THE EFFECTS OF RANDOM LINEAR TARGET DIRECTION IN A COMPUTERIZED DYNAMIC VISUAL ACUITY TASK

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(ABSTRACT)

Research on Dynamic Visual Acuity (DVA) to date has conventionally used visual targets originating from a single fixation point and moving in a single, predictable linear direction. These procedures (presumably dictated by apparatus constraints) ensured the observer knew when and from where the target would appear. A computerized test for DVA was developed and used to test DVA under viewing conditions not testable with conventional apparatuses. Two target direction conditions were compared over 3 durations (170, 370, 570 ms) and 5 velocities (0, 22, 45, 70, and 100 deg/s): fixed target direction (target originated from single fixation point, and moved horizontally from the observer's left to the observer's right, as has been the convention in DVA research over the past 57 years) and random target direction (the target emanated randomly from one of six screen locations and move linearly across the screen to a point 180 deg opposite its origin). As hypothesized, the random direction condition, which may more closely represent DVA as applied in the real world, proved to be significantly more difficult relative to the fixed direction condition. Contrary to expectations of the current research as well as the general consensus in the DVA literature, data were also presented indicating that the generally accepted relationship between increased target velocity and increased DVA thresholds, may be in part the consequence of conventional apparatuses and procedures. The effect training was also investigated on under both fixed and random target direction conditions. No significant effect of training was demonstrated over four sessions, which may be a result inadequate sensitivity of the test. Strengths and weaknesses of a computer testing platform to test DVA are discussed.

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TABLE OF CONTENTS

List of Tables

List of Figures

List of Figures (continued)

Dynamic Visual Acuity (DVA) refers to an observer's ability to resolve a critical detail in a visual target when there is relative motion between the observer and the target (one or both is in motion). This term was initially applied by Ludvigh and Miller (1958).

Target movement aids in target detection (determining the presence or absence of the target), however target movement generally impairs acuity (the ability to correctly resolve a critical detail of that target). Prestrude (1987) traced the history of the study of the effects of movement to object detectability to 1937. In the same article, Prestrude also abstracted three reviews of DVA literature: (Hoffman, Rouse & Ryan, 1981; Miller & Ludvigh, 1962; Morrison, 1980). These three reviews evaluate a total of 115 papers on DVA (Prestrude, 1987).

The introduction and literature review of this thesis is organized into four sections:

Section 1: Review of Factors Affecting DVA

Section 2: Review of Proposed DVA Mechanisms

Section 3: Review of Conventional DVA Methods

Section 4: Considerations, Objectives, and Hypotheses

Section 1: Factors Affecting DVA

Static Visual Acuity (SVA)

Good SVA may be viewed as a necessary but not sufficient prerequisite for good DVA. As noted by Burg and Hulbert (1961), a blind person will do poorly on tests of SVA as well as on tests of DVA.

It is generally accepted that DVA is poorer than SVA (Schiffman, 1990). Consequently, observers require larger targets for resolution under conditions of relative motion In reality, we are frequently called upon to resolve visual targets in motion. Daily activities such as walking, running, driving, participating in athletics, and operating equipment involve visual tasks under conditions of relative motion.

Proponents of DVA contend that measures of SVA do not completely assess the application of vision to real world tasks. Measures of SVA are designed to optimally measure refractive error of the visual system (Prestrude, 1987), and to optimize performance (National Research Council [NRC], 1982). Such conventional SVA measures typically use "easy" (static, high contrast) targets. Using measures of SVA, the smallest target a person with normal vision can resolve is one that subtends only one minute of arc upon the retina (Schiffman, 1990).

Individuals possessing identical SVA as measured by standard visual screening procedures like the Snellen Eye Charts or Static Landolt C's can vary considerably when performing a DVA task (see e.g. Burg & Hulbert, 1961; Long & Riggs, 1991; Long & Roarke, 1989; Miller & Ludvigh, 1962; Morrison, 1980). Certain individuals can sustain higher target velocities before their SVA levels deteriorate under dynamic conditions.

The NRC (1982) cited research indicating that DVA correlates more highly with performance measures than SVA tests which currently are used as vision screening measures. Declerk (1964, in NRC, 1982) demonstrated that DVA correlated more highly than did SVA for several in-flight aviation performance measures. Burg (1967, in NRC, 1982) showed that DVA showed the strongest relationship (from among a battery of seven vision tests) to automobile driving records. Henderson and Burg (1973, in NRC, 1982) similarly showed an inverse relationship between DVA and the accident records of bus and truck drivers.

Target Velocity

It is generally accepted that increases in target velocity degrade DVA. (Morrison, 1980; Prestrude 1987). Long and Garvey (1988) described this relationship as a positively accelerating function with little adverse impact at velocities up to 30 - 40 deg/s, followed by a marked deterioration as velocities increase. Other researchers vary in opinion concerning the velocities at which this marked deterioration impacts DVA. Brown (1972a) suggested 25 -30 deg/s; Prestrude (1987) suggested 50 deg/s. These differences in opinion may reflect differences in experimental conditions and methods.

Ludvigh and Miller (cited in Long & Roarke, 1989), illustrated a routine example in which target velocities exceed levels known to degrade DVA: An automobile traveling at 30 mph past an observer at a viewing distance of 30 ft corresponds to a target velocity of 84 deg/s for that observer.

Ludvigh and Miller (1958) and Miller (1958) proposed a mathematical model for the effects of velocity on DVA:

$$y = a + bx^3$$

In this model, y = visual angle in minutes of arc, a = individual predicted SVA level, x = target angular velocity in deg/s, and b = a dynamic acuity component. When velocity is reduced to zero, the effects of the bx term are negated and static acuity is the sole determinant. At higher velocities, the value of the equation is determined largely by the bx term (Morrison, 1980).

Illumination and Contrast

SVA appears to significantly improve with increases in target illuminance up to 10 ft-C, and then asymptotes with further increases in illuminance (Miller, 1958). DVA at 90 deg/s velocity continues to improve with illuminance levels exceeding 500 ft-C. (Miller & Ludvigh, 1962; see also Prestrude, 1987). Additionally, increased target contrast levels significantly improve DVA (Brown, 1972b).

Plane of Pursuit

Miller (1958) concluded that deterioration of DVA is similar whether the target is presented in a horizontal or vertical plane of pursuit. If an observer has good DVA for targets moving horizontally, the observer should also have good DVA for targets moving vertically. Miller (1958) also investigated the relationship between DVA and velocity as an observer viewed a stationary target while the observer was rotated in a horizontal plane. Based on Miller's 1958 research, it appears that DVA deteriorates in much the same manner whether a stationary observer views a target moving in a vertical or horizontal plane, or if an observer is rotated in a horizontal plane and views a stationary target.

Practice

Miller and Ludvigh (1962) summarized the effects of practice (multiple trials) on DVA at target velocities of 20 deg/s and 110 deg/s. Using 1,000 subjects, Ludvigh and Miller found slight improvement during the 20 deg/s velocity condition, and substantial improvement during the 110 deg/s velocity condition with practice. The improvement after 15-20 trials was not significantly different than the total improvement after 200 trials. Ludvigh and Miller (1962) also reported that the effects of practice were nine times as effective for the initially best performers as for the initially poorest performers.

Additionally, Miller and Ludvigh (1962) investigated the transfer effect of training. Practice on the 20 deg/s velocity transferred to the 110 deg/s condition. This transfer did not increase overall improvement gain over the 20 trials, however subjects obtained their asymptote threshold level faster. No transfer of training effect was demonstrated from the 110 deg/s velocity condition to subsequent performance on the 20 deg/s velocity condition.

Following the initial work by Miller and Ludvigh, researchers showed "sporadic" interest (Long & Roarke, 1989) in the investigation of DVA training effects. Long and Roarke justified reexamination of training effects on DVA for two reasons: The homogeneity of Miller and Ludvigh's population of study, a group of naval aviation cadets pre-selected as "physically qualified for naval flight training" (Miller & Ludvigh, 1962, p. 114"); and training effect reports (largely anecdotal) from sports vision literature.

The results of Long and Roarke (1989) were contrary to the initial findings of Miller and Ludvigh (1962). Long and Roarke reported that significant training effects were demonstrated well beyond the 15 - 20 trial asymptote reported by Miller and Ludvigh. Additionally, Long and Roarke demonstrated that the practice effect was greatest for those observers who demonstrated the poorest initial performance and under those conditions where performance was initially the poorest (faster velocities and briefer exposure duration).

In a subsequent study using free head viewing conditions, Long and Riggs (1991) supported the conclusions of Long and Roarke (1989). If DVA performance improves with training, DVA might be better viewed as a skill than an ability. Training on this skill might then be transferred to those tasks in which DVA is a critical component (Long & Riggs, 1991).

Individual Differences

In addition to SVA, observer age and observer gender are reported as individual differences which may impact DVA. Burg (1966) conducted a study of 17,500 subjects and found that DVA deteriorates progressively with increased observer age, and that this decline is more pronounced for DVA than for SVA (see also NRC, 1982; NRC, 1985). In the same study, Burg demonstrated that males have a slight, but significant advantage over females in both SVA and DVA. Burg prudently offered no causal explanation for this gender advantage. Individuals with identical SVA also exhibit varied performance on DVA tasks, especially at faster velocities (NRC, 1985).

Section 2: Proposed DVA Mechanisms

Ludvigh and Miller (1958) discussed several mechanisms which may affect DVA. (For a review of Miller and Ludvigh's early research on DVA, see Miller & Ludvigh, 1962). These mechanisms include: inadequate speed of voluntary eye movements, extra-foveal retinal imaging, movement of the image on the retina, and the inaccuracy of control of pursuit movements.

Citing Adler's earlier research, Ludvigh and Miller (1958) discounted the hypothesis that the eye is physically incapable of moving fast enough to pursue and track targets. Adler demonstrated that the eye can attain velocities up to 500-600 deg/s during smooth pursuit movements. The upper limit of target velocity studied by Miller and Ludvigh was 170 deg/s, and DVA deteriorated at even slower velocities (target velocity of

62 deg/s reduced 20/20 SVA to 20/200 DVA).

Ludvigh and Miller (1958) also discounted extrafoveal imaging as a possible explanation for DVA. Ludvigh and Miller imaged static and dynamic targets on a retinal region 2 deg from the fovea. Ludvigh and Miller determined although this extrafoveal imaging degraded static acuity (from 20/20 to 20/25) , the additional impact of target velocity of only 10 deg/s reduced acuity to 20/40, in the same (2 deg) extra foveal region. Ludvigh and Miller concluded that extrafoveal imaging is a negligible factor in DVA - the major factor is the movement of the image on the retina.

Ludvigh and Miller (1958) proposed that the imperfect pursuit movements of the eye may maintain the image in the vicinity of the fovea, but provide a moving image on the retina which reduces visual acuity. This moving image results in the eye receiving a lower intensity gradient than it would if the image were stationary. Ludvigh and Miller further reasoned that this hypothesis was supported by research showing that high illumination levels increased DVA performance. Ludvigh and Miller concluded:

> " Although the loss of acuity then, with increasing angular velocity of the test object may be directly attributable to loss of retinal intensity gradient, the ultimate cause is the inaccuracy of control of the pursuit movements."
> (Ludvigh & Miller, 1958, p. 802)

Following the logic of Miller and Ludvigh (e.g. 1962), Brown (1972a, 1972b, 1972c) investigated the physiological mechanisms involved in DVA. Brown (1972a) proposed two types of pursuit movement control errors. The first type of error Brown labeled velocity error. The second type of error Brown labeled as position error. Velocity error was defined as "the difference between the eye and target angular velocities during the last smooth pursuit movement in the eye movement sample period." Position error was defined as “the mean position of the target image on the retina with respect to the fovea during the last smooth pursuit movement." (Brown, 1972a, p. 314).

Brown (1972a) demonstrated that DVA deteriorated as a function of increased position and velocity error. By measuring eye movements, Brown (1972a) also demonstrated that during each successive smooth pursuit movement during a trial, the velocity mismatch between the eye and the target was reduced. Additionally, as target velocity increased from 20 to 90 deg/s, the mean interval between the first and second saccades diminished from 140 to 80 ms.

In simpler language, as target velocity increased, it took the eyes less time to make corrective movements (saccades). Following each of these saccades, the subsequent smooth pursuit velocity increased, and became closer to the target velocity. However, the final mean velocity mismatch between the target and the eye was greater for higher velocities (Brown, 1972a). Research on anticipatory tracking supports Brown's research. Elkin (in Morrison, 1980) demonstrated that anticipatory tracking time of only 0.2 s improved DVA performance.

Brown (1972b) suggested that the control of oculo-motor pursuit increases with: increased target size, and increased background illumination, increased target contrast. These factors together may serve to vary the efficiency with which the eye can summate available energy.

In 1958, Ludvigh and Miller suggested that " The value of an individual's dynamic visual acuity is dependent chiefly on the efficiency of the entire ocular pursuit mechanism..." (p.805). Subsequent researchers have arrived at similar conclusions.

Burg and Hulbert (1961, p.116) suggested that DVA involved "the efficiency of the entire oculo-motor system". Brown (1972, p.320) concluded that " DVA is not a fundamental visual attribute, but depends on sensory and motor components of the visual response and the complex feedback systems which link them." The NRC (1982, p.748) concluded that " Modern pilots can not be evaluated in terms of their physical skills; they must also be considered as managers of complex information systems ".

Section 3: Conventional Experimental Methods

To date, it is difficult to integrate the findings of earlier DVA research because of variations in apparatusses, stimulus conditions, observer sample, and psychophysical methods (Long & Riggs, 1991).

Targets

A number of targets have been used in DVA studies. (Prestrude, 1987; NRC, 1985). Burg (1966) and Burg and Hulbert (1961) used Bausch and Lomb Orthorater checkerboard targets. Other studies have used parallel bars (see Morrison, 1980), alphanumeric symbols, or vertical gratings (see Prestrude, 1987). The majority of studies have used Landolt C's (Prestrude, 1987). Schiffman (1990) provides examples and descriptions of visual acuity targets.

Landolt C's are reported to be reliable. Miller and Ludvigh, (1962) reported split half reliability of Landolt C's viewed at a velocity of 110 deg/s at .99, while the 10 month test retest reliability was .87. Miller and Ludvigh used eight different target orientations in this study.

Some researchers have expressed concerns about an orientation effect when using Landolt C's as DVA targets. Citing Methling and Wernike, Brown (1972c) suggested that horizontal target motion diminishes the visibility of targets with vertically oriented gaps more than it does with horizontally oriented gaps. Consequently, Brown (1972a) oriented the gaps of Landolt C's in the four oblique meridians. This convention was followed by other researchers (Long & Garvey, 1988; Long & Riggs, 1991; Long & Roarke, 1989).

Morrison (1980) presents an additional study by Van den Brink, which indicated that when target bar targets were oriented parallel to the direction of target movement, threshold energy levels required for detection were considerably lower than when the bars were oriented perpendicular to the direction of target motion. It is unclear from Morrison's (1980) report and Brown's (1972c) interpretation exactly which target was used in the Methling and Wernike study. If the targets used by Methling and Wernike were Landolt C's, Brown's target orientations may be warranted. If the targets used by Methling and Wernike were bars, Brown's target orientations may have been premature.

Prestrude (1987) presents data suggesting that an orientation effect may occur using Landolt C's to measure DVA. Right orientations were more easily recognized and down orientations more difficult to recognize during horizontal movement.

Apparatuses

The apparatuses conventionally used to measure DVA are large, complicated to use, and by no means portable. The concept behind this type of apparatus has not changed much since Ludvigh and Miller (1958). The observer views a target which is either reflected from a rotating front surface mirror, or directly projected, onto a hemicylindrical screen. The velocity of the target is created by rotating the mirror or the projector at a designated angular velocity. Burg and Hulbert (1961) and Burg (1966) provide photographs, and Brown (1972c) provides an excellent sketch of this type of apparatus.

Although the hemicylyndrical screen provides a distinct advantage of maintaining a constant distance between the observer and target, its use also has limitations (see Appendix B: Derivation of Velocity and Size).

