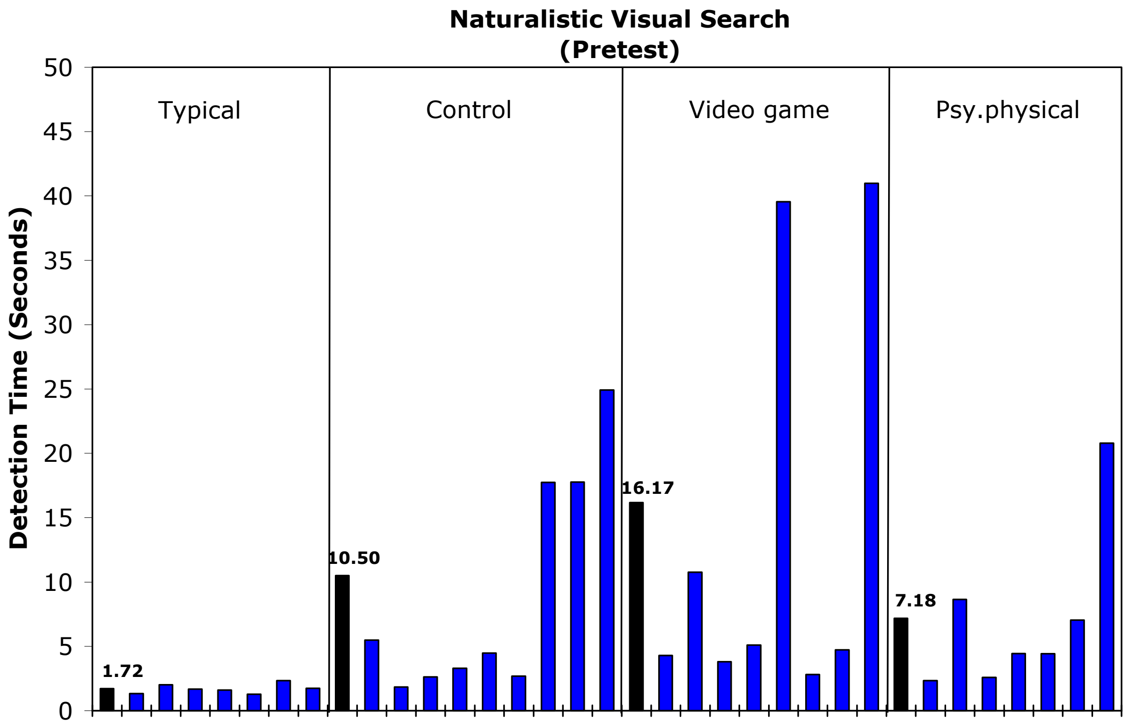

Figure 11: Average individual target detection time for visual search task. Participants are ordered within group by acuity from best to worst.

The preceding results have highlighted the considerable variability in visual thresholds for LV youth. Table 3 below provides a summary of these characteristics for each of the three training groups. Although individuals were randomly assigned to groups, thresholds and other characteristics differed between the three conditions before training. These initial group differences will be accounted for in the analyses of post-test group differences.

Table 3 Average pre-training vision thresholds and participant characteristics for each condition.

Pre-Training Measurements	Control Group (n=9)		Action Video Game (n=8)		Psy.physical Group (n=7)	
	M	(SD)	M	(SD)	M	(SD)
Snellen Acuity (20/X)	284	(75)	300	(38)	324	(91)
Age	13.1	(2.5)	15.3	(2.1)	15.6	(1.1)
Foveal Spatial Sensitivity (cycle/°)	2.7	(1.8)	2.8	(1.7)	3.5	(2.1)
Foveal Temporal Sensitivity (msec)	89.6	(96.0)	78.2	(88.0)	49.2	(34.2)
Simple Peripheral Motion Discrimination - 12° (msec)	153.5	(162.6)	341.6	(553.0)	78.5	(50.6)
Simple Peripheral Motion Discrimination - 25° (msec)	263.3	(255.6)	513.8	(627.7)	166.0	(116.6)
Complex Peripheral Motion Discrimination - 12° (msec)	168.6	(218.1)	360.0	(670.7)	113.6	(149.7)
Complex Peripheral Motion Discrimination - 25° (msec)	303.5	(324.3)	676.0	(776.3)	185.8	(198.2)
Peripheral Crowding - 8° (target/distractor distance)	4.8	(1.5)	6.8	(4.5)	3.8	(1.6)
Peripheral Crowding - 16° (target/distractor distance)	8.1	(3.0)	9.0	(3.7)	5.9	(1.9)
Visual Search (sec.)	9.0	(8.7)	14.0	(16.4)	7.2	(6.4)

Training

Improvement on training conditions was assessed with several measures (Table 4). Control video game progress was measured with the median score from session 1 subtracted from the median score during session 10, and then divided by the median score of session 1. All players showed improvements, with an average improvement of 376%. Improvement for the action video game was indexed by cumulative game statistics. Because this game progressed in difficulty and skill level as participants progressed through the game, three measures of summative game progress were used. "Total skill points" indicate level of mastery of various game skills, "completed challenges" is a measure of total game progress, and "tournament win/loss ratio" demonstrates progress, or lack of it. Improvement was clear for most players, although two individuals clearly progressed much slower than other participants. These two did, however, participate quite actively and seemed to be engaged and challenged throughout training.

Table 4: Individual training improvement for control, action, and psychophysical training (n=9, n=8, n=7, respectively).

	Control Video Game Condition		Action Video Game Condition				Psychophysical Training Condition	
	Median Change Session 1 to 10		Skill Points	Completed Challenges (87 total)	Tournament Win/Loss Ratio		TPI Median Change	Motion Threshold
1	323%	1	15	11	1 / 9	1	43%	-7%
2	433%	2	31	77	10 / 10	2	-1%	-9%
3	212%	3	28	54	11 / 37	3	8%	4%
4	407%	4	28	40	6 / 26	4	39%	-127%
5	481%	5	25	29	8 / 17	5	23%	-14%
6	387%	6	17	27	4 / 20	6	-10%	54%
7	503%	7	44	62	13 / 9	7	32%	6%
8	294%	8	14	11	1 / 5			
9	342%							

Improvement on the psychophysical task was measured with a derived measure labeled as tracking performance index (TPI). This measure factored together velocity of balls (QUEST staircase at 82% threshold), number of tracked targets, and number of distractors:

$$TPI = Velocity \times \# \text{ of } Stimuli_{Target} \times \# \text{ of } Stimuli_{Distractor}$$

Average temporal threshold of Gabor presentations (QUEST staircase at 82% threshold) was also measured. The median score from sessions 2 – 5 (Early $Sessions_{median}$) was compared to the median score for sessions 7 – 10 (Late $Sessions_{median}$). Improvement for TPI and Gabor thresholds was calculated as (Late $Sessions_{median}$ - Early $Sessions_{median}$) / (Early $Sessions_{median}$). Table 5 below includes individual values for both early and late performance. Average change was variable, with an average of 19% for TPI and -13% for temporal threshold. The psychophysical training task was controlled by two QUEST staircases which keep performance at approximately 82%. These staircases insured that performance was generally good even when these training measures indicate little or even negative change.

Table 5. Individual median performance for several indicators during early and late sessions on the psychophysical training task.