Target Presentation

Miller and Ludvigh (1962) reported the effects of DVA target presentation in horizontal planes, vertical planes, and circular planes (See Section 1). These and other DVA studies typically present successive targets moving in a single, predictable direction. This may be, in large part due to the mechanisms used to rotate the image across the hemicylindrical screen. This rotation has been created by different devices, but has usually been in a clockwise fashion. Gramophones (Brown, 1972c), variable speed turntables (Long & Garvey, 1988), or specially constructed electric motors (Ludvigh & Miller, 1958; Burg, 1966) have provided the desired rotation.

Typically, these successive targets are moved from the observer's left to the observer's right (Brown, Heagerstrom-Pourtney, Adams, Jones, & Jampolski 1982; Long & Garvey 1989; Burg, 1966) and the bulk of DVA studies conducted over the past 57 years. Following a warning signal to alert the observer, the target predictably emanates from a single, predetermined, fixation point and moves along a linear path. Consequently, the observer knows when and from where the target will appear. Using such procedures, the process of initially acquiring the target is simplified and does not fully replicate the challenges of DVA in real world applications. Very often in the real world, we are not made aware of the emanation point of a potentially relevant visual target.

Binocular Viewing

Prestrude (1987) cited earlier research of Cutler & Ley, and also provided data of his own which indicate that binocular viewing improves DVA over SVA. Studies have varied in use of monocular (e.g.. Long & Roarke, 1989) and binocular (e.g.. Burg, 1966) viewing conditions.

Free versus Fixed Head Viewing

Much of the DVA research has used fixed head viewing conditions, using either headrests (e.g.. Brown, 1972c) or biteboards (e.g. Burg & Hulbert, 1961). Eliminating head movement as a confounding variable reduces the error of angular velocity of the target as imaged on the retina. Prestrude (1987) suggested that target velocity, rather than angular velocity (the velocity of the image on the retina) may be a more appropriate measure. Even using fixed head viewing procedures, the observer retains the ability to move his or her eyes. Consequently, the accuracy and stability of the observer's eye movements will vary the angular velocity as imaged on the retina for any given target velocity.

The stability of retinal images is important for optimal visual functioning (Adams, 1992; Deemer, Goldberg, Jenkins, & Porter, 1987). Deemer et al. discussed two mechanisms which induce eye movements to stabilize the retinal image: Head acceleration, which produces compensatory eye movements called the vestibular-ocular reflex (VOR); and visually perceived motion, which produces optokinetic eye movements. Pursuit and optokinetic eye movements, along with VOR, produce visual-vestibular interaction. This visual vestibular interaction, induced partly by head acceleration, contributes to the stability of retinal images.

Since active and passive head movements are an integral part of activities such as walking and driving, retinal image slip (blurring caused by the mismatch between the velocity of the eye and the velocity of the target) would constantly degrade DVA were it not for these compensatory eye movements (Deemer, et al, 1987). Consequently, studies which have used fixed head viewing (although better for obtaining measures of retinal angular velocity), have excluded a contributing factor in the effective imaging of moving targets.

Fixed head viewing conditions limit the angular rotation of the eye to permit foveal vision to an arc of about 90 to 100 deg, whereas the combination of eye and head movements allows the subject to fixate up to 180 deg (Burg and Hulbert, 1961). Burg and Hulbert suggested that free head viewing measures of DVA correlated higher with SVA than did fixed head measures of DVA. This increased DVA/SVA correlation under free head viewing conditions is likely the result of the observer using both eye and head movements to minimize retinal image slip.

Long and Riggs (1991), similarly expressed concerns that differences in DVA and SVA might be due to the atypical viewing conditions used in DVA studies. Replicating a study which used fixed head viewing conditions (Long & Roarke, 1989), Long and Riggs examined the effects of training on free head versus fixed head viewing conditions in a DVA task. Free head viewing was found to significantly improve DVA threshold scores under a variety of target velocities and durations. DVA under free head viewing was also found to be markedly different from SVA.

Additionally, Long and Riggs (1991) demonstrated a training effect under free head viewing for all observers. Similar to the findings of Long and Roarke, (1989) this training effect was most dramatic for the initially poorest observers, and under the initially most difficult conditions.

Section 4: Considerations, Objectives and Hypotheses

Considerations

The NRC (1982; 1985) indicated that DVA may be an important and practical measure of acuity. The NRC cited research showing that DVA may be more closely related to flight performance, automobile operation, and correlate significantly with the frequency of accidents of bus and truck drivers. DVA has "real potential for the assessment of vision." (NRC, 1985, p.24)

Because traditional measures of SVA do not completely assess this important aspect of vision, the NRC (1982) included DVA among several visual functions not assessed by visual examinations currently administered to both military and commercial pilots. Because DVA and other functions are not assessed, deterioration of these visual abilities could remain undetected with "potentially serious consequences. " (NRC, 1982, p.755) These findings led the NRC to the following recommendation:

> "The working group suggests it would be highly desirable to supplement current visual examinations for both military and civilian pilots - if feasible - with measures of these visual and information processing functions. Feasibility assessment should precede any attempt to implement supplementary tests, and both research and policy issues would have to be examined." (NRC, 1982, p. 755)

The purpose of the current research was to address some of these feasibility concerns.

Objectives

The first objective to the current study was to develop a computer program to test DVA, and initiate a program of research examining the potential strengths and weakness of a computer as a viable platform to test DVA. As discussed in Section 3, the apparatuses conventionally used to study DVA are by no means portable. Prestrude, (1987) called for the development of a DVA screening test in the form of a microcomputer program which could provide a small, portable, and standardized screening instrument. Such an instrument might be more readily applied by flight surgeons and used to conveniently obtain normative DVA data.

The second objective of the current study was to use the flexibility provided by a computer display to examine DVA under conditions which conventional apparatuses have not allowed. The current study investigated the effects of **random** linear target direction under monocular free head viewing conditions on DVA. Instead of successively presenting moving targets from a single fixation point and moving along a common path, as has been the convention, this computer application also allowed successive targets to randomly emanate from one of six locations and move in six linear paths. The introduction of random linear target direction may be a first step in answering the call of DVA researchers for studies of DVA involving unpredictable targets (Long & Riggs, 1991; Prestrude, 1987) and may also further distinguish DVA from SVA, increasing the benefit of including DVA screening in test batteries (Long & Riggs, 1991; NRC, 1982).

The third objective of the current study was to investigate how practice on this computerized DVA task impacted performance under conventional and random linear target direction conditions.

DVA appears to involve the integration of the entire oculomotor system (Brown, 1972a; Burg and Hulbert, 1961; Ludvigh and Miller, 1958; NRC, 1982; NRC 1985). In the proposed study, viewers will be less able to focus the oculomotor system on a single fixation point to initially acquire and subsequently resolve the DVA target. Theoretically, the proposed study should provide a more rigorous and realistic test of the entire oculomotor system in a DVA task. A demonstrated practice effect on this more realistic task might add support the belief of researchers (e.g. Long & Riggs, 1991) that training on DVA skills might transfer to real world DVA applications.

Hypotheses

H1 : A computerized test of DVA will support existing research. Specifically, thresholds will increase: a) as target velocity increases; b) target exposure duration decreases; and c) velocity and duration should significantly interact, difficulty will increase when increased velocities are compounded with decreased durations.

H2 : The introduction of random linear target direction in a DVA task will increase the difficulty of the task over conventional procedures. Because this random target presentation will cause the observer to first acquire the target, threshold sizes should increase relative to conventional procedures.

H3 : As demonstrated by Long and Riggs (1990) and Long and Roarke (1989), the effects of training on DVA tasks are greater under those conditions where performance is initially poorest. Consequently, training should have a significantly greater impact on the more complicated task of acquiring and identifying the target.

Method

Participants

30 undergraduate and graduate students participated in this study. These 30 participants included 14 men and 16 women between 18 and 24 years of age ($\underline{M} = 21$). Of these 30 participants, 10 volunteered for participation in a single one-hour session (Phase I only participants). The remaining 20 participants volunteered for continued participation in three additional one-hour sessions (Phase I and II participants). Undergraduate participants earned class credit for participation in the study (see Appendix A, Informed Consent Form). Participants were screened for 20/40 or better binocular near SVA (corrected) using the OPTEC 2000 with the Stereo Optical Industrial Vision Tester Record Form. This level of corrected vision is similar to that used by Long and Riggs (1991) and Long and Roarke (1989), and represents the minimum legal level of static acuity to qualify for a driver's license in many states in the USA. All who volunteered met this minimum screening requirement, so no one was precluded from participation. The range of binocular near SVA spanned from 20/30 to 20/13, averaging 20/17. These experimental procedures were approved by the Virginia Polytechnic Institute and State University Human Subjects Review Board.

Variables

DURATION. Three target exposure durations were used: 170, 370, and 570 ms. These durations are comparable to the 200, 400, and 600 ms durations used by Long and Riggs (1990). The durations applied to the physical presentation of the target and in no way limited the subjects' available time to respond (See Procedure, and Appendix C)

VELOCITY. The bulk of DVA research has expressed velocity in deg/s as a function of viewing distance. This measure was appropriate because the targets were projected onto hemicylindrical screens at a constant viewing distance. The current research presented the target on a flat computer screen. The linear velocities used in the study were derived from angular measures. Consequently, these velocities were expressed in "Degrees per Second " (deg/s). Velocity was calculated by determining the length of the base of an arc of "x" degrees as a function of the radius of the arc (minimum viewing distance). Five velocities were be considered: 0, 22, 45, 70, and 100 deg/s. The 0 deg/s velocity represents static testing, whereas the 22, 45, 70, and 100 deg/s velocities represent dynamic testing. See Appendix B and Tables B1 and B2 for further clarification of velocity derivations for the current study.

TARGET. Targets used were positive contrast Landolt Cs. The luminance of the Landolt C was displayed at 10 cd/m^2 and the luminance of the background was displayed at 1.5 cd/m^2. Using the formula provided by Schiffman (1990):

$$C = \frac{\max - \min}{\max + \min}$$

(Where C = contrast, max = maximum luminance, min = minimum luminance) the display resulted in a 73.9% contrast. The critical detail (gap) in the Landolt C was oriented randomly toward one of four directions: top, right, bottom, and left of the computer screen. These orientations were selected to maintain the fidelity of the Landolt Cs on the computer display. This critical detail orientation is contrary to the recommendation of Brown (1972a). Brown suggested that the critical detail of the Landolt C should be oriented in the four oblique meridians because horizontal target motion tends to diminish the visibility of targets with vertically oriented gaps more than horizontally oriented gaps. The split half reliability of Landolt Cs has been reported at .99 with a 10 month retest reliability of .87 (Miller and Ludvigh, 1962).

SESSION. Phase I and II participants completed four sessions. Phase I only participants complete a single session.

THRESHOLD. The dependent measure for study was threshold (min). Within a session, a threshold score was obtained by each subject for the fifteen factorial combination of the three durations (170, 370, and 570ms) with the five target velocities (0, 22, 45, 70, and 100 deg/s). Threshold data were obtained using nine target sizes by modified descending method of limits (staircased) procedure (see Procedures, and Appendix C). The critical detail of the target (gap) ranged from 23.7 to 2.6 min in the following steps: 23.7, 21.0, 18.4, 15.8, 13.1, 10.6, 7.9, 5.3, and 2.6 min. Long and Garvey (1988) and Long and Riggs (1991) used critical detail sizes ranging from 43.2 to 2.3 min. Appendix B and Table B3 compare the critical detail sizes used in the current study with the critical detail sizes used by Long and colleagues. Long's increments are more sensitive at the smaller target sizes. The increments used in the current study were fixed primarily due to constraints imposed by the computer display. On a computer monitor, the size of the critical detail can be increased by only one pixel per increment (see Appendix B).

Experimental Condition: Target Direction

FIXED DIRECTION. Targets emanated from the same position (center, left side) on the computer screen and moved from the observer's left to the observer's right along a linear path. This condition parallels the conventional target presentation conditions used by Long and Riggs (1991) and others over 57 years to assess DVA.

RANDOM DIRECTION. Targets emanated from one of six randomly selected cardinal directions on the computer screen and moved linearly to a point 180 deg opposite the point of origination on the computer screen (ie left to right, right to left, as well as top to bottom and bottom to top across the two diagonals.) Movement along the vertical plane was not investigated in the current study. In order to minimize the target size and maximize viewing distance from the screen, the vertical direction was discarded.

Apparatus

The computer program developed and used for the study is called DYNAQUE (Shevlin, Shevlin, & Prestrude, 1995). Dynaque was administered using an IBM compatible CyberMax Inc. MaxMedia P9828 PCI 90MHz Intel Pentium (tm) personal computer, equipped with 8MB Ram, 256K Cache, 850MB 10 ms Enhanced IDE HDD, 64 bit 2MB PCI SVGA, and 16 bit sound card.

The program was displayed on a MAG DX17F .26 mm flat screen 1280 x 1024 non- interlaced monitor, meeting MPRII emissions requirements. The video resolution was set at 1280 x 1024, 256 colors, and 75 MHZ vertical refresh rate. All subject inputs to the program were made using a standard IBM compatible keyboard. The screen luminance was calibrated using a Minolta Luminance Meter at the beginning of each session.

The computer monitor was placed on a table, with the center of the screen 129.5 cm from the floor. A horizontal bar (following the procedure of Long and Riggs 1990), was placed 137cm from the floor parallel to the computer screen. This bar prevented participants from leaning forward and reducing the minimum viewing distance to the screen. This bar inhibited head movement toward the screen, but afforded any other head movements. The screen was located 34 cm from the seated observer. The monitor, table, and horizontal bar remained stationary throughout the experiment.

All sessions were conducted in a windowless room, illuminated with a 25 watt incandescent light bulb which reflected light from the ceiling to minimize reflection and glare on the computer screen.

Procedure

The procedures for this experiment were based in part on the procedures used by Long and Riggs (1991) . The experiment was conducted in two phases. Phase I included recruitment, SVA screening, and stratified random assignment of all participants to either the RANDOM DIRECTION condition, or the FIXED DIRECTION condition. Phase I of the experiment concluded when all 30 participants completed session 1. During phase II of the experiment, the twenty participants who initially volunteered for Phase I and II participation completed three additional sessions over a three week period. Participants were not allowed to complete more than one session in the same day. Participants assigned to either the RANDOM DIRECTION or FIXED DIRECTION experimental conditions were tested and trained only under their respective condition.

During session 1, each participant was screened for 20/40 or better binocular near SVA (corrected) using the OPTEC 2000 with the Stereo Optical Industrial Vision Tester Record Form. Participants then proceeded to the computer, and were raised to a common viewing height (129.5 cm from the floor), using an adjustable height chair. To accomplish this, each participant sat in the adjustable height chair and faced a wall perpendicular to the computer monitor screen. This wall featured an “x”, which corresponded with the height of the center of the screen. Participants raised the height of the chair until they felt as though their eyes were level with the “x”. Participants then rotated the chair to face the computer monitor, and the experimenter verified that the subject's forehead touched the bar and the subject sat comfortably at the appropriate height to view the center of the computer monitor. The experimenter calibrated the luminance of the screen using the Minolta Luminance meter at the beginning of each session for each participant, using a split screen display (see Appendix C).

Once the chair height was properly adjusted, each participant began the computerized DVA training and testing. (Appendix C: Detailed Instructions to Participants, describes in detail all verbal and computer generated instructions provided to participants.) Each session consisted of familiarization training and testing under static conditions (0 deg/s) followed by familiarization training and testing under dynamic conditions (22, 45, 70, and 100 deg/s).

Familiarization training for static (0 deg/s) parameters began with presentation of the largest sized Landolt C (23.7 min) in the center of the computer screen for one of the three durations (chosen at random by the computer). Participants used the arrow keys on the keyboard to indicate the direction in which the gap of the Landolt C was oriented. The computer indicated “correct” or “incorrect” for each response. Following each correct response, the size of the Landolt C was reduced by one increment of size. (See

Appendix B). All participants were required to input a minimum of three static familiarization responses prior to proceeding to static testing, however they were allowed to continue familiarization training until they felt comfortable with the task and input mechanism.

Testing for the static (0 deg/s) parameters was then conducted. The computer assigned at random the sequence in which each static parameter (0 deg/s crossed with 170, 370, and 570ms durations) was tested. For each of these static parameters, a threshold (min) was obtained using a modified descending method of limits procedure.