Participant	Median # of Targets	Median # of Distractors	Velocity of Balls (°/sec)	Avg. Gabor Threshold (msec)	TPI Median Change	Motion Threshold Change
1 Early	2	3	13.1	327.9		
1 Late	3	6	15.0	352.1	43%	-7%
2 Early	2	4	13.5	910.7		
2 Late	2	4	13.1	991.0	-1%	-9%
3 Early	4	6	7.5	87.6		
3 Late	4	6	13.5	84.3	8%	4%
4 Early	2	3	6.8	335.5		
4 Late	3	4	9	762.1	39%	-127%
5 Early	4	6	20.3	85.8		
5 Late	4	6	24	97.8	23%	-14%
6 Early	3	7	9.8	221.9		
6 Late	3	7	14.3	101.0	-10%	54%
7 Early	3	6	12	884.6		
7 Late	4	7	16.5	829.1	32%	6%

Effects of Training on Vision Thresholds

The effects of training are examined separately for each visual task. Because participants have substantial initial differences on pre-test measures, these differences are statistically controlled by using pre-test thresholds as covariates for each analysis. Other participant-level characteristics are also included in analyses when appropriate.

Foveal Tasks

Both foveal tasks were analyzed separately with a 3 X 2 ANCOVA using training (control, action, or psychophysical) and etiology (nystagmus vs. not nystagmus) as between-subjects factors and age, acuity, and pre training performance covariates. The post-training measure of temporal sensitivity was not different between groups $F(2, 23) =$

.417, p < .67; and post-training spatial sensitivity thresholds were not significant either F(2, 23) = .881, p < .44. Figure 12 below provides the post test thresholds by group, adjusted for pre-training thresholds, for both foveal tasks.

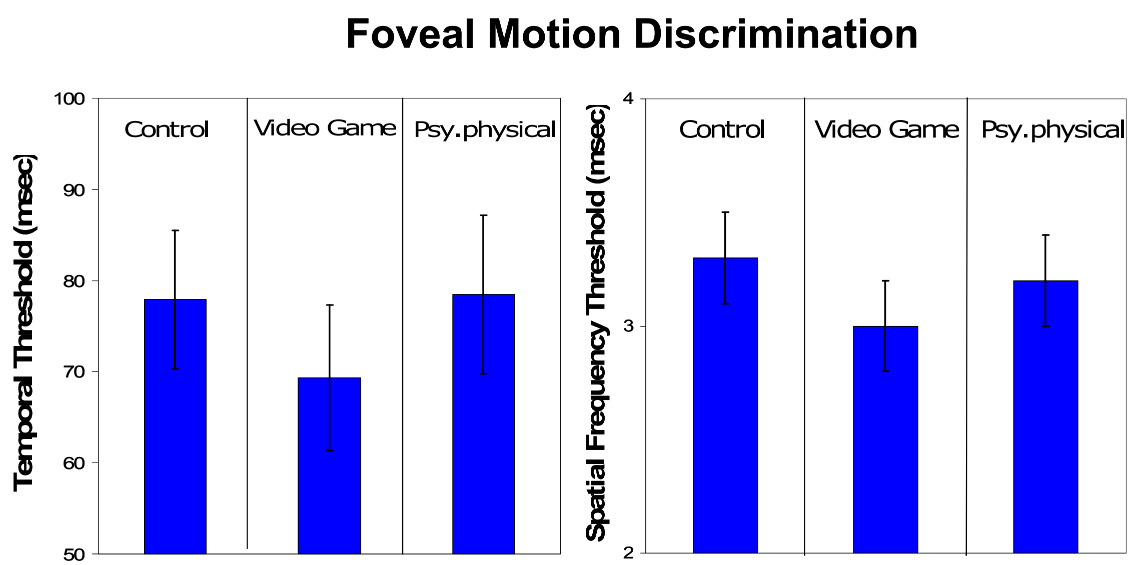

Figure 12. Adjusted post test thresholds for foveal motion discrimination tasks.

<u>Individual training effects on foveal tasks</u>

Individual pre- and post-training performance on these foveal tasks is shown below for video game and psychophysical training. The horizontal lines running through the graphs depict the average typically-sighted threshold along with confidence intervals. Notice that most LV thresholds were as good as or better than typically-sighted thresholds before training. Performance for this task may already be at optimal levels. It is not surprising to find that LV participants have reduced central acuity. Notice, however, that individuals in the psychophysical condition have a slight but consistent pattern of improvement after training. Five of seven individuals improved, which is not statistically significant using a sign-test, p > .46.

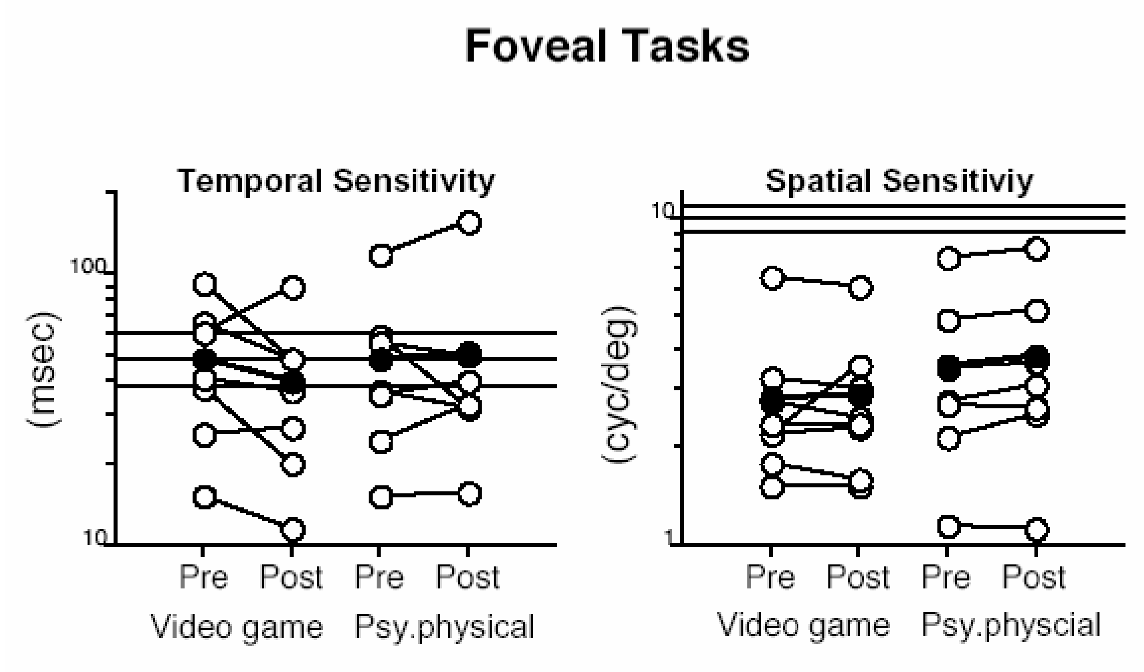

Figure 13. Individual pre-post thresholds for central acuity and central motion discrimination and typically-sighted baseline.

Peripheral Tasks

Simple peripheral motion discrimination

Of primary interest for this study is whether peripheral vision is enhanced after training LV youth. Thresholds for the simple motion discrimination task were tested for between group differences using a 3 X 2 X 2 MANCOVA. Training (control, action, or psychophysical) and etiology (nystagmus vs. no nystagmus) were included as between-subjects factors and eccentricity (12° vs. 25°) as a within-subjects factor. Pre-training group differences were again controlled by including age, acuity and both 12° and 25° pre-test thresholds as covariates.