The computer sounded an audible warning tone 1 s prior to presenting each target (Long & Riggs, 1991, used a verbal signal). The testing procedure began with presentation of the largest sized Landolt C (23.7min), displayed in the center of the computer screen. The participant then reported the position of the gap in the target (top, bottom, left or right) using the computer keyboard number pad. (Long and Riggs used subject verbal report, however Brown, 1972c used a similar input mechanism). Unlike the familiarization training, the computer provided no feedback during testing. After the participant correctly reported the gap position for the large target, progressively smaller Landolt-C Targets were presented in succession until an incorrect response was entered. At this point, the computer presented the next larger target. If a correct response was then given, the computer reduced the size of the subsequent target; If an incorrect response was given the computer again presented the next largest target. This procedure continued with targets being made smaller after correct responses and larger after incorrect responses, until two errors were made for the same target size. The next largest size was then recorded into the computer data base as the observer's resolution threshold for that target parameter.

Once a threshold score (min) was obtained for the participant for each of the three the static (0 deg/s) parameters, that participant proceeded to dynamic (22, 45, 70, 100 deg/s) training and testing. Participants in each experimental condition received computerized and verbal instructions relevant only to their respective task (See Appendix C).

Familiarization training for the dynamic (22, 45, 70, 100 deg/s) parameters was conducted in similar fashion as the static familiarization training. Familiarization began with presentation of the largest sized Landolt C (23.7 min) for one of the twelve remaining duration and velocity parameters (chosen at random by the computer). Participants in the fixed direction condition viewed targets which always emanated from the center left side of the computer screen, and moved linearly from the observer's left to the observer's right. Participants in the random direction condition viewed targets which emanated randomly from one of 6 locations and moved linearly across the screen to a point 180 deg opposite from the target's point of origination. Participants again used the arrow keys on the keyboard to indicate the direction in which the gap of the Landolt C was oriented. The computer indicated "correct" or "incorrect" for each response. Following each correct response, the size of the Landolt C was reduced by one increment of size (See Appendix B). All participants were required to input a minimum of three dynamic familiarization responses prior to proceeding to static testing, however they were allowed to continue familiarization training until they felt comfortable with the task and input mechanism.

Testing for the dynamic (22, 45, 70, and 100 deg/s) parameters was then conducted. The computer assigned at random the sequence in which each of the twelve dynamic parameters (22, 45, 70, and 100 deg/s velocity crossed with 170, 370, and 570ms durations) was tested. For each of these 12 dynamic parameters, a threshold (min) was obtained using a modified descending method of limits procedure described above.

Phase I of the experiment concluded when all 30 participants had been screened for SVA and completed the computer familiarization training and testing for the static and dynamic parameters in session 1. The ten participants who volunteered for Phase I only participation were then thanked and dismissed.

Phase II of the experiment continued with the remaining twenty participants. Over the next 2 -3 weeks, these participants participated in three additional sessions. Each of these additional sessions was conducted in the same manner as the initial session, with the exception of the SVA screening procedure. During these additional sessions, participants proceeded immediately with static familiarization and testing followed by dynamic familiarization and testing on the computer. The computer randomly generated the sequence with which the three static and twelve dynamic parameters were tested for each participant during each session.

Phase II of the experiment concluded when all remaining 20 participants had been screened for SVA and completed the computer familiarization training and testing for the static and dynamic parameters in sessions 1, 2, 3, and 4. These twenty participants who volunteered for Phase I and II participation were then thanked and dismissed.

Phase I data included the fifteen thresholds (three static and twelve dynamic) for the fifteen participants in each experimental condition. Phase II data included the fifteen thresholds (three static and twelve dynamic) for the ten participants in each condition, repeated over four sessions.

Analysis

PHASE I

All hypotheses were tested at alpha = .05. Phase I data were analyzed using a 2 (condition) x 3 (duration) x 5 (velocity) repeated measures ANOVA, with Huynh-Feldt corrections applied when required (Table 1) to compensate for violations of independence among repeated measures. All interactions and main effects were significant at $p < .01$.**

Insert Table 1 about here

The three way interaction (Condition x Velocity x Duration, $\underline{F}_{(8,224)} = 4.28^{**}$) is portrayed graphically in Figure 1. The relationship between Duration and Velocity is significantly impacted by Condition (target direction). Specifically, in the fixed direction condition, the 170 ms duration thresholds significantly exceeded the other duration thresholds (370, 570 ms) only at the 22 and 70 deg/s velocities, supporting to H1b (thresholds increase with decreases in duration). However in the random direction condition, the 170 ms duration thresholds were significantly higher than the other duration thresholds (370, 570 ms) across all dynamic (22, 45, 70, and 100 deg/s) velocities, supporting H1b (thresholds increase with decreased duration) and H2 (Random direction thresholds higher than fixed direction thresholds). Additionally, in the random direction condition at 22 deg/s, significant differences existed between all three durations (170, 370, and 570 ms). The magnitude of difference between conditions at the 170 ms duration was significantly greater (Figure 2) under the random target direction condition (supporting H2, random direction thresholds higher than fixed direction thresholds). With static targets (0 deg/s) no significant differences existed between the fixed and random direction conditions. This is understandable because the static (0 deg/s) tasks were the same for both conditions.

Insert Figures 1 and 2 about here

To summarize the three way interaction, the relationship between Velocity and Duration depended upon Condition (fixed vs random direction). Thresholds in the random direction condition were increased at briefer durations and slower velocities relative to the fixed direction condition. Additionally, threshold increases in the random direction condition were significantly greater relative to threshold increases in the fixed direction condition.

The two way interaction between Duration and Velocity ($F_{(8, 224)} = 6.15^{**}$) is portrayed graphically in Figure 3. When collapsed across condition, the effect of target movement (22, 45, 70, and 100 deg/s) increased thresholds at the 170 ms duration, supporting H1a (Thresholds increase with increases in velocity). No increase was demonstrated with static targets (0 deg/s). This two way interaction is should be interpreted considering the higher order three way interaction (Condition x Velocity x Duration) presented in figure 1, because the magnitude of this two way relationship changes with condition (fixed vs random direction).

Insert Figure 3 about here

Figure 4 graphically presents the two way interaction between Duration and Condition ($F_{(2, 56)} = 45.00$**). This two way interaction is also presented in the left column (duration) of Table 2. When collapsed across velocities, the random direction thresholds are significantly greater than the fixed direction thresholds at all durations (170, 370, and 570 ms), supporting H2. Using Tukey's HSD comparison, (Table 2) the 170 ms duration thresholds exceed the 370 and 570 ms duration thresholds in both the fixed and random direction conditions, supporting H1b (thresholds increase as duration decreases). The magnitude of this difference between conditions varies as a function of duration, with the random condition being more difficult at briefer durations, supporting H2 (random thresholds higher than fixed thresholds). The magnitude of difference is greater at briefer durations (4.91 min at 170 ms, 1.08 min at 370 ms, and 0.61 min at 570 ms). The two way interaction between duration and condition should be interpreted considering the three way interaction described on page 23, because this two way relationship further varies as a function of velocity.

Insert Figure 4 about here

Insert Table 2 about here

Figure 5 graphically presents the two way interaction between Velocity and Condition ($F_{(4, 112)} = 7.46^{**}$). This relationship is also presented in the right hand (velocity) column of Table 2. Again, with static targets (0 deg/s) , thresholds did not significantly differ between conditions (Table 2) . The static task (0 deg/s) was identical regardless of condition. With dynamic targets (22, 45, 70, and 100 deg/s) thresholds were significantly higher for the random direction condition (Table 2), supporting H2 (random direction thresholds higher than fixed direction thresholds). Results from Tukey's HSD comparison between velocities differed depending on condition (Table 2). Within the random condition, the dynamic thresholds (22, 45, 70, and 100 deg/s) were significantly greater than the static (0 deg/s) thresholds. Within the fixed direction condition, however, thresholds increased significantly only between 45 and 70 deg/s velocities. (0 deg/s, 22 deg/s, 45 deg/s < 70 deg/s, 100 deg/s). Within the random target direction condition, the effect of velocity increased thresholds sooner (at lower velocities, between 0 deg/s and 22 deg/s) than within the fixed target direction condition (between 45 deg/s and 70 deg/s), further supporting H2. This two way interaction between velocity and condition should be interpreted considering the three way interaction described on p. 23, because this two way relationship varies with duration.

Insert Figure 5 about here

Figure 6 graphically presents the main effect of Duration. This main effect is also presented in the left hand column of Table 2. When collapsed across velocity and condition, the 170 ms duration thresholds were significantly increased relative to the 370 ms and 570 ms durations, supporting H1b (thresholds increase with decreased duration). Using Tukey's HSD comparison, the 170 ms duration mean threshold (6.02 min) was significantly greater than the 370ms duration (3.75 min) and 570 ms (3.34 min) thresholds when collapsed across velocity and condition. (This main effect must be interpreted considering the higher order interactions described in the preceding pages).

Insert Figure 6 about here

Figure 7 graphically presents the main effect of Velocity. This man effect is also presented in the right hand (velocity) column of Table 2. When collapsed across duration and condition, the dynamic mean thresholds (22, 45, 70, and 100 deg/s) were significantly greater than the static (0 deg/s) mean thresholds using Tukey's HSD comparison (Table 2), supporting H1a (thresholds increase with increases in velocity). This main effect indicates the increase in thresholds due to target movement, however this main effect must be interpreted considering the higher order interactions described on the preceding pages.

Insert Figure 7 about here

Figure 8 graphically presents the main effect of Condition. When collapsed across velocity and duration, the mean threshold in the random condition was significantly greater than the mean threshold in the fixed direction condition, supporting H2 (random direction thresholds greater than fixed direction thresholds). Table 3 further examines this main effect. The mean threshold for the random direction condition (5.35 min) significantly exceeded the mean threshold for the fixed direction condition (3.39 min) by 1.96 min ($F_{(1, 28)}$ = 106.48**) when all fifteen parameters were included[(170, 370, 570 ms) crossed with (0, 22, 45, 70, and 100 deg/s)]. When the static parameters, [(0 deg/s) crossed with (170, 370, and 570 ms)] were not included, the mean threshold for the random direction condition (5.95 min) significantly exceeded the mean threshold for the fixed direction condition (3.51 min) by 2.43 min ($F_{(1, 28)}$ = 118.92**). The 2.43 min difference obtained excluding the static parameters may provide a more realistic estimate off the threshold difference attributable to differences in condition (fixed vs random direction), by eliminating the thresholds obtained under the static parameters, which were common to each condition. This main effect must be interpreted considering the higher order interactions described previously.

Insert Figure 8 about here

Insert Table 3 about here

PHASE II.

All hypotheses were tested at alpha = .05. Phase II data were analyzed using a 4 (Session) x 2 (Condition) x 3 (Duration) x 5 (Velocity) repeated measures ANOVA, with Huynh-Feldt corrections applied when required (Table 4) to compensate for violations of assumed independence among repeated measures.

Insert Table 4 about here

The four way interaction (Session x Condition x Duration x Velocity) was not significant ($F_{(24, 432)}$ = 0.43). (All effects involving session were not significant, with the exception of the two way interaction between Session and Duration, which will be presented with the other two way interactions). This general lack of support for an effect of session fails to support H3 (performance in both fixed and random directions would improve with practice, with performance in the random direction task demonstrating greater improvement).

The three way interaction not involving Session (Condition x Velocity x Duration, $F_{(8,144)}$ = 13.41**) is portrayed graphically in Figure 9. As with the phase I data, the relationship between Duration and Velocity was significantly impacted by Condition (target direction). Specifically, in the fixed direction condition, the 170 ms duration thresholds significantly exceeded the both other duration thresholds (370, 570 ms) at the 22 deg/s velocities, and exceeded the 570 ms duration thresholds at the 45 and 70 deg/s velocities, supporting to H1b (thresholds increase with decreases in duration). However in the random direction condition, the 170 ms duration thresholds were significantly higher than the other duration thresholds (370, 570 ms) across all dynamic (22, 45, 70, and 100 deg/s) velocities, supporting H1b (thresholds increase with decreased duration) and H2 (Random direction thresholds higher than fixed direction thresholds).

Insert Figure 9 about here

Additionally, in the random direction condition at 22 deg/s, significant differences existed between all three durations (170, 370, and 570 ms). The magnitude of difference between conditions at the 170 ms duration was significantly greater for the random direction condition relative to the fixed direction condition (Figure 9) (supporting H2, random direction thresholds higher than fixed direction thresholds). With static targets (0 deg/s) no significant differences existed between the fixed and random direction conditions. This is understandable because the static (0 deg/s) tasks were the same for both conditions.

Table 5 compares the Phase II interaction between Condition and Velocity at the 170 ms duration using Tukey's HSD. Within the fixed direction condition, no significant differences exist between the dynamic (22, 45, 70, and 100 deg/s) parameters. The effect of velocity is accounted for between the static (0 deg/s) parameters and the dynamic parameters (Table 6), supporting H1a. However within the random direction condition, thresholds significantly decrease with increased velocity: 22 deg/s = 9.95 min, 45 deg/s = 8.31 min, 70 deg/s = 7.85 min, 100 deg/s = 7.78 min, contradicting H1a (thresholds increase with increased velocity. Explanations for this contradiction will be further explored in the discussion section.

Insert Tables 5 and 6 about here

To summarize the three way interaction, the relationship between Velocity and Duration depended upon Condition (fixed vs random direction). Thresholds in the random direction condition were increased at briefer durations and slower velocities relative to the fixed direction condition, Supporting H2 (random direction thresholds greater than fixed direction thresholds). Additionally, threshold increases in the random direction condition were significantly greater relative to threshold increases in the fixed direction condition, further supporting H2. Thresholds within the random direction condition for dynamic parameters at the 170 ms duration decreased with increased velocity, contradicting H1a.

The two way interaction between Duration and Velocity ($F_{(8, 144)} = 19.35^{**}$) is portrayed graphically in Figure 10. When collapsed across condition, the effect of target movement (22, 45, 70, and 100 deg/s) increased thresholds at the 170 ms duration, supporting H1a (Thresholds increase with increases in velocity). No increase was demonstrated with static targets (0 deg/s). This two way interaction is should be interpreted considering the higher order three way interaction (Condition x Velocity x Duration) presented in figure 1, because the magnitude of this two way relationship changes with condition (fixed vs random direction).

Insert Figure 10 about here

Figure 11 graphically presents the two way interaction between Session and Duration ($F_{(6, 108)} = 2.97^{**}$). This interaction is the only Phase II effect involving session which was significant. As evidenced by figure 11, the relationship between thresholds at the three durations (170, 370, and 570 ms) changes slightly between sessions one and two. In session one, significant differences exist between all three durations, whereas in sessions two, three, and four, the significant difference between the 370 and 570 ms durations is absent.

Insert Figure 11 about here

Figure 12 graphically presents the two way interaction between Duration and Condition ($F_{(2, 56)} = 45.00^{**}$). This two way interaction is also presented in the left column (duration) of Table 6 for Phase II data. (Tables 7 - 10 present the Table 6 data separated by session, however the patterns remain essentially the same across sessions.)

When collapsed across velocities, the random direction thresholds were significantly greater than the fixed direction thresholds at all durations (170, 370, and 570 ms), supporting H2. Using Tukey's HSD comparison, (Table 6) the 170 ms duration thresholds exceed the 370 and 570 ms duration thresholds in both the fixed and random direction conditions, supporting H1b (thresholds increase as duration decreases). The magnitude of this difference between conditions varies as a function of duration, with the random condition being more difficult at briefer durations, supporting H2 (random thresholds higher than fixed thresholds). The magnitude of difference is greater at shorter durations (3.75 min at 170 ms, 0.92 min at 370 ms, and 0.69 min at 570 ms). The two way interaction between duration and condition should be interpreted considering the three way interaction described earlier, because this two way relationship further varies as a function of velocity.

Insert Figure 12 about here

Insert Tables 6 - 10 about here

Figure 13 graphically presents the two way interaction between Velocity and Condition ($F_{(4, 112)} = 7.46^{**}$). This relationship is also presented in the right hand (velocity) column of Table 6. Again, with static targets (0 deg/s) , thresholds did not significantly differ between the random and fixed direction conditions (Table 2) . The static task (0 deg/s) was identical regardless of condition. With dynamic targets (22, 45, 70, and 100 deg/s) thresholds were significantly higher for the random direction condition (Table 6), supporting H2 (random direction thresholds higher than fixed direction thresholds). Results from Tukey's HSD comparison between velocities differed depending on condition (Table 6). Within the random condition, the dynamic thresholds (22, 45, 70, and 100 deg/s) were significantly greater than the static (0 deg/s) thresholds. Within the fixed direction condition, however, thresholds increased significantly only between 22 and 45 deg/s velocities. (0 deg/s, 22 deg/s, < 45 deg/s, 70 deg/s, 100 deg/s). Within the random target direction condition, the effect of velocity increased thresholds sooner (at slower velocities, between 0 deg/s and 22 deg/s) than within the fixed target direction condition (between 45 deg/s and 70 deg/s), further supporting H2. This two way interaction between velocity and condition should be interpreted considering the three way interaction described earlier, because this two way relationship varies with duration.

Insert Figure 13 about here

Figure 14 graphically presents the main effect of Duration. This main effect is also presented in the left hand column of Table 6. When collapsed across velocity and condition, the 170 ms duration mean threshold was significantly increased relative to the 370 ms and 570 ms duration mean thresholds, supporting H1b (thresholds increase with decreased duration). Using Tukey's HSD comparison, the 170 ms duration mean threshold (5.52 min) was significantly greater than the 370ms duration (3.67 min) and 570 ms (3.35 min) thresholds when collapsed across velocity and condition. (This main effect must be interpreted considering the higher order interactions described in the preceding pages).

Insert Figure 14 about here

Figure 15 graphically presents the main effect of Velocity. This man effect is also presented in the right hand (velocity) column of Table 6. When collapsed across duration and condition, the dynamic mean thresholds (22, 45, 70, and 100 deg/s) were significantly greater than the static (0 deg/s) mean thresholds using Tukey's HSD comparison (Table 6), supporting H1a (thresholds increase with increases in velocity). This main effect indicates the increase in thresholds due to target movement, however this main effect must be interpreted considering the higher order interactions described on the preceding pages, and especially considering the exception contradicting H1a described earlier.

Insert Figure 15 about here

Figure 16 graphically presents the main effect of Condition. When collapsed across velocity and duration, the mean threshold in the random condition was significantly greater than the mean threshold in the fixed direction condition, supporting H2 (random direction thresholds greater than fixed direction thresholds). Table 11 further examines this main effect. The mean threshold for the random direction condition (5.07 min) significantly exceeded the mean threshold for the fixed direction condition (3.28 min) by 1.78 min ($F_{(1, 18)} = 175.27^{**}$) when all fifteen parameters were included[(170, 370, 570 ms) crossed with (0, 22, 45, 70, and 100 deg/s)]. When the static parameters, [(0 deg/s) crossed with (170, 370, and 570 ms)] were not included, the mean threshold for the random direction condition (5.61 min) significantly exceeded the mean threshold for the fixed direction condition (3.40 min) by 2.21 min ($F_{(1, 18)} = 186.61^{**}$). The 2.21 min difference obtained excluding the static parameters may provide a more realistic estimate off the threshold difference attributable to differences in condition (fixed vs random direction), by eliminating the thresholds obtained under the static parameters, which were common to each condition. This main effect must be interpreted considering the higher order interactions described previously.

Insert Figure 16 about here

Insert Table 11 about here

Discussion

Recall this thesis had three objectives:

1) Develop a computer program to test DVA, and initiate a program of research examining the potential strengths and weaknesses of a computer as a viable DVA test platform.

2). Use the flexibility provided by a computerized DVA platform to examine DVA under conditions which conventional apparatuses had not allowed. (fixed vs random direction).

3) Examine the effects of training on DVA performance under conventional (fixed) and random linear target direction tasks.

These three objectives will be discussed in turn.

The first objective of this thesis was achieved (develop a computer program to test DVA, and initiate a program of research to investigate the potential strengths and weaknesses of a computer as a viable platform to measure DVA). Dynaque (Shevlin, Shevlin, & Prestrude, 1995) was consequently developed and refined. This computer program and platform demonstrated several advantages and disadvantages in the process of achieving the goals of the current study.

Among the advantages of the computer application, the platform was relatively portable and lightweight. Target luminance and contrast were easy to calibrate using a luminance meter and the brightness and contrast controls on the monitor. Systematic manipulations in luminance might be also programmed into the computer software. Precise temporal manipulations were easily achieved via programming using the internal clock of the computer. Once the program was developed, the test was easy to administer, requiring a few short keyboard entries by the experimenter to initiate a test session. Computerized testing for each session required approximately 20 minutes per session.

Additionally, the computer recorded data directly into a data base which could be easily tailored to assimilate other data. For the current experiment, the data base recorded each participant's administrative data, target size, gap orientation, response, correct or incorrect, and response time for each entry within each parameter combination.

The computer platform demonstrated several limitations. Perhaps the biggest drawback to the computer involves the size increments with which targets can be displayed and increased, compounded with the limited size of the display area of the monitor (See Appendix B). In order to achieve targets size increments of 1.1 min (as used by Long and Riggs, 1991) at the small end of the threshold scale, viewing distance would have to be increased to 85 cm. Such an increase in viewing distance would reduce the maximum target velocity to 36 deg/s (at 570ms duration) which is on the minimum border at which velocity appears to degrade DVA.

Consequently, the current viewing distance of 34 cm was selected to compromise between minimized target size (2.6 min), minimized target increment of increase (2.6 min) and maximized velocity (100 deg/s). This trade off resulted in a much less sensitive measure (2.6 min compared to 1.1 min) of threshold the smaller end of the scale where effects have been demonstrated in the existing literature (e.g. Long & Riggs, 1991).

A computer monitor also restricts the peak luminance levels at which targets can be displayed. As luminance levels increase, moving targets leave a perceptual tail on the screen which may confound acuity measurement. Larger targets also appear to jitter slightly during movement, however with the smaller targets, this jitter disappears. As affordable personal computer technology improves, the utility of a computer based platform to test DVA will no doubt also improve.

The second objective of this thesis was also met. The flexibility in variable manipulation afforded by a computerized DVA platform was only partially tapped with the current program (fixed vs random target direction). With further imagination and insight, additional manipulations (intermittent targets, non linear targets, three dimensional movement, etc) might be investigated. The purpose of the current study was not to complete all of these investigations, but rather to begin a program of study which would investigate and develop the potential of a computer platform to test DVA.

Dynaque demonstrated the potential flexibility afforded by computer applications over conventional apparatuses used to date in DVA assessment. By allowing targets to be presented under conditions not testable to date with current apparatuses (random direction condition), this thesis demonstrated two unique contributions to the DVA literature.

First, Phase I and Phase II data clearly support H2 (random direction thresholds greater than fixed direction thresholds). DVA research over the past 57 years has typically presented targets moving from the observer's right to the observer's left. Using these conventional procedures, the observer was aware of when and from where the target would appear. In real-world daily activities we are seldom made aware of the time and location from which our next relevant visual target will appear (trap shooting is an acknowledged exception). Results from this thesis demonstrated a significant increase in threshold between random and fixed target directions (Phase I difference = 2.43 min, Phase II mean difference = 2.21 min) (see tables 3 and 11). Further, this effect of condition interacted with duration and velocity. The difference between conditions was more pronounced at briefer durations (Tables 2 and 6) reflecting the increased difficulty of acquiring and resolving a moving target with less time available to complete the visual task. These data suggest that DVA as applied in reality requires additional skills of first resolving the target.

Secondly, Phase II data suggest that the traditionally accepted relationship between threshold and velocity may in part be a consequence of existing procedures. As stated earlier on page 2, the general consensus in the DVA literature is that increases in target velocity decrease thresholds. This logic justified H1a (thresholds would increase with increased velocity) of the current study.

This generally accepted relationship was supported in the fixed direction condition data in both phases I and II of the current experiment (see Tables 2 and 6), however this relationship was contradicted by phase II random direction condition data (Table 5). Within the fixed direction condition, no significant differences existed between the dynamic (22, 45, 70, and 100 deg/s) parameters at the 170 ms duration. The effect of velocity is accounted for between the static (0 deg/s) parameters and the dynamic parameters (Table 6), supporting H1a.

Within the random direction condition, however, thresholds significantly **decreased** with **increased** velocity: 22 deg/s = 9.95 min, 45 deg/s = 8.31 min, 70 deg/s = 7.85 min, 100 deg/s = 7.78 min, contradicting H1a. These data suggest that the generally accepted relationship between increased velocity and decreased threshold may in part be a consequence of conventional procedures. Specifically at the 170 ms duration, thresholds decreased with increases in target velocity between 22 and 100 deg/s.

These data suggest that the generally accepted relationship between increased threshold sizes and increased velocities may be in part the consequence of conventional DVA assessment procedures used to date. Specifically, when an observer is aware of the emanation point of a visual target, the generally accepted relationship holds true: slower targets are easier to resolve. However, for briefer durations, when the observer is unaware of the emanation point of a visual target, increased velocity actually enhances target resolution. This enhancement may well occur because the observer can more quickly detect and consequently more quickly begin to track the target. The faster velocity moves the target into the center of the screen more quickly, where the observer is more likely acquire the target and initiate eye movements to track and resolve the target. Although substantial data from this study do not support such a conclusion, it seems reasonable to assume that with further increases in velocity, DVA thresholds would again deteriorate resulting in a "U shaped" function.

Brown's research (1972a; 1972b; 1972c) may offer partial explanations for the two unique findings of the current study. Brown (1972b) demonstrated that initial eye movement latencies were between 100 and 200 ms for high contrast targets moving at 51 deg/s. Latencies decreased with increases in target velocities. (The eyes responded more rapidly to targets moving at faster velocities). Brown (1972b) further reported that increases in target velocity from 20 deg/s to 90 deg/s diminished the mean interval between first and second saccade from 140 to 80 ms (the eyes more rapidly corrected for initial pursuit mismatch between the eye and target for faster velocity targets). Finally, for target exposure times of 450 ms, Brown demonstrated the percent of occurrence of third saccade increased as a function of target velocity. For targets moving at 20 deg/s, the percent of third saccade occurrence was near 0 %, increasing to approximately 80% for targets moving at 90 deg/s. (For faster moving targets, the eyes made more corrective saccade in the same amount of time).

In the fixed direction condition, the observer is aware of the emanation point of the target and can "preposition" his or her eyes. This prepositioning eliminates the initial corrective movement required in the random direction condition following acquisition of the moving target. Consequently, increased thresholds under the random target direction relative to the fixed target direction may be explained as a function of time available to acquire and initiate corrective movements to track the target.

This argument is strengthened by research showing that anticipatory tracking of dynamic targets improves performance (Elkin, in Morrison, 1980). Using anticipatory tracking, initial corrective movements have already been completed to match the velocity of the eye and the target prior to target resolution. Observer's using anticipatory tracking have a significant "head start" relative to the fixed direction condition, which allows for optical prepositioning. If retinal smearing caused by the velocity mismatch between the eye and the target is primarily responsible for DVA deterioration, the differences between DVA performance using anticipatory tracking, fixed direction viewing, and random direction viewing might be explained as a function of the time available to the eyes to initiate corrective movements. This argument is supported by the interaction between duration and condition in the current study (Figures 4 and 11, briefer durations increased thresholds, more so in the random direction condition).

This argument does not entirely explain the contradiction of H1a (thresholds will increase with increased target velocities) by the three way interaction between duration, condition, and velocity presented in Figures 1 and 8, as well as in Table 5. Recall from page 37, that thresholds significantly **decreased** with **increased** velocity: 22 deg/s = 9.95 min, 45 deg/s = 8.31 min, 70 deg/s = 7.85 min, 100 deg/s = 7.78 min, contradicting H1a. Specifically at the 170 ms duration, thresholds decreased with increases in target velocity between 22 and 100 deg/s. These data may in part be a result of the eyes making more corrective movements more rapidly and frequently based on faster target velocities as presented by Brown (1972c). If this were a complete explanation, the inverse relationship between threshold and velocity would hold true for both conditions. It does not. Increased target velocities decrease thresholds only under random target direction and only under the 170 ms (very brief) durations.

The reason for this inverse relationship may well be that for briefer durations, when the observer is unaware of the emanation point of a visual target, acuity is enhanced with increased velocity because the target moves farther and more quickly into the center of the visual field. For example, a target moving at 22 deg/s moves 22.1 mm in 170 ms, whereas a target moving at 100 deg/s moves 88.4 mm in the same time (Table B2). The observer can thus more rapidly acquire the target and initiate eye movements to track and resolve the target.

The third objective of this thesis was to examine the effects of training on DVA performance under conventional (fixed) and random linear target direction tasks. Training effects were investigated over 4 sessions, and data provided essentially no support for H3 (effect of training). All effects and interactions involving Session were not significant, with the exception of the two way interaction between Session and Duration (Figure 10). This interaction is significant due to a small but significant difference between the 370 and 570 ms durations which is present in Session one, but is absent in Sessions 2, 3, and 4.

The noticeable absence of any relevant effect of training in the current study fails to support H3 (effect of training), but should not be taken as disproof of training claims made by previous researchers (eg Long & Riggs, 1991). In order to display Landolt Cs on a the computer screen for the current study, tradeoffs were made (see page 35 and Appendix B).

One of the limitations of a computer platform to test DVA described earlier involves the size increments with which targets can be displayed and increased, compounded with the limited size of the display area of the monitor (See Appendix B). In order to achieve targets size increments of 1.1 min (as used by Long and Riggs, 1991) at the small end of the threshold scale, viewing distance would have to be increased to 85 cm. Such an increase in viewing distance would reduce the maximum target velocity to 36 deg/s (at 570ms duration) which is on the minimum border at which velocity appears to degrade DVA.

This decreased sensitivity of the computer scale relative to conventional measures offers a partial explanation for the lack of support for H3 (effect of training). Long and Riggs (1991) did not report mean differences between training sessions indicating the effect size of improvement, however from their graphs this effect size appears to be roughly 2 min at 90 deg/s. Even if similar improvement were demonstrated in the current study, the increment of measure (2.6 min) is too large to reliably capture such improvement. It is difficult to measure improvement in inches with a yard stick.

The decreased sensitivity might also explain why H1 (a) was only partially supported in the current experiment. As reported in Tables 2 and 5, the effect of motion (22, 45, 70, and 100 deg/s) significantly increased acuity relative to static conditions (0 deg/s) however the differences between dynamic parameters were not significant.

This decreased sensitivity actually lends support to H2 of the current study. Even using this less sensitive measure, the difference between the fixed and random target directions was significant. It is reasonable to assume that use of a more sensitive measure would make this difference even **more** pronounced.

Implications

This study provides several unique contributions to the DVA literature. Dynaque demonstrates some of the potential strengths and weaknesses of using a computer platform to measure DVA. This program serves as a possible step towards fielding a reliable, portable, and convenient measure to investigate DVA. The computer application enabled testing of DVA under conditions which have not been allowed using existing apparatuses.

This investigation yielded two findings of importance to the study of DVA. First, DVA thresholds increase when an observer is unaware of the emanation point of a dynamic visual target. Because in the real world, we are seldom made aware of the origin of our next relevant visual target, these findings may have impact on daily activities involving DVA. Additionally, the general consensus within the DVA literature that threshold sizes increase with increases in velocity may be partially the consequence of existing procedures.

Numerous questions remain to be asked. Can these findings be replicated? Might this program be superimposed on existing eye movement tracking technology? How can one develop a computerized test of DVA which enables smaller increments between threshold sizes while still allowing for a wide range of velocities? Might a projection device be used to display computer generated targets onto a larger screen? Would such a display compromise the fidelity of the targets? How would nonlinear and or intermittent target presentations impact DVA? What is normative data for DVA with random target direction? How do manipulations in contrast effect thresholds? Does training in fact decrease thresholds under different target movement conditions? If so, what type of training is the most effective? Can these findings be further generalized and empirically linked to specific performance measures?

The introduction of a viable computer platform (Dynaque) to measure DVA is a positive step towards answering these questions. As affordable personal computer technology improves, the potential utility of this instrument will no doubt increase as well. With further research, hopefully the scientific community may produce a portable, reliable, and valid measure of DVA which may be conveniently used in the field, as well as in the laboratory.