There was a main effect of training, with estimated mean post test thresholds of 261.2 , 233.9, and 200.3 for control, action, and psychophysical conditions, respectively, $F(2, 14) = 4.14$, $p < .04$, (observed power = .63). Estimated post test means are based on mean pre test scores of 194.3 (12°) and 318.4 (25°) and average acuity of 20/301 and average age of 14.5. There was a significant interaction between training condition and eccentricity, $F(2, 19) = 9.34$, $p < .004$, (observed power = .94), with lower thresholds only in the far periphery for both video game and psychophysical training compared to control (Figure 14). Nystagmus was not a significant factor $F(1, 14) = .329$, $p < .58$, (observed power = .08).

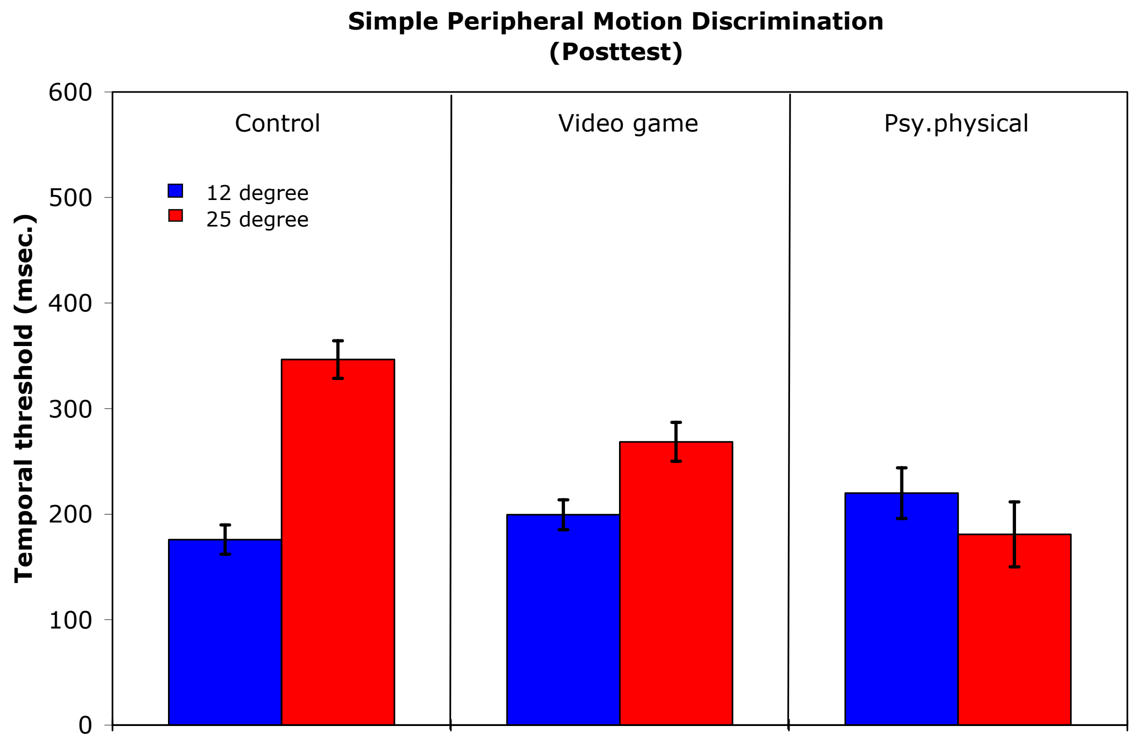

Figure 14. Estimated group mean post thresholds for simple motion discrimination, groups equated with pre-training thresholds as covariate.

Individual training effects on simple peripheral motion discrimination

The individual thresholds (pre and post) for the action and psychophysical conditions show that virtually all individuals have improved thresholds, with greater average improvement in the 25° task (Figure 15).

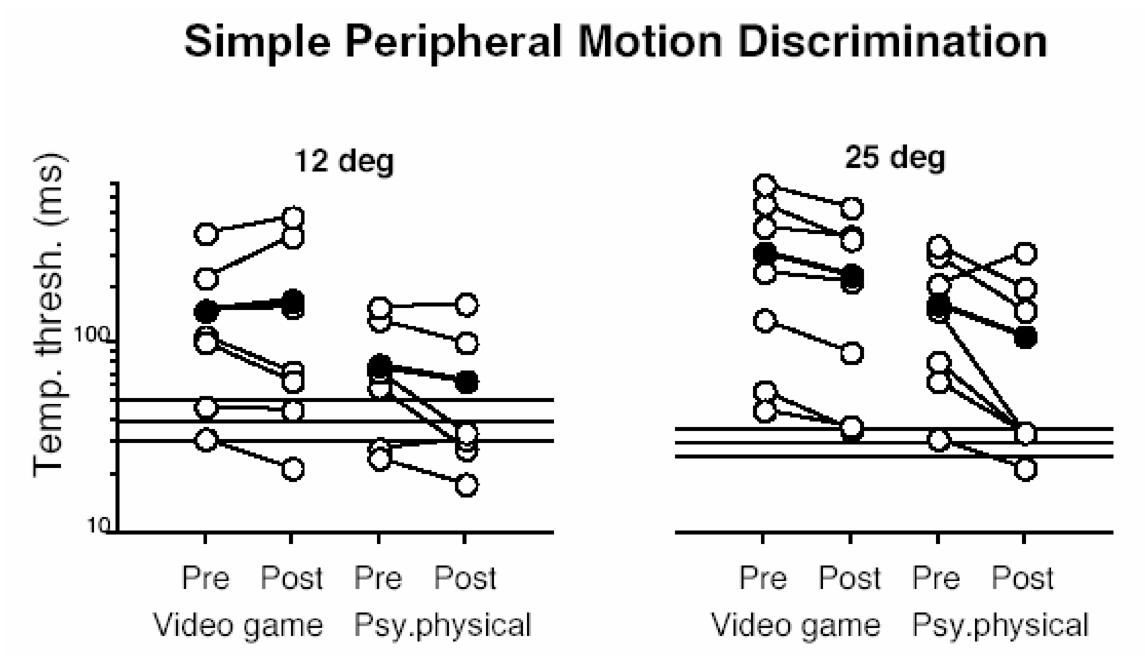

Figure 15. Individual pre-post thresholds for simple peripheral motion discrimination and typically-sighted baseline.

Complex peripheral motion discrimination

Training effects on peripheral motion discrimination were also tested using performance thresholds on the complex motion discrimination task. This was tested using a 3 X 2 X 2 MANCOVA, with training (control, action, or psychophysical) and etiology (nystagmus vs. no nystagmus) as between-subjects factors and eccentricity (12° vs. 25°) as a within-subjects factor. Age, acuity, and both 12° and 25° pre-test thresholds were used as covariates.

A marginal effect of training occurred, with estimated mean post test thresholds of 331.2 , 229.3, and 104.4 for control, action, and psychophysical conditions, respectively, $F(2, 14) = 3.69$, $p < .053$, (observed power = .58). Estimated post test means are based on mean pre test scores of 216.4 (12°) and 393.4 (25°) and average acuity of 20/301 and average age of 14.5. There was a significant interaction between training condition and eccentricity, $F (2, 14) = 4.27$, $p < .036$, (observed power = .65), with experimental training groups having greater differences in the far periphery compared to control (Figure 16). Nystagmus was not a significant factor $F (1, 14) = .013$, $p < .92$, (observed power = .05).