Table 1

Repeated Measures Analysis of Variance, Dynamic Visual Acuity Phase I

Source	df	Huhyn-Feldt	SS	MS	F
	Between Subjects				
Condition (C)	1		431.79	431.79	106.48**
Error	28		113.55	4.06	
	Within Subjects				
Velocity (V)	4	.95384	236.92	59.23	16.44**
C X V	4		107.56	26.89	7.46**
Within + Residual	112		403.44	3.60	
Duration (D)	2	.76078	627.65	313.82	99.39**
C X D	2		284.18	142.09	45.00**
Within + Residual	56		176.82	3.16	
V X D	8	.61376	139.71	17.46	6.15**
C X V X D	8		97.24	12.15	4.28**
Within + Residual	224		636.51	2.84	

Note. Between subject factors are grouped by the denominator for F statistic. Huyhn-Feldt correction applied to F values.** significant at $p < .01$.

Table 2

Comparison of Mean Acuity Thresholds (min) for Fixed and Random Target Direction as a Function of Viewing Condition, Phase I

Target Direction		Duration (ms) 570	370	170	Velocity (deg/s) 0	22	45	70	100
Combined	M	3.34_a	3.75_a	6.02_b	2.93_a	4.77_b	4.59_b	4.86_b	4.71_b
	SD	1.24	1.44	3.74	0.89	3.15	3.01	2.72	2.59
	SE	0.10	0.12	0.31	0.09	0.09	0.32	0.29	0.27
Random									
	M	3.64_a	4.29_a	8.12_b	2.96_a	6.15_b	5.86_b	6.04_b	5.74_b
	SD	1.39	1.51	4.10	0.93	3.82	3.64	3.17	3.05
	SE	0.16	0.17	0.47	0.14	0.57	0.54	0.47	0.45
Fixed									
	M	3.03_a	3.21_a	3.93_b	2.90_a	3.38_a	3.32_a	3.68_b	3.68_b
	SD	1.00	1.10	1.50	0.86	1.24	1.33	1.45	1.45
	SE	0.12	0.14	0.18	0.13	0.18	0.20	0.22	0.22
Difference									
	M	0.61	1.08	4.19	0.06	2.77	2.54	2.37	2.06
	SE	0.19	0.22	0.51	0.18	0.59	0.58	0.52	0.50
	t (1 tail)	3.09**	4.92**	8.26**	0.32	4.63**	4.39**	4.55**	4.09**
	df	28	28	28	28	28	28	28	28

Note. Difference is obtained by subtracting M (fixed) from M (random). Means in the same row and viewing condition(Duration or Velocity) which do not share a common subscript differ at $p < .05$ in the Tukey HSD comparison. ** denotes significance at $p < .01$, * denotes significance at $p < .05$.

Table 3
Comparison of Mean Acuity Thresholds (min) for Fixed and Random Target Direction, Phase I.

Target Direction		Viewing Condition [a] All Parameters	Viewing Condition [a] Dynamic Parameters Only
Random			
	M	5.35	5.95
	SD	3.32	3.41
	SE	0.22	0.25
Fixed			
	M	3.39	3.51
	SD	1.30	1.37
	SE	0.08	0.10
Difference			
	M	1.96	2.43
	SE	.24	0.27
	$F_{(1,28)}$	106.48**	118.92**

Note. Difference is obtained by subtracting M (fixed) from M (random). ** denotes significance at $p < .01$. a "All parameters" includes 15 measurements resulting from factorial combination of five velocities (0, 22, 45, 70, and 100 deg/s) and three durations (170, 370, and 570 ms). "Dynamic parameters" includes twelve of above measurements, without 0 deg/s velocity.

Table 4

Repeated Measures Analysis of Variance, Dynamic Visual Acuity Phase II

Source	df	Huyhn-Feldt	SS	MS	F
		Between Subjects			
Condition (C)	1		954.26	954.26	175.27**
Error	18		98.00	5.44	
		Within Subjects			
Session (S)	3	1	12.12	4.04	1.49
C x S	3		5.14	1.71	0.63
Within + Residual	54		146.55	2.71	
Velocity (V)	4	1	516.06	129.01	47.57**
C x V	4		248.21	62.05	20.95**
Within + Residual	72		213.21	2.96	
Duration (D)	2	0.65364	1103.53	551.76	210.15**
C x D	2		580.34	290.17	110.52**
Within + Residual	36		94.52	2.63	
S x V	12	0.87511	24.47	2.46	0.97
C x S x V	12		28.83	2.40	0.95
Within + Residual	216		548.12	2.54	
S x D	6	0.85	34.11	5.68	2.97**
C x S x D	6		11.71	1.95	1.02
Within + Residual	108		206.50	1.91	
V x D	8	0.65133	286.24	35.78	19.35**
C x V x D	8		198.37	24.80	13.41**
Within + Residual	144		266.33	1.85	
S x V x D	24	0.76136	85.09	3.55	1.50
C x S x V x D	24		24.37	1.02	0.43
Within + Residual	432		1019.92	2.36	

Notes. Between subjects factors are grouped by denominater for F statistic. F ratios calculated with Huyhn-Feldt correction. ** significant at $p < .01$

Table 5

Comparison of Mean Acuity Thresholds (min) for Fixed and Random Target Direction, 170 ms Duration, 22, 45, 70, and 100 deg/s Velocity, Phases I and II

			Velocity (deg/s)			
Phase	Target Direction		22	45	70	100
I	Random	M	10.21_a	9.48_a	9.15_a	8.61_a
		SD	3.83	4.08	3.60	3.06
		SE	0.99	1.05	0.92	0.79
I	Fixed	M	4.22_a	3.67_a	4.57_a	4.03_a
		SD	1.37	1.69	1.59	1.71
		SE	0.35	0.44	0.41	0.44
II	Random	M	9.95_a	8.31_{ab}	7.85_b	7.78_b
		SD	3.11	3.07	2.96	2.54
		SE	0.49	0.49	0.47	0.40
II	Fixed	M	3.95_a	4.01_a	3.81_a	3.40_a
		SD	1.49	1.60	1.48	1.51
		SE	0.24	0.25	0.23	0.24

Notes. Means in each row which do not share a common subscript differ at $p < .05$ in the Tukey HSD comparison. Notice within random target direction, thresholds decrease with increases in velocity (significant only during Phase II). Phase I $n = 15$ per condition, Phase II $n = 10$ per condition.

Table 6

Comparison of Mean Acuity Thresholds (min) for Fixed and Random Target Direction as a Function of Viewing Condition, Phase II

Target Direction		Duration (ms) 570	370	170	Velocity (deg/s) 0	22	45	70	100
Combined									
	M	3.35_a	3.67_a	5.52_b	2.88_a	4.67_b	4.52_b	4.40_b	4.43_b
	SD	1.24	1.35	3.27	0.83	2.95	2.45	2.32	2.27
	SE	0.06	0.06	0.16	0.05	0.19	0.16	0.15	0.15
Random									
	M	3.69_a	4.12_a	7.40_b	2.92_a	6.06_b	5.54_b	5.36_b	5.47_b
	SD	1.38	1.39	3.50	0.87	3.46	2.86	2.69	2.53
	SE	0.10	0.10	0.25	0.08	0.32	0.26	0.25	0.23
Fixed									
	M	3.01_a	3.21_a	3.65_b	2.85_a	3.27_{ab}	3.50_b	3.43_b	3.39_b
	SD	0.97	1.13	1.47	0.78	1.22	1.37	1.30	1.32
	SE	0.07	0.80	0.10	0.07	0.11	0.13	0.12	0.12
Difference									
	M	0.69	0.92	3.75	0.07	2.79	2.04	1.93	2.09
	SE	0.12	0.13	0.27	0.11	0.34	0.29	0.27	0.26
	t (1 tail)	5.77**	7.23**	13.95**	0.63	8.32**	7.06**	7.10**	8.00**
	df	18	18	18	18	18	18	18	18

Notes. Difference is obtained by subtracting M (fixed) from M (random). Means in the same row and viewing condition(Duration or Velocity) which do not share a common subscript differ at $p < .05$ in the Tukey HSD comparison. ** denotes significance at $p < .01$, * denotes significance at $p < .05$.

Table 7

Comparison of Mean Acuity Thresholds (min) for Fixed and Random Target Direction as a Function of Viewing Condition, Phase II, Session 1

Target Direction		Duration (ms) 570	370	170	Velocity (deg/s) 0	22	45	70	100
Combined									
	M	3.19_a	3.76_a	6.06_b	2.91_a	4.69_b	4.65_b	5.01_b	4.42_b
	SD	1.18	1.44	3.95	0.87	3.45	2.86	3.04	2.65
	SE	0.12	0.14	0.39	0.11	0.44	0.37	0.39	0.34
Random									
	M	3.57_a	4.22_a	8.22_b	2.87_a	6.14_b	5.80_b	6.43_b	8.22_b
	SD	1.41	1.53	4.39	0.82	4.29	3.43	3.52	4.38
	SE	0.20	0.22	0.62	0.15	0.78	0.63	0.64	0.62
Fixed									
	M	2.82_a	3.30_{ab}	3.89_b	2.96_a	3.23_a	3.49_a	3.59_a	3.89_a
	SD	0.74	1.20	1.64	0.93	1.16	1.47	1.49	1.64
	SE	0.10	0.16	0.23	0.17	0.21	0.27	0.27	0.23
Difference									
	M	0.75	0.91	4.33	-.09	2.92	2.30	2.84	4.33
	SE	0.22	0.27	0.66	0.23	0.81	0.68	0.70	0.66
	t (1 tail)	3.34**	3.32**	6.54**	0.40	3.59**	3.39**	4.07**	6.54**
	df	18	18	18	18	18	18	18	18

Notes. Difference is obtained by subtracting M (fixed) from M (random). Means in the same row and viewing condition(Duration or Velocity) which do not share a common subscript differ at $p < .05$ in the Tukey HSD comparison. ** denotes significance at $p < .01$, * denotes significance at $p < .05$.

Table 8

Comparison of Mean Acuity Thresholds (min) for Fixed and Random Target Direction as a Function of Viewing Condition, Phase II, Session 2

		Viewing Condition							
		Duration (ms)			Velocity (deg/s)				
Target Direction		570	370	170	0	22	45	70	100
Combined									
	M	3.41_a	3.71_a	5.37_b	2.78_a	4.56_b	4.56_b	4.39_b	4.52_b
	SD	1.30	1.33	2.91	0.68	2.62	2.25	2.06	2.20
	SE	0.13	0.13	0.29	0.09	0.34	0.29	0.26	0.28
Random									
	M	3.79_a	4.16_a	7.12_b	2.87_a	6.15_b	5.36_b	5.28_b	7.12_b
	SD	1.45	1.34	2.94	0.82	2.79	2.56	2.31	3.62
	SE	0.21	0.19	0.42	0.15	0.51	0.47	0.42	0..41
Fixed									
	M	3.03_a	3.25_a	3.62_a	2.69_a	2.96_{ab}	3.77_b	3.50_{ab}	3.62_b
	SD	1.00	1.16	1.52	0.49	0.93	1.52	1.29	1.52
	SE	0.14	0.16	0.21	0.09	0.17	0.28	0.24	0.21
Difference									
	M	0.75	0.92	3.50	0.18	3.20	1.60	1.77	3.50
	SE	0.25	0.25	0.46	0.17	0.53	0.54	0.48	0.47
	t (1 tail)	3.02**	3.65**	7.47**	1.03	5.95**	2.93**	3.67**	7.47**
	df	18	18	18	18	18	18	18	18

Notes. Difference is obtained by subtracting M (fixed) from M (random). Means in the same row and viewing condition(Duration or Velocity) which do not share a common subscript differ at $p < .05$ in the Tukey HSD comparison. ** denotes significance at $p < .01$, * denotes significance at $p < .05$.

Table 9

Comparison of Mean Acuity Thresholds (min) for Fixed and Random Target Direction as a Function of Viewing Condition, Phase II, Session 3

Target Direction		Duration (ms) 570	370	170	Velocity (deg/s) 0	22	45	70	100
Combined									
	M	3.38_a	3.57_a	5.21_b	2.96_a	4.65_b	4.34_b	4.08_b	4.25_b
	SD	1.23	1.30	3.07	0.93	2.82	2.62	1.87	1.97
	SE	0.12	0.13	0.31	0.12	0.36	0.33	0.24	0.25
Random									
	M	3.79_a	3.95_a	6.91_b	2.96_a	6.07_b	5.36_b	4.74_b	6.91_b
	SD	1.35	1.36	3.41	0.93	3.26	3.21	2.14	3.41
	SE	0.19	0.19	0.48	0.17	0.59	0.59	0.39	0.48
Fixed									
	M	2.97_a	3.19_{ab}	3.51_b	2.96_a	3.23_a	3.32_a	3.41_a	3.23_a
	SD	0.95	1.13	1.29	0.93	1.61	1.21	1.26	1.29
	SE	0.13	0.16	0.18	0.17	0.21	0.22	0.23	0.18
Difference									
	M	0.81	0.76	3.39	0.00	2.84	2.14	1.33	3.38
	SE	0.23	0.25	0.51	0.24	0.63	0.62	0.45	0.52
	t (1 tail)	3.47**	3.02**	6.57**	0.00	4.49**	3.25**	2.94**	6.57**
	df	18	18	18	18	18	18	18	18

Notes. Difference is obtained by subtracting M (fixed) from M (random). Means in the same row and viewing condition (Duration or Velocity) which do not share a common subscript differ at $p < .05$ in the Tukey HSD comparison. ** denotes significance at $p < .01$, * denotes significance at $p < .05$.

Table 10

Comparison of Mean Acuity Thresholds (min) for Fixed and Random Target Direction as a Function of Viewing Condition, Phase II, Session 4

		Viewing Condition							
		Duration (ms)			Velocity (deg/s)				
Target Direction		570	370	170	0	22	45	70	100
Combined									
	M	3.41_a	3.63_a	5.45_b	2.87_a	4.78_b	4.52_b	4.12_b	4.52_b
	SD	1.24	1.32	3.02	0.82	2.90	2.09	2.05	2.25
	SE	0.12	0.13	0.30	0.11	0.37	0.27	0.27	0.29
Random									
	M	3.62_a	4.16_a	7.33_b	2.96_a	5.59_b	5.64_b	5.01_b	7.33_b
	SD	1.32	1.35	3.03	0.93	3.51	2.18	2.35	3.03
	SE	0.19	0.19	0.43	0.17	0.64	0.40	0.43	0.43
Fixed									
	M	3.19_a	3.09_a	3.57_a	2.78_a	3.67_b	3.41_{ab}	3.23_{ab}	3.57_{ab}
	SD	0.95	1.05	1.41	0.68	1.51	1.26	1.16	1.41
	SE	0.16	0.15	0.20	0.13	0.28	0.23	0.21	0.20
Difference									
	M	0.43	1.08	3.76	0.18	2.20	2.23	1.78	3.76
	SE	0.25	0.24	0.47	0.21	0.70	0.46	0.48	0.47
	t (1 tail)	1.76*	4.48**	7.95**	0.85	3.16**	4.86**	3.71**	7.95**
	df	18	18	18	18	18	18	18	18

Notes. Difference is obtained by subtracting M (fixed) from M (random). Means in the same row and viewing condition(Duration or Velocity) which do not share a common subscript differ at $p < .05$ in the Tukey HSD comparison. ** denotes significance at $p < .01$, * denotes significance at $p < .05$.

Table 11
Comparison of Mean Acuity Thresholds (min) for Fixed and Random Target Direction, Phase II.

Target Direction		Viewing Condition [a] All Parameters	Dynamic Parameters Only
Random			
	$\underline{M}$	5.07	5.61
	$\underline{SD}$	2.84	2.91
	$\underline{SE}$	0.12	.13
Fixed			
	$\underline{M}$	3.28	3.4
	$\underline{SD}$	1.23	1.3
	$\underline{SE}$	0.50	.06
Difference			
	$\underline{M}$	1.78	2.21
	$\underline{SE}$	.13	.14
	$\underline{F}_{(1, 18)}$	175.27**	186.61**

Note. Difference is obtained by subtracting M (fixed) from M (random). ** denotes significance at $p < .01$. a "All parameters" includes 15 measurements resulting from factorial combination of five velocities (0, 22, 45, 70, and 100 deg/s) and three durations (170, 370, and 570 ms). "Dynamic parameters" includes twelve of above measurements, without 0 deg/s velocity.

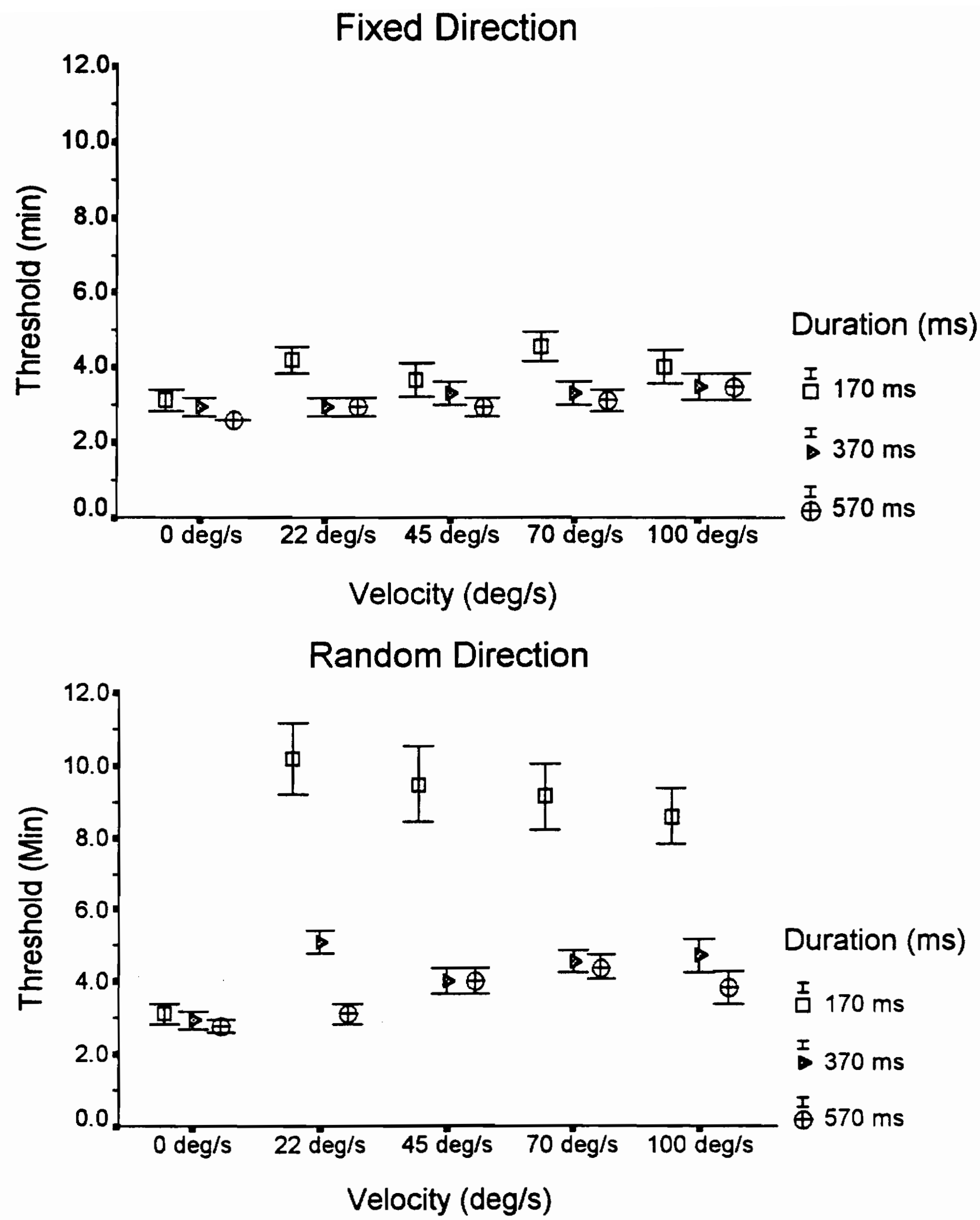

Figure 1. Three way interaction between Condition (target direction), Velocity, and Duration, Phase I. Error bars denote +/- 1 SE of the mean.

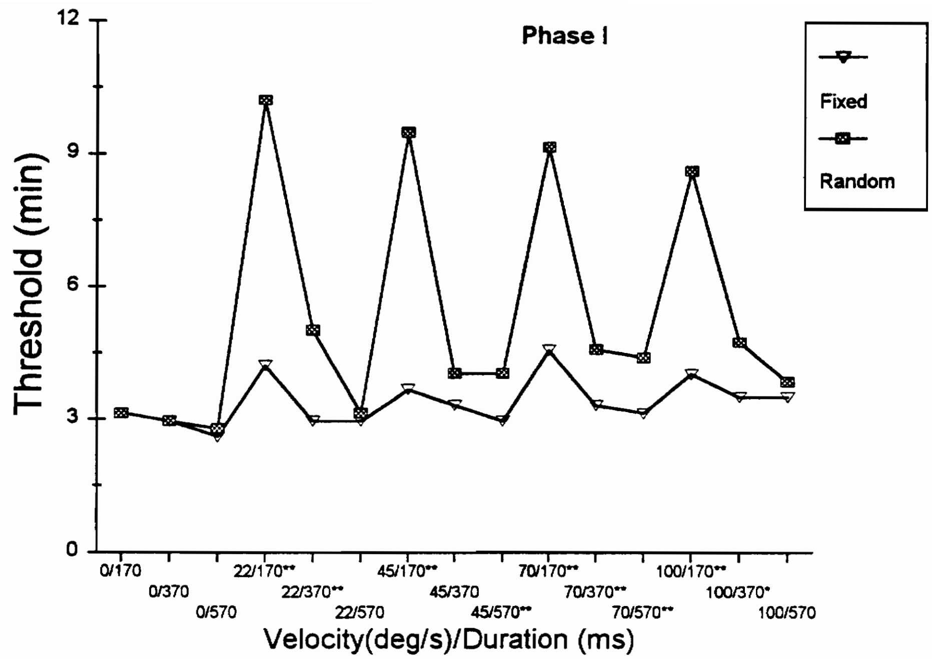

Figure 2. Comparison of mean acuity threshold (min) of fifteen target velocity/duration parameters for fixed (left to right) or random (six possible) linear target direction conditions ($\underline{n} = 15$ per condition). Mean differences obtained by subtracting $\underline{M}$ fixed from $\underline{M}$ random for each parameter. Mean differences for parameter significant at $\underline{p} < .01$** or $\underline{p} < .05$*. Single session Phase I.

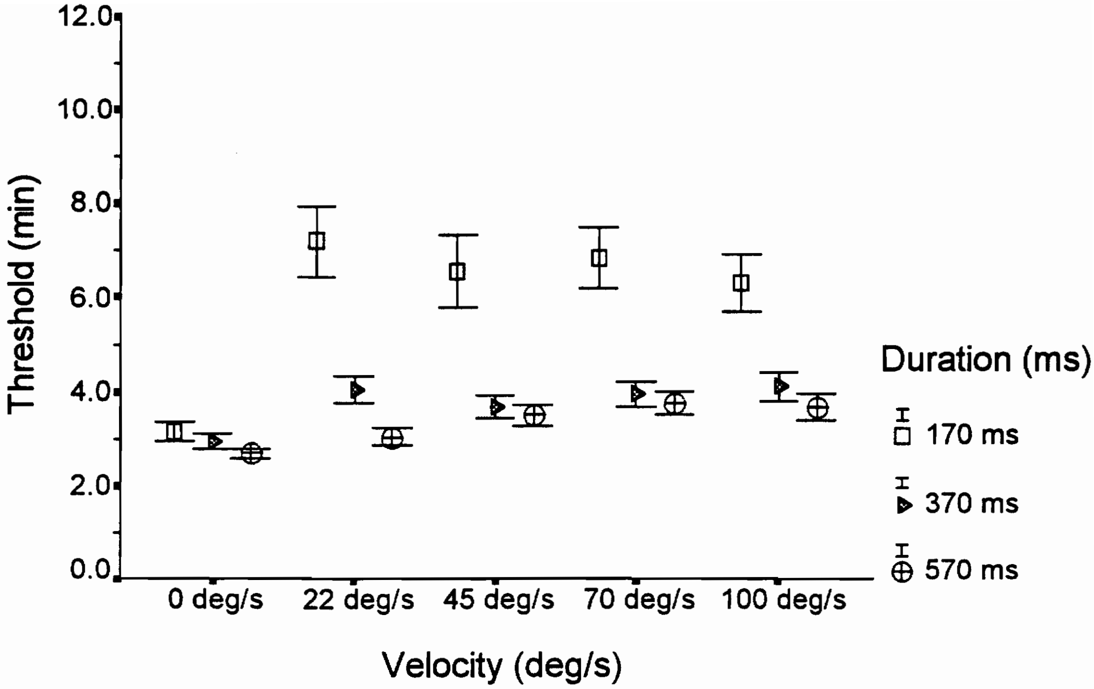

Figure 3. Two way Interaction between Duration and Velocity, Phase I. Error bars denote +/- 1 SE of the mean.

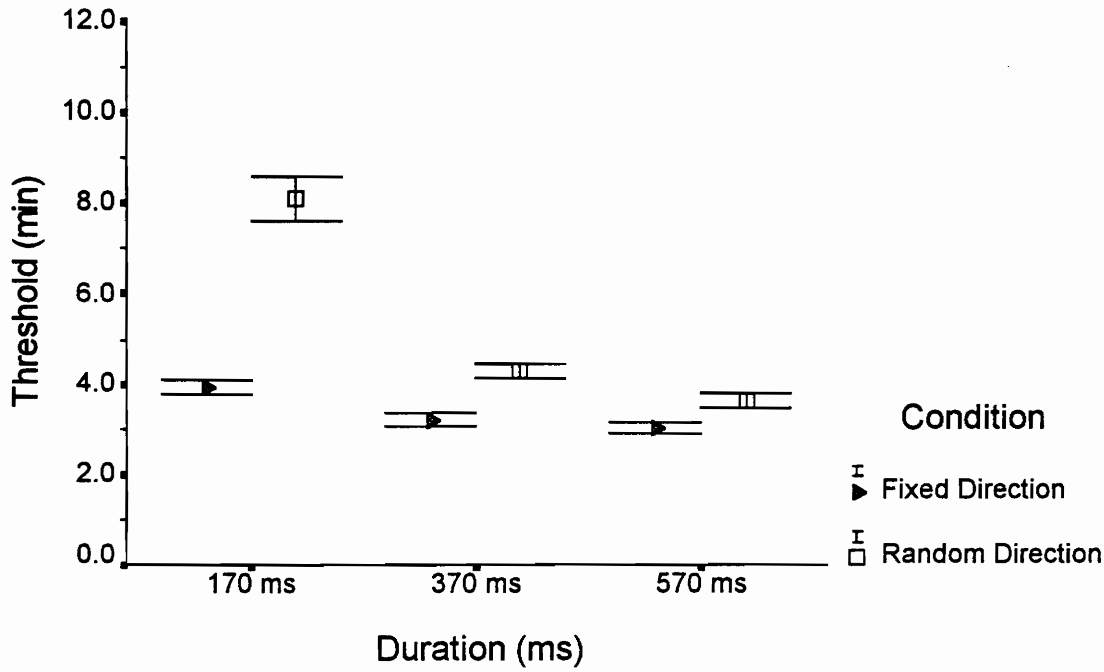

Figure 4. Two way interaction between Duration and Condition. Phase I. Error bars denote +/- 1 SE of the mean.

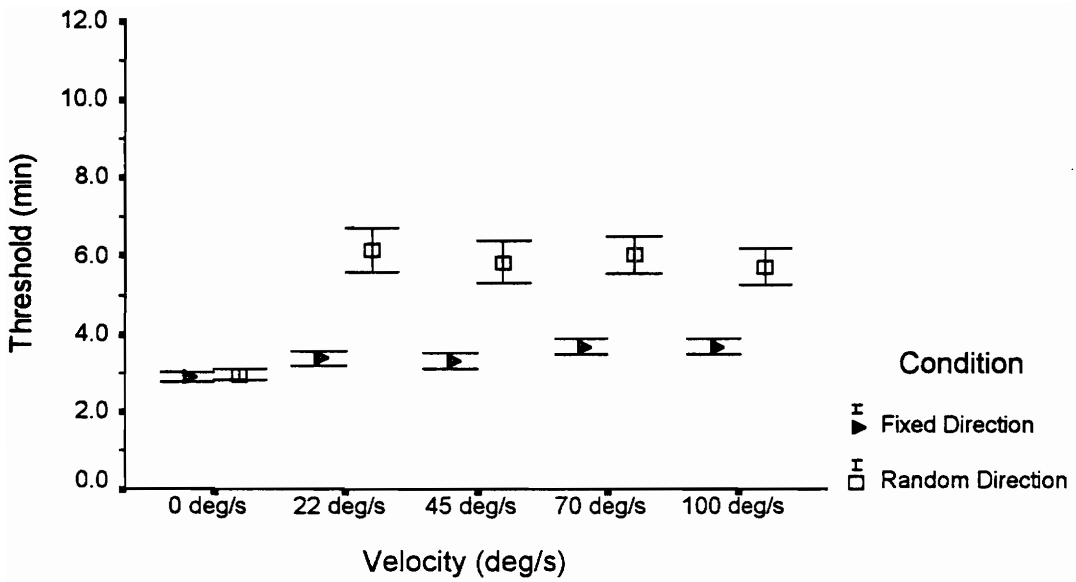

Figure 5. Two way interaction between Velocity and Condition, Phase I. Error Bars denote +/- 1 SE of the mean.

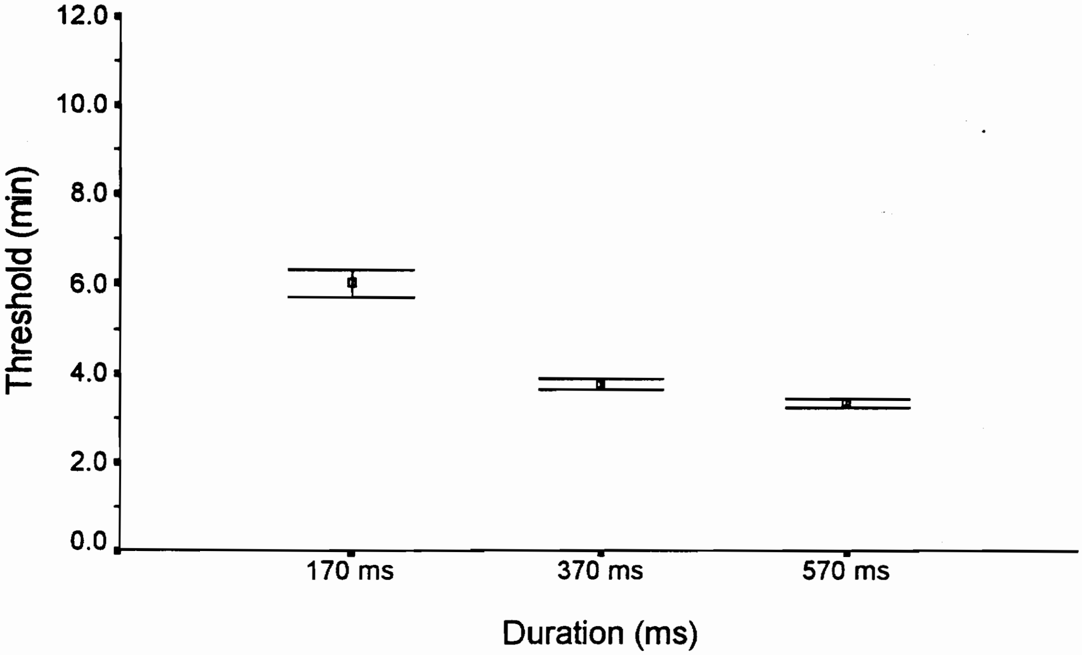

Figure 6. Main Effect of Duration, Phase I. Error bars denote +/- 1 SE of the mean.