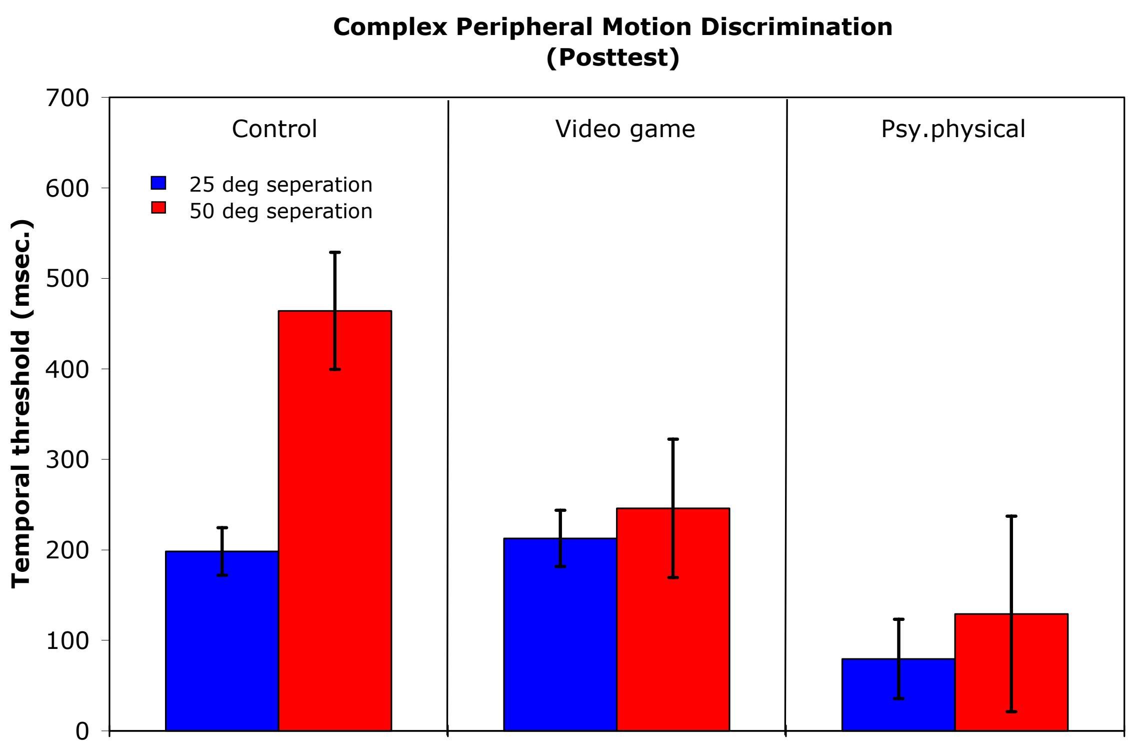

Figure 16. Estimated group mean post thresholds for complex motion discrimination, groups equated with pre-training thresholds as covariate.

The graph above helps to explain why the main effect was only marginally significant. Although there is substantial improvement for the psychophysical condition, the action video game condition shows a negligible change overall. The video game condition is introducing variability that hinders the detection of real differences between the control and psychophysical training conditions.

An even clearer picture emerges with pre-post scores at the individual level (Figure 17). Individuals in the video game training remained very similar from pre- to post-test. The average improvement for this group in the 25° condition seems to be solely due to one individual who displayed dramatic improvement. In contrast, virtually all participants in the psychophysical training demonstrate improvement.

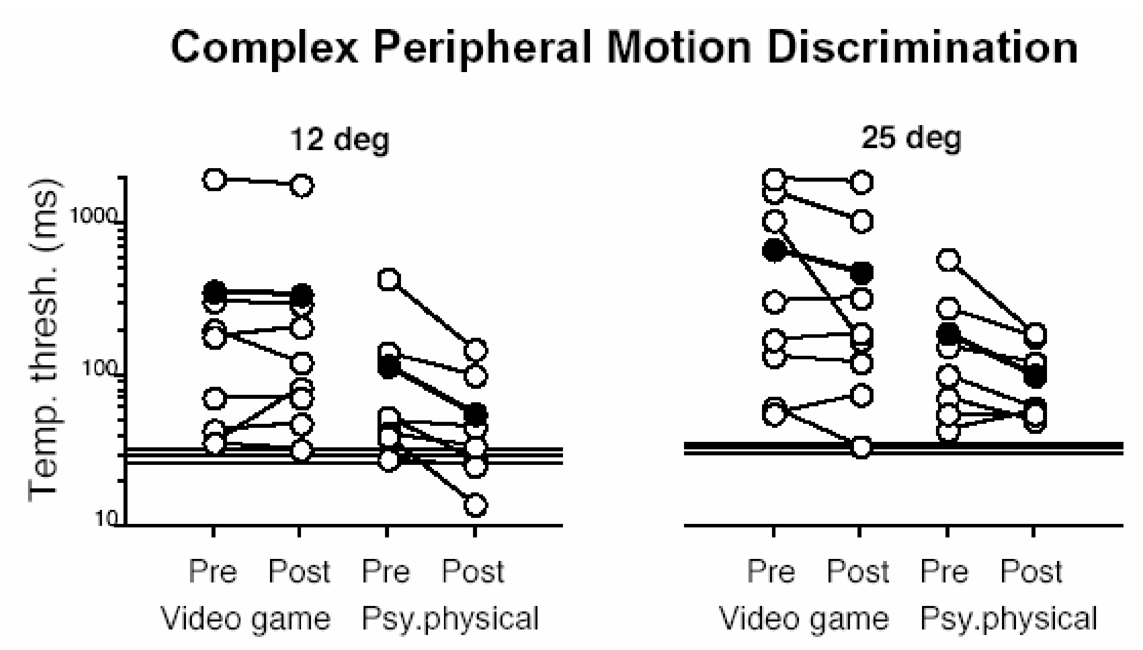

Figure 17. Individual pre-post thresholds for complex peripheral motion discrimination and typically-sighted baseline.

As mentioned earlier, this task elicited two distinct strategies from participants. Some used a strategy of moving their fixation to each stimulus location separately instead of the correct strategy of maintaining central fixation. A final test for training effects was performed with the data removed for participants who performed this task incorrectly. The criteria for removal included any threshold above 300 msec. This value ensures that the incorrect strategy could not be performed since this is not enough time for such a strategy. One participant from each condition was excluded due to elevated thresholds. This test entirely excluded the 50 degree separation task because many thresholds were above this threshold. An ANCOVA was performed with the 25 degree post test thresholds, using pre-test thresholds as covariates. An effect of condition was not found, but a similar pattern existed as shown in Figure 16.

Crowding

Peripheral acuity was tested with a 3 X 2 X 2 MANCOVA with training (control, action, or psychophysical) and etiology (nystagmus vs. not nystagmus) as between-subjects factors and eccentricity (8° and 16°) as a within-subjects factor. Age, acuity and pre-training thresholds (8° and 16°) were all included as covariates.

There was an effect of training, with estimated mean post test thresholds of 3.99, 2.57, and 2.29 degrees for control, action, and psychophysical conditions, respectively, $F(2, 14) = 5.76$, $p < .016$, (observed power = .78). Estimated post test means are based on mean pre test scores of 2.2 (8°) and 4.0 (25°) and average acuity of 20/301 and average age of 14.5. The graph (Figure 18) indicates that both video game and psychophysical training performed significantly better than the control group for both 8°

and 16° conditions. There was a marginally significant interaction between training condition and eccentricity, $F(2, 14) = 3.29$, $p < .068$, (observed power = .53), with a greater improvement in thresholds in the far periphery compared to near periphery for both video game and psychophysical training compared to control. Nystagmus was again non-significant $F(1, 14) = .39$ $p < .55$, (observed power = .09).

Several participants performed at ceiling or floor levels on this task during pre-test, and remained at this level at post test, demonstrating no change on this measure. The same analysis was re-run omitting these four individuals. Two were removed from the psychophysical condition and one each was removed from the control and video game conditions. The effect of condition was marginally-significant, $F(2, 10) = 3.87$, $p < .058$, (observed power = .56). No other interactions or effects were reliable. This test is limited, however, due to the very small number of participants.

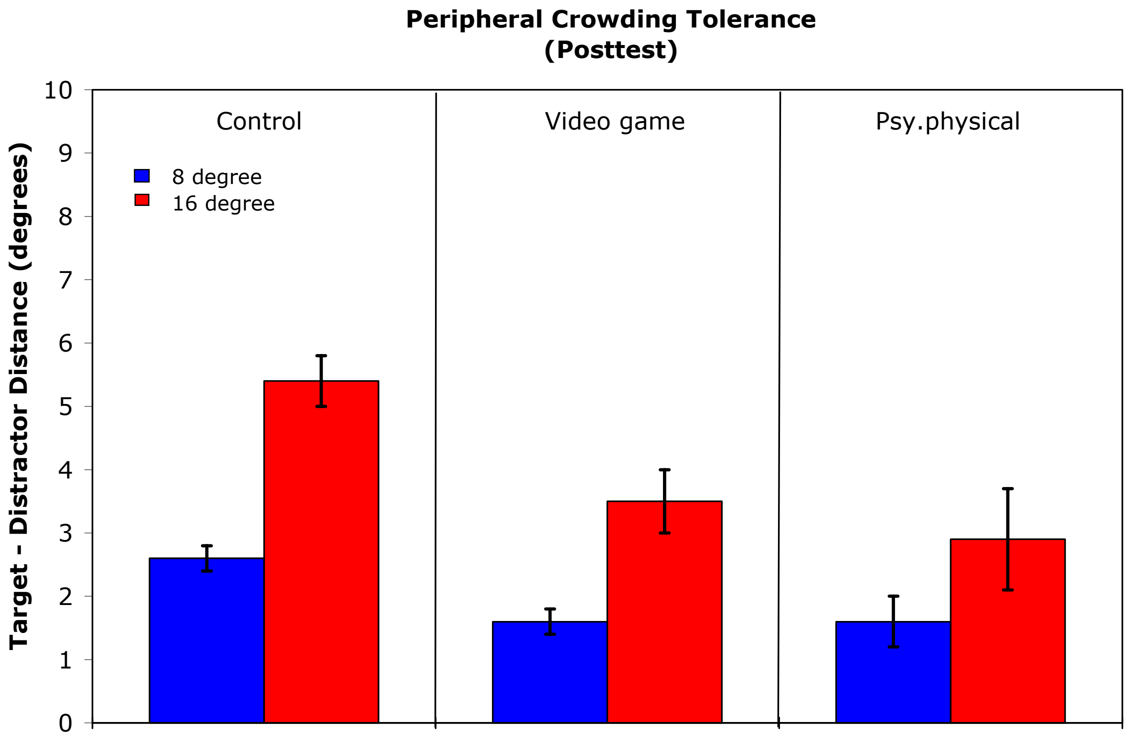

Figure 18. Estimated group mean post thresholds for crowding, groups equated with pre-training thresholds as covariate.

Figure 19 below shows that on average LV individuals are performing very similar to their typically-sighted counterparts. This is not completely surprising, given that our previous findings (Nyquist et al., 2005) showed remarkably good peripheral acuity for LV youth.

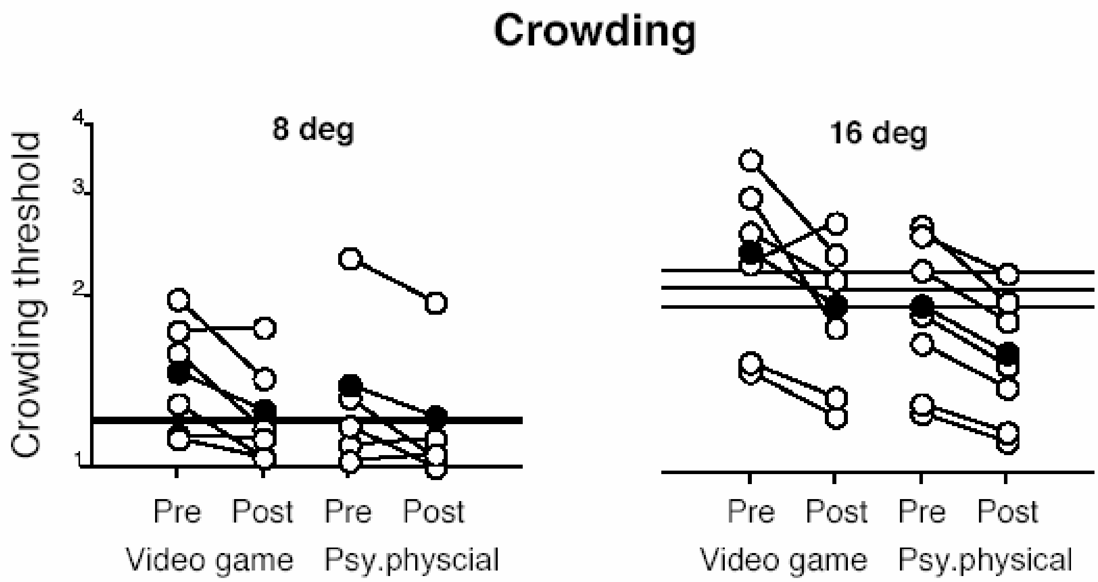

Figure 19. Individual pre-post thresholds for crowding task and typically-sighted baseline.

Visual Search

Visual search performance was analyzed with a 3 X 2 ANCOVA, including training (control, action, or psychophysical) and etiology (nystagmus vs. not nystagmus) as between-subjects factors and age, acuity and pre test performance as covariates. There was an effect of training, with estimated mean post test thresholds of 8.6, 5.5, and 4.0 seconds for control, action, and psychophysical conditions, respectively, $F(2, 14) = 4.49$, $p < .031$, (observed power = .67). Estimated post test means are based on mean pre test scores of 10.1 seconds, average acuity of 20/301 and average age of 14.5. The graph (Figure 20) indicates that both video game and psychophysical training performed significantly better than the control group on post-test. Nystagmus was again non-significant $F(1, 14) = .63$ $p < .45$, (observed power = .12).