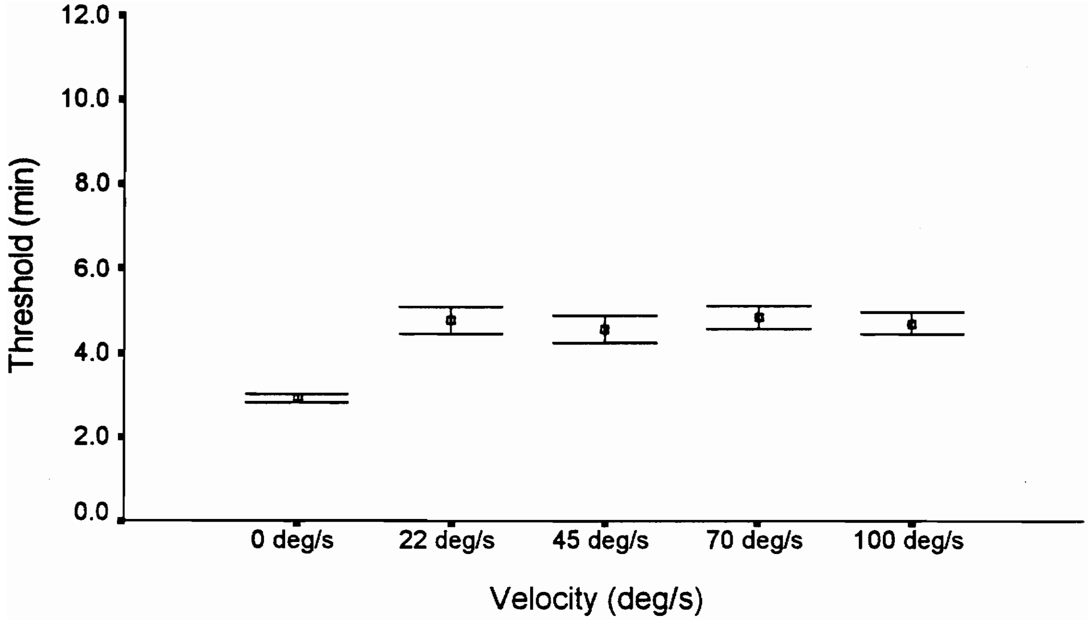

Figure 7. Main effect of Velocity, Phase I. Error bars denote +/- 1 SE of the mean.

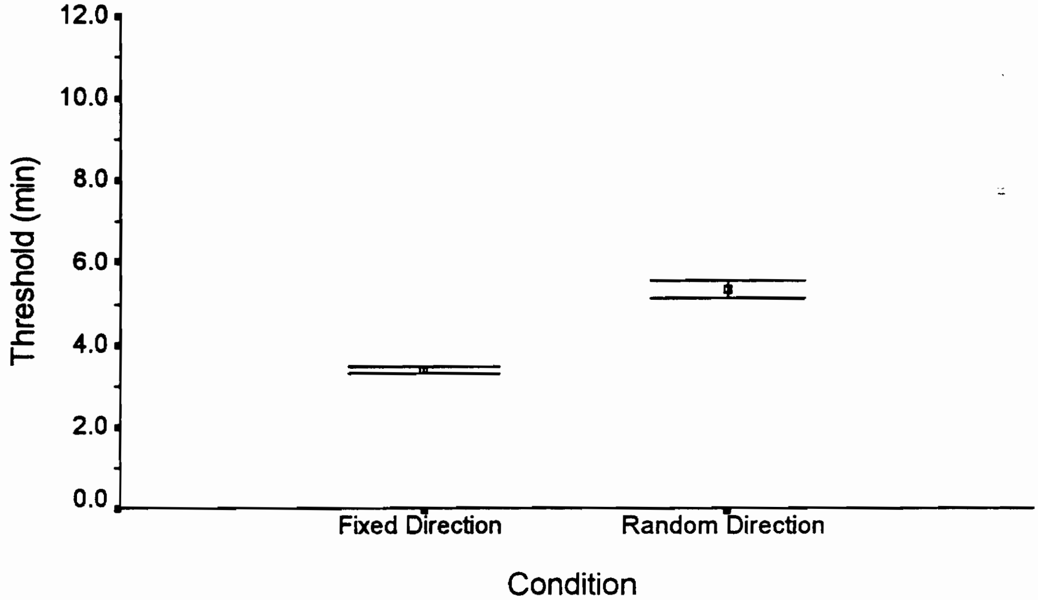

Figure 8. Main Effect of Condition, Phase I. Error bars denote +/- 1 SE of the mean.

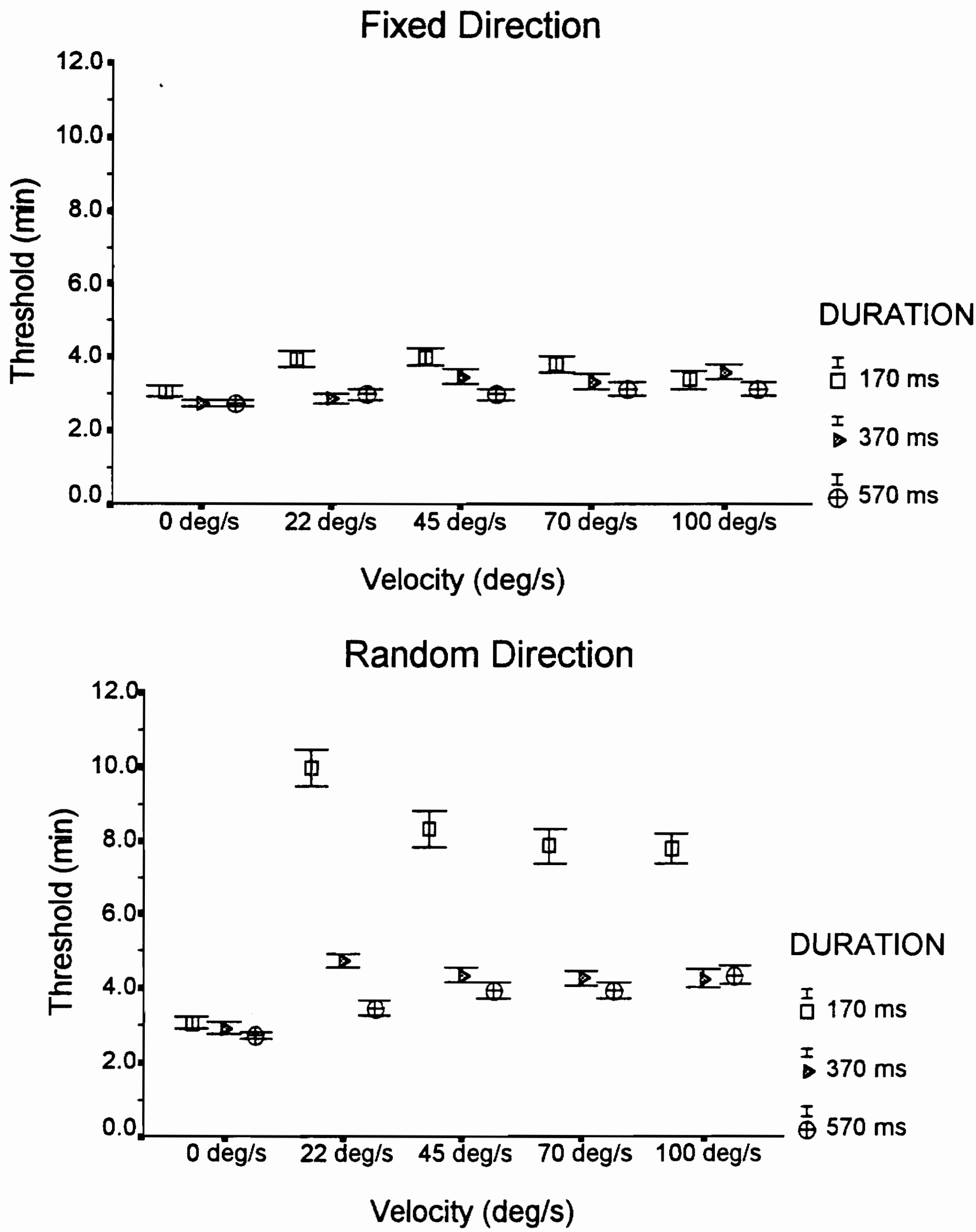

Figure 9. Three way interaction between Condition (target direction), Velocity, and Duration, Phase II. Error Bars denote +/- 1 SE of the mean.

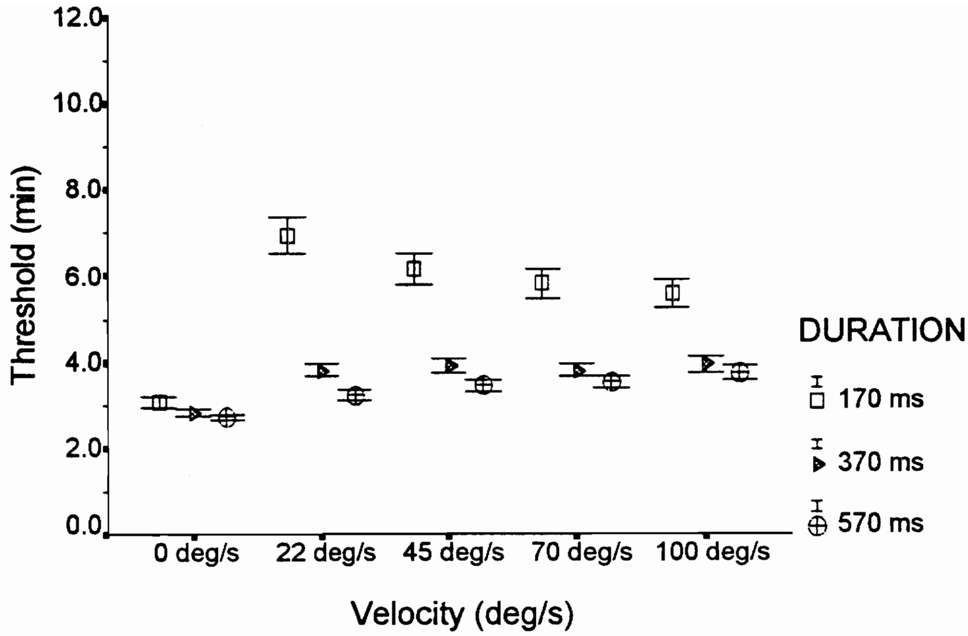

Figure 10. Two way interaction between Duration and Velocity, Phase II. Error Bars denote +/- 1 SE of the mean.

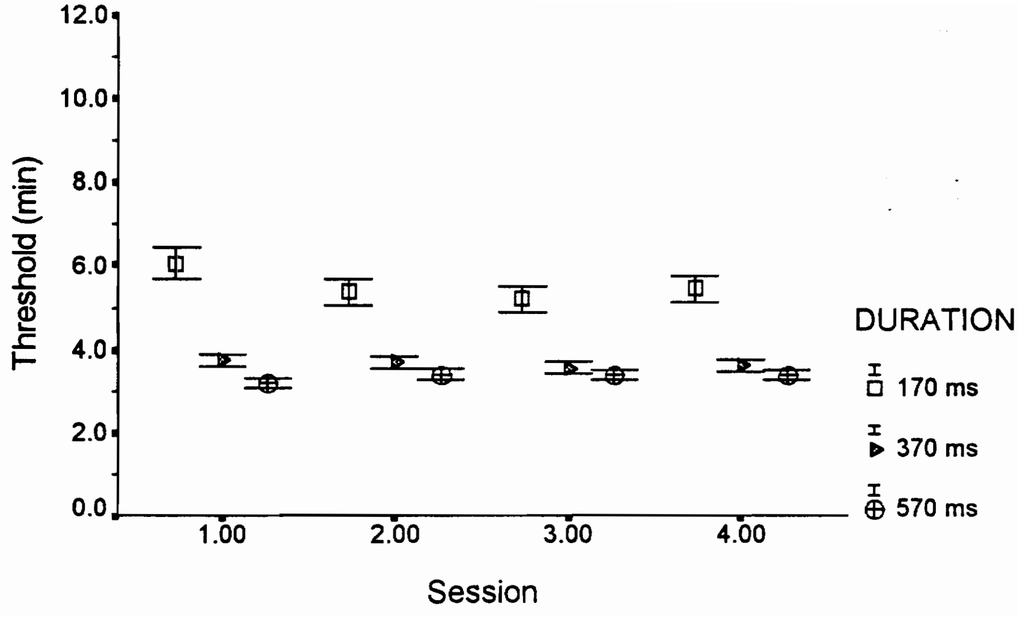

Figure 11. Two way interaction between Session and Duration, Phase II. Error Bars denote +/- 1 SE of the mean.

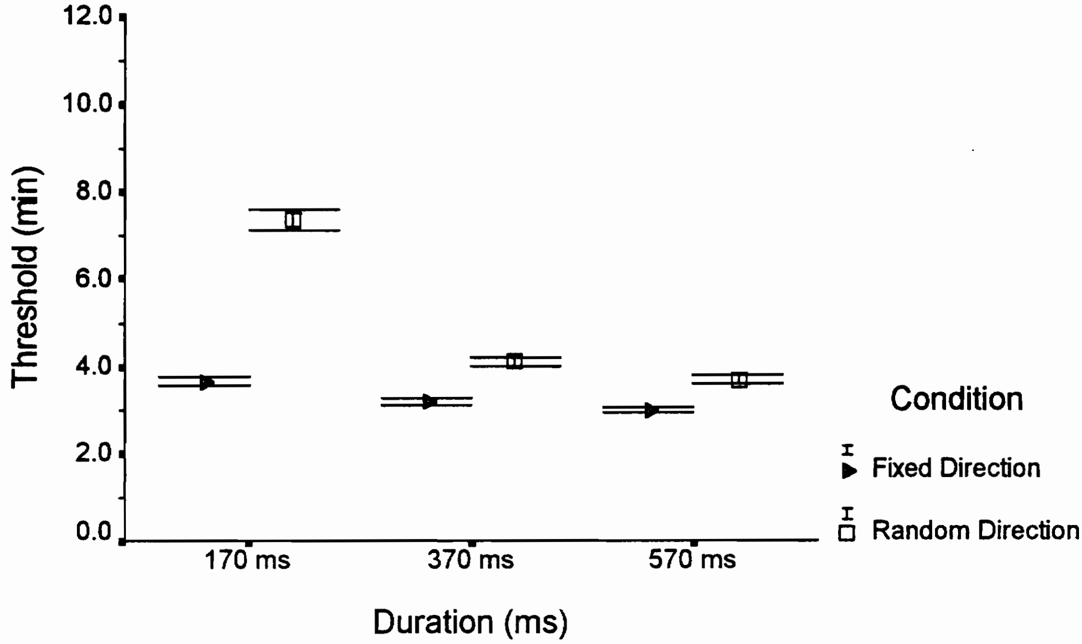

Figure 12. Two way interaction between Duration and Condition. Error bars denote +/- 1 SE of the mean.

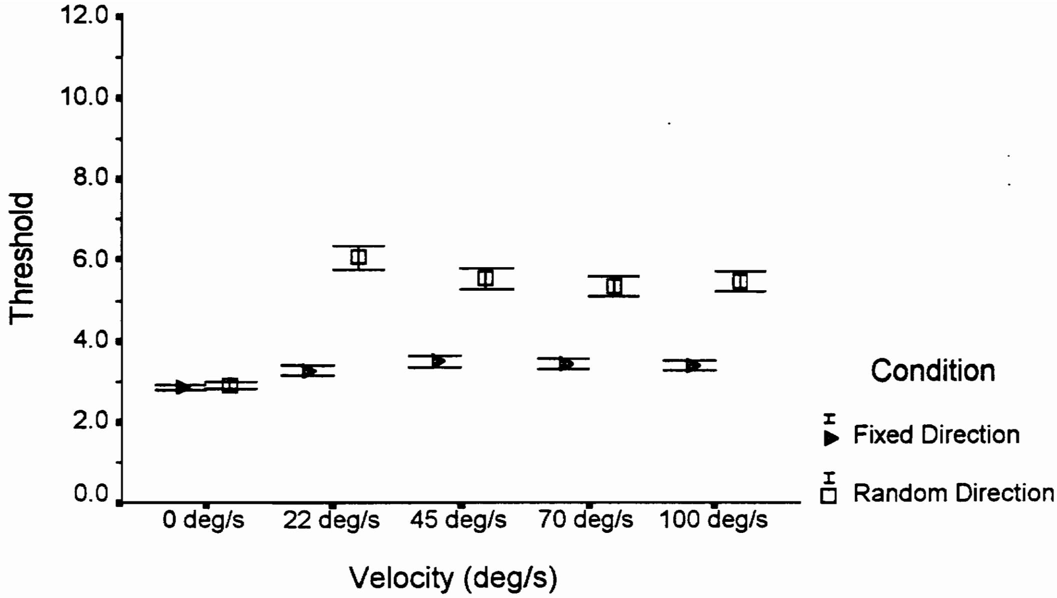

Figure 13. Two way interaction between Velocity and Condition, Phase II. Error Bars denote +/- 1 SE of the mean.