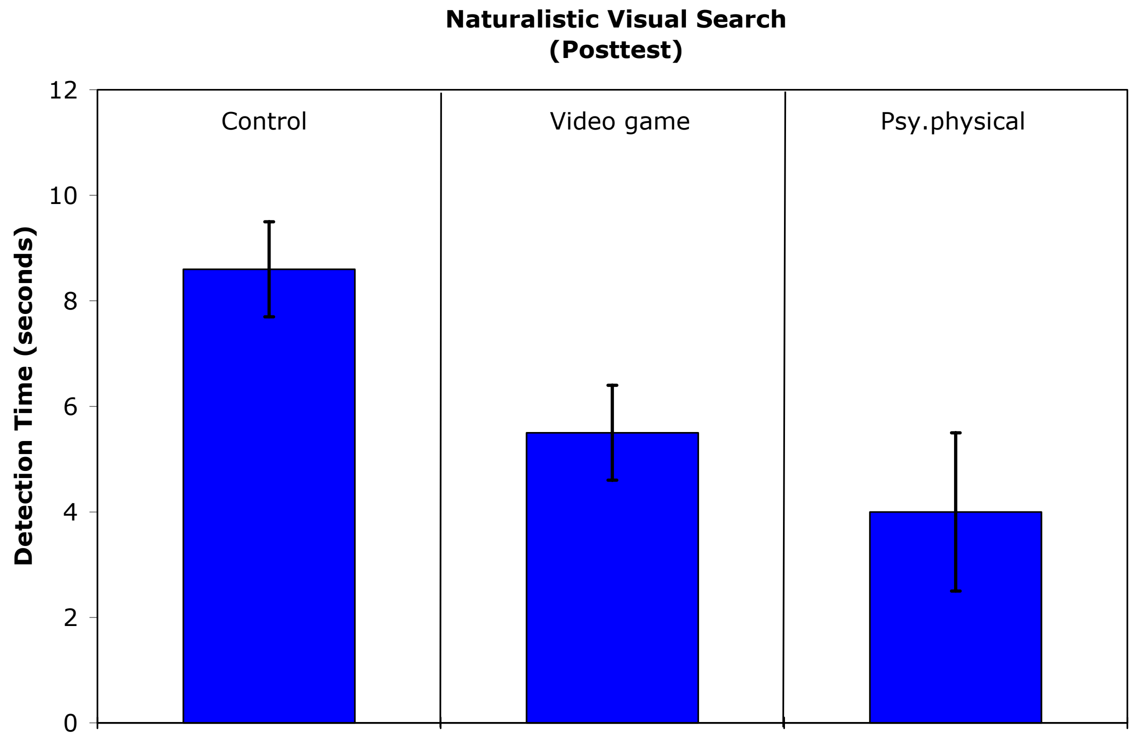

Figure 20. Estimated group mean post thresholds for visual search task, groups equated with pre-training thresholds as covariate.

The graph (Figure 21) below indicates that every subject in video game training and psychophysical training improved after training. Several participants even matched or exceeded typically-sighted performance on this task.

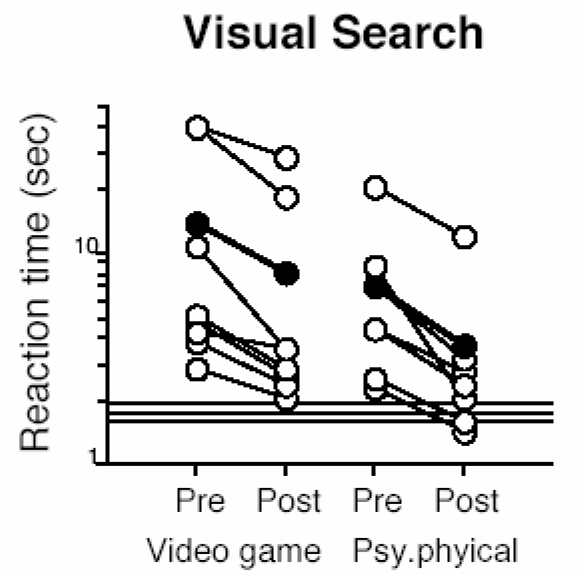

Figure 21. Individual pre-post thresholds for a visual search task and typically-sighted baseline.

Overall Size of Training Effects

It is impressive to consider the effect sizes caused by training (Figure 22). Across all non-central visual tasks, seven in all, there were only two negative group effect sizes for the two training groups, with both of these being very small. To give more meaning to this, an effect size of 0.5 is considered medium and an effect size of 0.8 is considered large (Cohen, 1988). The graph shows a clear pattern of larger improvements for the psychophysical task, with non-foveal effect sizes ranging from 0.27 to 0.69. Also, this graph again shows the pattern of larger improvements for tasks involving the far periphery.

Appendix D provides the correlations of these effects sizes between each task, broken out by training group.

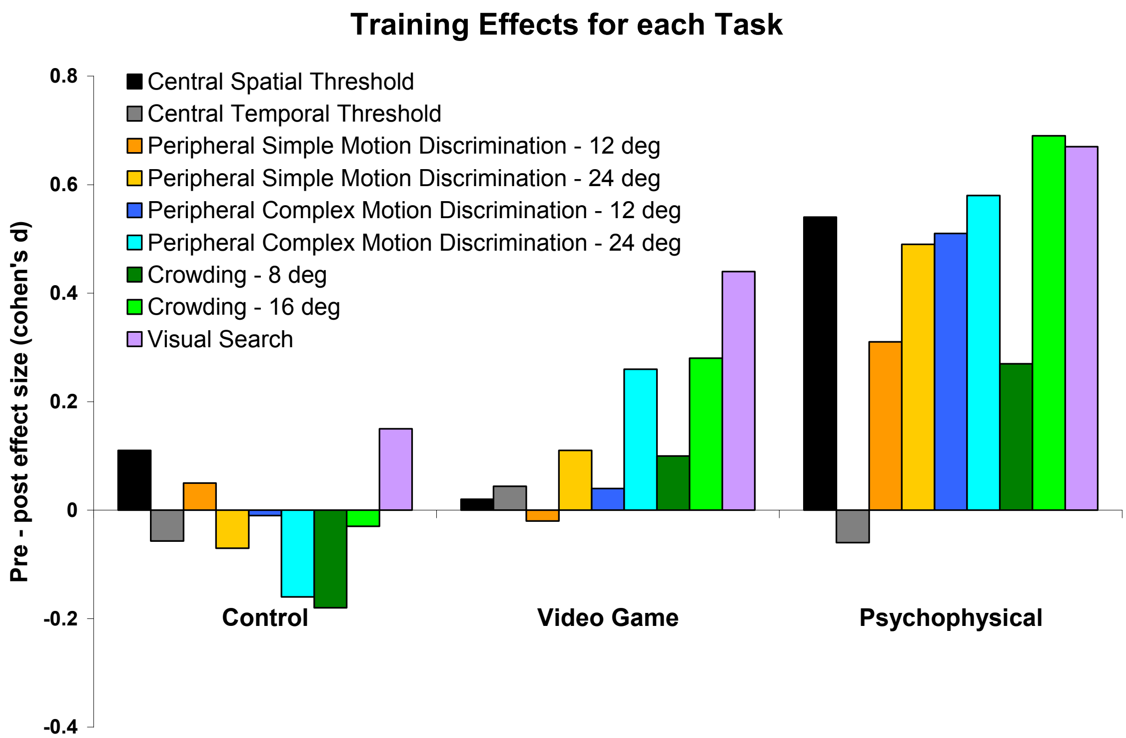

Figure 22. Average pre-post effect sizes for each visual task broken out by training condition. Similar tasks depicted by shades of the same color.

CHAPTER IV

DISCUSSION AND CONCLUSIONS

The preceding analyses clearly show visual skills can be enhanced for LV youth. Three of the four measures of peripheral visual functioning were improved after action video games and psychophysical training. These improvements are substantial, with most effect sizes ranging from medium to large (Cohen, 1988). These three measures are thought to involve the alerting and orienting functions of attention while the fourth (complex peripheral motion discrimination) is thought to require more executive function of attention. Although the omnibus test for this measure was only marginally significant, a clear difference does exist between the control group and psychophysical training group.

It may also be the case that the far periphery is subject to even more substantial training effects. Results show a consistent trend of larger improvements for tasks involving the far peripheral fields. Virtually every measure demonstrated this trend for both training conditions.

Such improvements will likely have effects on everyday functioning for LV individuals. Research illustrates that everyday activities require access to environmental information over a wide field of view, in both central and peripheral regions. LV youth seem to have underutilized peripheral skills, which likely play a part in the difficulties they encounter with everyday tasks such as mobility. Their improved peripheral functioning should positively impact their quality of life.

Past research using LV populations often cannot relate LV performance to typically-sighted performance. The current study reveals a large range of abilities for LV youth, with some LV performances at virtually an identical level to their typically-sighted counterparts on some tasks, while others are substantially below typical performance. Despite this variability, nearly all LV participants show a clear attenuation on motion perception tasks in the far periphery, whereas typical sight is characterized by heightened peripheral motion perception. This result, along with larger training effects in the far periphery, points to an underutilization of the peripheral fields for LV youth.

This study also extends the impact of video game training, and perceptual training in general, by demonstrating a transfer of training effects to a naturalistic visual search task. This is thought to provide a measure of a more typical visual function used in everyday life. Participants had exposure to the same pictures during pre and post testing, which introduces top-down influences such as visual memory. Despite this weakness, the training effects reported here are based on between-group comparisons. All groups were randomly assigned and received the same double exposure to these materials. The average post test scores for both training groups was significantly better in relation to the control post test. These differences can be attributed to the training interventions. This study demonstrates that exposure to a low-level psychophysical training program can transfer to a higher-level visual task.

The specific mechanisms responsible for improved visual search are still unclear. Future studies on the effects on visual search would benefit from using eye-tracking during the search process. For example, if the distance of a saccade-to-target is significantly larger after training, this would be strong evidence for an improvement in the size of visual field that is attended to. This requires a minor adjustment to the task, where new scenes are used at post-test. Improved distractor rejection may also be uncovered by eye-tracking if the time spent on distractors decreases after training.

This study takes a first step beyond the video game training studies to uncover the basic qualities that may be necessary for enhancing visual attention and visual functioning. The psychophysical training task employed a simple set of task demands and stimulus characteristics. This task had very few of the extraneous factors that are found in the video games used for training. Task demands include tracking multiple dynamic objects, which requires quickly switching and perhaps dividing attention, and making simple discriminations to peripheral Gabors, which requires vigilance to peripheral locations. The individual and relative contribution that each of these has on training effects is still unknown. Additional examination could help further uncover the essential qualities responsible for enhancing visual functioning.

Next Steps

Fleshing out training effects

One purpose of the current study was to demonstrate that training effects can occur across a range of visual functions. Future studies should include a number of other measures. This is a two-fold endeavor, including both everyday tasks and more basic visual functions such as the continued fleshing out of visual attention.

Several candidate measures that may respond to training include reading comprehension, memory storage and retrieval, and executive control, since efficient attentional orienting has been suggested as a prerequisite for all these functions (e.g.

Fischler, 1998; Pashler, 1998; Posner & DiGirolamo, 1998). Reading in particular has clear practical implications for quality of life, especially for students with low vision. One review of studies showed that the primary presenting complaint at low vision clinics is problems with reading (Leat, Legge and Bullimore, 1999). A large body of research on reading processes and reading comprehension exists for LV populations. This research shows that there are two components to reading difficulty in low vision: the reduced range of print sizes that are legible, and the speed of reading (Legge, 2007). According to Gordon Legge (2007), a renowned authority on normal and low vision reading, speed of reading is approximately equal to the mean saccade length divided by the average fixation time. It appears that low-vision readers primarily differ from normal readers by having abnormally short saccades (Bullimore & Bailey, 1995; Rumney & Leat, 1994; Trauzettel, Klosinski, Teschner, Tornow & Zrenner, 1994). Research indicates that these shorter saccades are due to a reduction in the visual span (Legge, et. al., 1997; 2001), which is the number of letters that can be recognized in one fixation. The improvements found in the current study would suggest potential improvements in the visual span of these participants, which could translate into faster reading speeds.

It is still unclear how training impacts other practical tasks. Independent and effective mobility, for example, is a primary goal of the LV community. Interestingly, there is some evidence that difficulties in reading and mobility are due to two distinct visual functions. Stelmack and colleagues (2007) have analyzed self-report visual function questionnaires and found two independent factors of visual function, where reading ability loads most heavily onto one factor and mobility ability loads heavily onto the other. An important next step will be to investigate training effects on mobility, using a sensitive measure of this critical function.

Future studies should also strive to further flesh out how training affects the various attentional mechanisms, including alerting, orienting and executive control functions. Although the current study points to improvements in each of these attentional networks, future studies should incorporate more direct measures of these three attentional functions. One such measure, called the Attentional Network Test (ANT), has versions for adults (Fan, McCandliss, Sommer, Raz, & Posner, 2002) and school aged children (Rueda et al., 2004). Other measures for future studies could include eye-tracking during video game training. Using such equipment to measure how players are moving their eyes around during this task could be informative. For example, knowing where their eyes are just prior to localizing a target or shooting at a target could provide valuable information about the use of peripheral vision.

Finally, similar training studies with a LV population should include a blocked assignment design that uses additional individual factors including age, etiology, and acuity.

Essential training characteristics

A second purpose of the current study was to better define the training characteristics responsible for improvements in visual functioning. The current study demonstrates that a more basic psychophysical task can improve vision functions as much or better than an action video game. Compared to action video games, this task has a considerably smaller set of task characteristics and stimulus attributes. This result then reduces the necessary characteristics needed to train and enhance various visual functions.

There are still many more questions to explore regarding the characteristics of training programs and how they relate to visual improvements. For example, does a shorter or longer period of training change the levels of training effects? One way to examine this, besides simply varying the duration or number of training sessions, is to compare the amount of improvement on the training task with the amount of improvement on the outcome measures. The psychophysical training program used in the current study was not designed to measure improvement in a clear way because several parameters were adjustable in order to provide a strong training program. Therefore, a score on one parameter is not meaningful without the scores on other parameters, and there is no clear way to compare or combine these measures. This limitation was intentional because the current study was designed to implement the most robust training program we could design in order to find training effects with a non-video game training task.

Another open question is whether an even more robust training program can be developed. There is reason to think that training programs can still be even more powerful instruments of change than currently available.

Who can benefit and how much

It is not clear at this point which types of visual impairments may best respond to visual attentional training. The current group consisted primarily of persons with Nystagmus, ROP, and Stargardt's Disease. This sample was used because these types of impairments tend to have relatively good acuity and intact visual fields. It is unknown, however, if groups with more serious visual impairments may benefit from training. For example, persons with cortical visual impairments (CVI) may respond well to simpler versions of the psychophysical training program. The parameters of the psychophysical task are well-suited to adjust to the visual qualities that work well for individuals with CVI. For example, CVI often responds well to visual information with simple, constant and predictable visual characteristics, with repetition of the same objects and same tasks. The color system is often intact in CVI as well, so bright fluorescent colors such as red, yellow, pink, and orange are responded to well. These characteristics can easily be incorporated into a psychophysical program.

In conclusion, the results of this project provide a new direction for helping improve the lives of LV individuals. This work also opens up the possibility for a number of future studies that might examine additional ways that training might help the LV community as well as provide a more basic insight into visual functioning.

Vision is the dominant sense and arguably our most important single tool for interacting with the world and gathering information from our current surroundings. Efficient visual functioning enables us to understand the world around us better and to guide our actions accurately and quickly. We should strive to provide the best possible version of this gift to every person.

A. – QUESTIONNAIRE OF VISUALLY DEMANDING ACTIVITIES

GUIDED QUESTIONNAIRE

General Information

Name: ________________ Eye condition / diagnosis:

Subject # _____ Age: ______ Gender: ________

Independent Mobility

1. “Are you a driver?” *(If of legal age)*

   Yes ___ No

2. “What type of optical devices, if any, do you use?”

   Near: ____ Far: _________

Near	Far
None	None
A few times a year	A few times a year
A few times a month	A few times a month
Every week	Every week
Every day	Every day

3. “Do ever go anywhere by yourself?”

   (If yes) “Where?” ____

   “How frequently?”

   None
   A few times a year
   A few times a month
   Every week
   Every day

   “Do you take public transportation by yourself?

   (If yes) “What kind?” ________________________________

   “How frequently?

   None
   A few times a year

A few times a month
Every week
Every day

"Do you cross streets on your own?"

(If yes) "What kind?" ___

"How frequently?

None
A few times a year
A few times a month
Every week
Every day

Experience with Video Games

4. "Do you, or have you ever played any video games (for example games using a playstation, xbox, or game cube)." (*If yes*) "Which ones?"

_________________________________ _____________________

____

5. (*If answer is yes to previous question*) "Do you, or have you ever, played games that control a character? (If participant does not understand, give a few examples: snow boarding games, shooting games, Mario sunshine, etc)." (*If yes*) "Which ones?"

____

6. "Now I am wondering about a certain type of game called a first-person shooter. These are games that have a certain look to them. The game world moves much like the real world because the character has his or her back to you on the screen and you control and move them thru this world much as you would move yourself if you were in the game. Do you, or have you ever played any games like this" (*If yes*) "Which ones?"

____

Frequency of Video Game Play

7. "In the last few months, how often have you played video games?"

None
Once
A few times month

Every week
Every day

8. "In the last few months, how often have you played driving video games?"

None
Once
A few times a month
Every week
Every day

9. "In the last few months, how often have you played first-person shooter video games?"

None
Once
A few times a month
Every week
Every day

10. "In the last few years, how often have you played video games?"

None
A few times a year
A few times a month
Every week
Every day

11. "In the last few years, how often have you played driving video games?"

None
A few times a year
A few times a month
Every week
Every day

12. "In the last few years, how often have you played first-person shooter video games?"

None
A few times a year
A few times a month
Every week
Every day

Sports and Outdoor Activities

13. "Please tell me any sports / activities you have played, and amount during the last few months (examples: playing catch, frisbee, tennis, ping-pong, running, biking)"

Activity #1 ______________________

None
Once
A few times a month
Every week
Every day

Activity #2 ______ __________________

None
Once
A few times a month
Every week
Every day

Activity #3 ________ ________________

None
Once
A few times
Every week
Every day

14. "Please list any outdoor activities not already mentioned that you have done in the last few months (examples: four-wheeling, hunting, etc.)"

Activity #1 ________________________

None
Once
A few times
Every week
Every day

Activity #2 ________________________

None
Once
A few times

Every week
Every day

Activity #3 _________________________

None
Once
A few times a month
Every week
Every day

15. "List any sports / activities you have played, and amount during the last few years (examples: playing catch, frisbee, tennis, ping-pong, running, biking)"

Activity #1 ____________ ____________

None
A few times a year
A few times a month
Every week
Every day

Activity #2 _____________ __________

None
A few times a year
A few times a month
Every week
Every day

Activity #3 _____________ ___________

None
A few times a year
A few times a month
Every week
Every day

16. "Please list any outdoor activities not already mentioned that you have done in the last few years (examples: four-wheeling, hunting, etc.)"

Activity #1 _________________________

None
A few times a year

A few times a month
Every week
Every day

Activity #2 ________________________

None
A few times a year
A few times a month
Every week
Every day

Activity #3 _________________________

None
A few times a year
A few times a month
Every week
Every day

Questions for school faculty and staff

List the student's eye condition / diagnosis?

____

____

List any known learning disabilities:

____

List any known measures of spatial abilities:

____

Mobility: have they participated in the TAPS program?

Yes ___ No _

B. – PROCESS FOR ASSIGNING TO EXPERIENCE LEVEL

ASSIGNMENT TO HIGH EXPERIENCE

1. Playing first-person shooter video games (FPS) everyday

2. OR, Playing FPS every week along with weekly frequency (or more) of highly visually demanding activities

3. OR, Highly visually demanding activities everyday

ASSIGNMENT TO MEDIUM EXPERIENCE

1. Playing FPS once a week along with less than weekly frequency of highly visually demanding activities

ASSIGNMENT TO LOW EXPERIENCE

1. All other participants who did not meet criteria for high or medium groups.

List of highly visually demanding activities

Playing catch or other ball-based sports
Riding bike or dirt bike
Running

Appendix C – EXAMPLES OF VISUAL SEARCH PHOTOGRAPHS

Appendix D – CORRELATIONS BETWEEN IMPROVEMENTS ON VISION TASKS

Correlation between effect sizes for control group (cohen's d for pre and post measures).
* significant at .05
** significant at .01

Control Condition

Tasks	Simple Motion 12°	Simple Motion 25°	Complex Motion 12°	Complex Motion 25°	Crowding 8°	Crowding 16°	Search
Simple Motion 0°	0.63**	0.13	0.27	0.45	0.08	0.22	-0.03
Simple Motion 12°		-0.20	-0.30	0.42	-0.03	0.20	-0.12
Simple Motion 25°			0.17	0.17	0.10	0.32	0.17
Complex Motion 12°				0.35	0.38	0.33	-0.20
Complex Motion 25°					0.72**	0.92**	-0.50*
Crowding 8°						0.57*	-0.18
Crowding 16°							-0.58*
Search							

Correlation between effect sizes for video game group (cohen's d for pre and post measures).
* significant at .05
** significant at .01

Video Game Condition

Tasks	Simple Motion 12°	Simple Motion 25°	Complex Motion 12°	Complex Motion 25°	Crowding 8°	Crowding 16°	Search
Simple Motion 0°	0.40	-0.40	0.69**	-0.02*	-0.22*	-0.48	-0.57*
Simple Motion 12°		0.19	-0.17	-0.62	0.27	-0.21*	-0.67
Simple Motion 25°			-0.71*	-0.57	0.47	0.14	-0.26*
Complex Motion 12°				0.43	-0.46*	-0.24	-0.05**
Complex Motion 25°					-0.82	-0.41	0.48
Crowding 8°						0.76*	0.05
Crowding 16°							0.55
Search							

Correlation between effect sizes for psychophysical group (cohen's d for pre and post measures).
* significant at .05
** significant at .01

Psychophysical Condition

Tasks	Simple Motion 12°	Simple Motion 25°	Complex Motion 12°	Complex Motion 25°	Crowding 8°	Crowding 16°	Search
Simple Motion 0°	0.36	0.04	-0.71**	-0.54*	-0.56*	0.43	0.57*
Simple Motion 12°		0.04	0.00	-0.04	-0.15	0.61	0.07
Simple Motion 25°			-0.54*	0.39	0.01	-0.04	0.61*
Complex Motion 12°				-0.04	0.54*	-0.29	-0.86**
Complex Motion 25°					0.29	-0.11	0.21
Crowding 8°						-0.62*	-0.24
Crowding 16°							-0.07
Search							

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