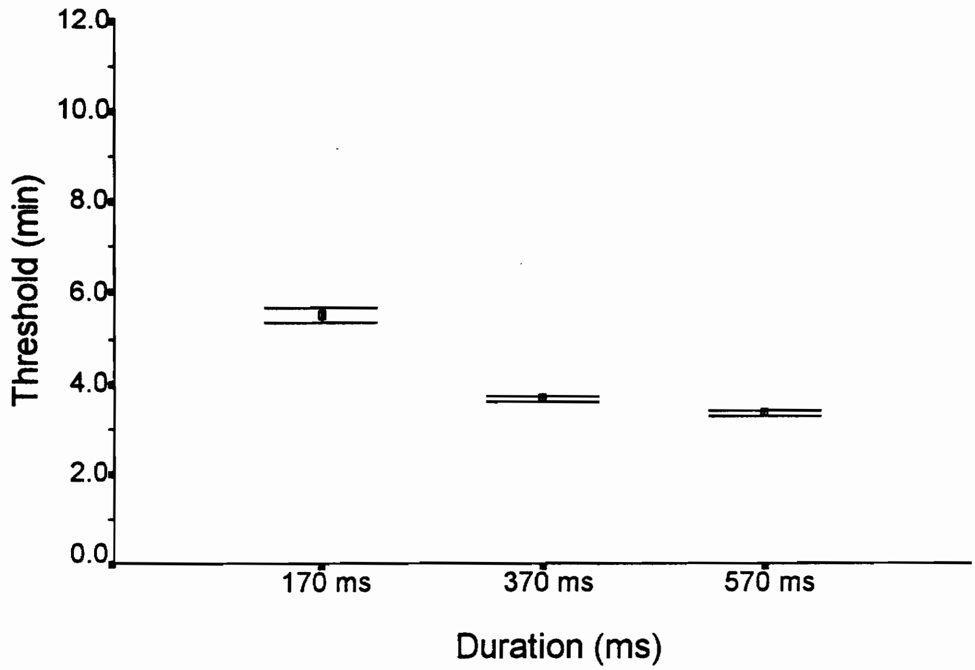

Figure 14. Main Effect of Duration, Phase II. Error bars denote +/- 1 SE of the mean.

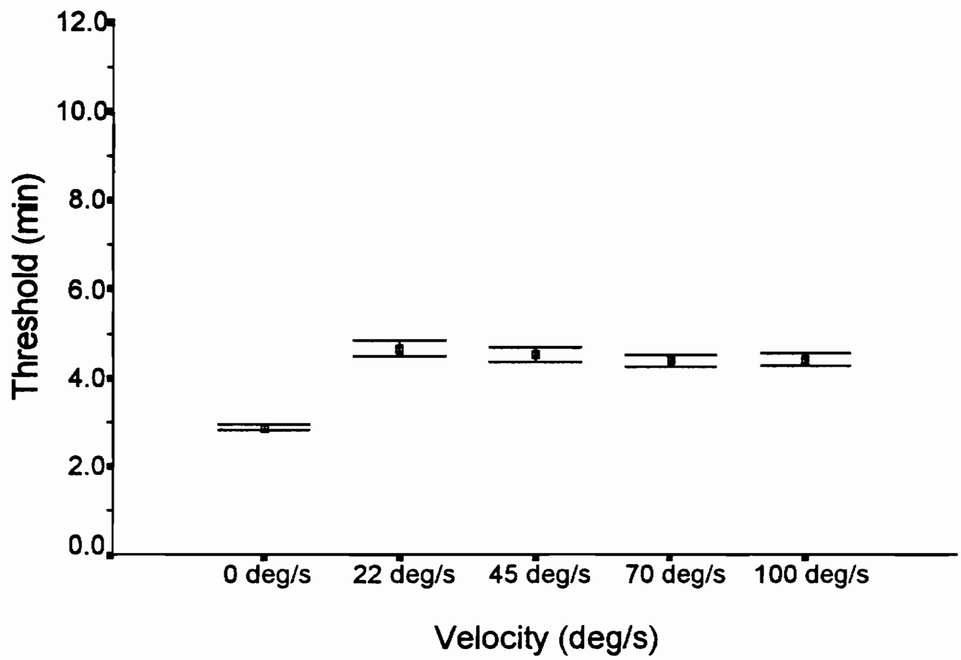

Figure 15. Main effect of Velocity, Phase II. Error Bars denote +/- 1 SE of the mean.

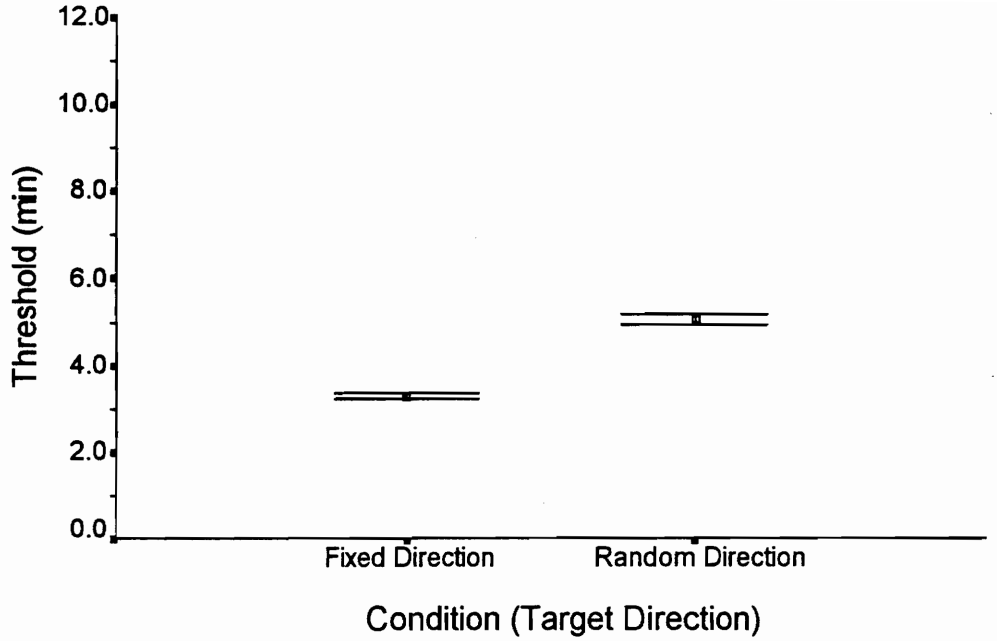

Figure 16. Main effect of Condition, Phase II. Error bars denote +/- 1 SE of the mean.

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APPENDIX A: VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
INFORMED CONSENT FORM

TITLE: Dynamic Visual Acuity (Study # 95-168)

PRINCIPLE INVESTIGATOR: Joseph P. Shevlin

1. **PURPOSE OF EXPERIMENT**: You are invited to participate in an experiment which will examine the effects of object movement on an observer's ability to see and correctly identify a critical feature of that object.

2. **PROCEDURES**: To accomplish the goals of this study, you will be asked to participate in up to four one-hour sessions. During the first session, your corrected vision (wearing your contact lenses or glasses if applicable) will be tested using the OPTEC 2000 vision tester. This OPTEC test requires you to look through a device which is similar to a binocular microscope, and determine the smallest object you can correctly identify. This examination should provide you with a good estimate of your visual acuity (ie 20/20, 20/30, etc), but should not be viewed as a substitute for an eye examination conducted by an optometrist. Your vision will be tested with the OPTEC only during the first session.

During the remainder of the first session, as well as the subsequent three sessions, you will participate in a visual screening test which will be similar to a computer game, again wearing your eyeglasses or contact lenses. You will be seated in a chair no closer than 29 cm to a computer monitor. The letter 'C" will be displayed on the computer screen, starting with a large "C". This letter "C" will either be stationary or move across the screen at several different speeds and for several different durations. Your task will be to correctly identify the direction in which the gap in the "C" is oriented and input your decision into the computer using the arrows on the keyboard. The "C" will continue to get smaller with each correct response, until the computer determines the smallest "C" you can correctly identify for that combination of speed and duration. Each of these four sessions will last approximately one hour. You will be provided with rest breaks every fifteen minutes, or at your request in between trials.

3. **CONFIDENTIALITY**: The results of this study will be kept strictly confidential. At no time will the researchers release your results to anyone without your written consent. The information you provide will have your name removed and only a subject number will identify you during analysis and any write up of the research.

4. **DISCOMFORTS AND RISKS FROM PARTICIPATION IN THIS STUDY**: There are no apparent risks to you from participating in this study.

5. **EXPECTED BENEFITS**: The results from this study may be potentially relevant for visual screening and training for activities such as flying, driving, operating equipment, or participating in athletics.

6. **FREEDOM TO WITHDRAW**: You are free to withdraw at any time without penalty

7. **EXTRA CREDIT**: For participating in this study, you will receive 1 experimental extra-credit point for each session in which you participate. Two bonus extra credit points will be awarded participants who complete all four sessions, for a maximum total of six experimental extra-credit points. See your teacher for alternate ways to earn extra credit.

8. **USE OF RESEARCH DATA**: The information from this research may be used for scientific or educational purposes. It may be presented at scientific meetings and/or published and reproduced in professional journals or books, or used for any other purpose that Virginia Tech's department of Psychology considers proper in the interest of education, knowledge, or research.

9. **APPROVAL OF THIS RESEARCH**: This research has been approved by the Human Subjects Committee of the Department of Psychology and the Institutional review board of Virginia Tech. (Study # 95-168).

10. **SUBJECT'S PERMISSION**:

I have read and understand the above description of this study. I have had the opportunity to ask questions and have had them all answered. I hereby acknowledge the above and give my voluntary consent for participation in this study.

I further understand that if I participate, I may withdraw at any time without penalty, and will receive experimental credit only for those sessions which I have completed.

I also understand that should I have any further questions regarding this research and its conduct, I should contact any of the persons named below.

I have been provided a copy of this form for my records.

PRIMARY RESEARCHER:	Joseph P. Shevlin	381-9702
FACULTY ADVISOR:	Al Prestrude, Ph.D.	231-5673
CHAIR, HSC:	Richard Eisler, Ph.D.	231-7001
CHAIR, IRB:	Ernest Stout, Ph.D.	231-9359

PARTICIPANT'S SIGNATURE:______________________________ DATE:______________

PARTICIPANTS ID:______________________________

Appendix B: Derivation of Measures of Velocity and Size

Discussion

The size (visual angle) of a target as imaged on the retina is a function of the target's physical size and the target's distance from the observer. This relationship is expressed by one of two formulae: (Schiffman, 1990)

$$\text{Tan } b/2 = s/2d$$

or

$$\text{Tan } b = s/d \quad \text{(for angles less than 10 deg)}$$

Where: b = visual angle in degrees s = physical size of target; d = viewing distance.

Similarly, the velocity of a target as imaged on the retina varies with the target's physical rate of movement and the target's distance from the observer. As viewing distance doubles, the physical rate of target movement must also double to achieve perceptually equivalent velocity..

Because perceptual size and perceptual velocity change as viewing distance, two interdependent issues had to be addressed to display and move targets on a flat screen: target size and target velocity.

Target Size

Most DVA research has used hemicylindrical screens to display moving visual targets. These round screens enabled researchers to hold viewing distance constant. Consequently, the retinal image size (visual angle) of a moving target remained constant when projected onto the hemicylindrical screen.

Because the computer screen is flat, the viewing distance to targets displayed in the peripheral areas of the screen will be greater than the viewing distance to targets displayed in the center of the screen. Because of this discrepancy in viewing distance, targets displayed on the screen periphery will register a smaller visual angle on the retina. As a target moves towards the center of the screen, the visual angle projected onto the retina increases in size, and as the target moves away from the center of the screen the retinal image of the target decreases in size.

All measurements of target size in this study represent the largest possible visual angle imaged by a target on the retina. The d in the formula tan B = s/d is no greater than the 34 cm viewing distance, which is the minimum possible viewing distance in the current study.

Table B1 compares the target sizes used in the current study with the target sizes used in prior research (Long & Riggs, 1991; Long & Roarke, 1989). The range of target sizes is comparable in the current and prior research, however the increments between sizes differ. Long et al's scale contained 13 size increments ranging from 2.3 min to of 43.2 min. The increments between targets was unequal, increasing by 1.1 min at smaller end of the scale and by 11.4 min at the larger end of the scale.

The current research used a 9 increment scale ranging from 2.6 min to 23.7 min. (Target sizes greater than 23.7 min were not included in the current study based on pilot research.) The increments between targets was equal (2.629 min).

Because of the equality of increments used in the current study, this scale is less sensitive for targets smaller than 19 min compared to the scale used by Long and colleagues. The equality of increments is a consequence of displaying Landolt C targets on a computer screen. The size of the equal increment is a function of minimum viewing distance (34 cm in the current study).

Landolt C targets feature a gap (critical detail) which is one fifth the diameter of the C. The size of the gap corresponds with the thickness of the line which forms the C. (Schiffman, 1990). Consequently, the smallest Landolt C a computer can display is five by five pixels, with a 1 pixel gap (critical detail). The next largest Landolt C possible is ten by ten pixels, with a two pixel gap. Larger Landolt Cs can be displayed by increasing the C by five pixels and the gap by one pixel.

The size of increment used in the current study could be reduced to 1.1 min by increasing the viewing distance to 85 cm. Such an increase in viewing distance, would reduce the maximum possible velocity to 36 deg/s for 570 ms.

Target Velocity

Target velocities in DVA research have been conventionally expressed in deg/s, based on the angle of arc over which the targets traversed on the hemicylindrical screens. The measurement of deg/s in the current study reflects a similar concept, although has slightly different perceptual implications from conventional DVA measures of deg/s. The current study bases flat screen velocity measures of deg/s on prior research using the angular measure of deg/s.

As opposed to traveling along the physical length of the arc of "x" degrees per second, as has been the convention, the current targets travel along the physical length of the base of this same arc per second. Because the shortest distance between two points is a line, the length of the base of an arc is always shorter than the length of the arc itself. Consequently, in the current study, flat screen targets will traverse a shorter physical distance in the same amount of time compared to conventional hemicylindrical screen measures. Perceptually, this distinction will manifest itself in predictable distortion of apparent target size, as discussed above.

Table B2 outlines the formulae used to calculate arc base length. Table B3 describes properties of the computer display, the flat screen distance the targets traversed based on a exposure duration (170, 370, 570 ms), and resulting velocity based on the minimum viewing distance of 34 cm.

Table B1

Formulae for Arc Base Length

	Degrees of Arc			
	120 deg	90 deg	60 deg	30 deg
BASE	sin 120(r/sin 30)	sin 90(r/sin 45)	sin 60(r/sin 60)	sin 30(r/sin 75)

Note: r = radius of the circle, which corresponds to the minimum viewing distance. The current experiment will use a viewing distance of 34 cm. At this viewing distance base length of 100 deg = 52 cm, 70 deg = 39 cm, 45 deg = 26 cm, 13 cm.

Table B2

Computer Display Properties and of Measure of Velocity Based on Exposure Times (ET)

Display Movement Properties			Physical Distance Based on ET				Velocity
Pixels Moved	Frequency	Rate mm/ms	Rate mm/s	mm/ 570ms	mm/ 370ms	mm/ 170ms	Velocity deg/s
1	2ms	.13	130	74.1	48.1	22.1	22.04
1	1ms	.26	260	148.2	96.2	44.2	44.95
3	2ms	.39	390	222.3	144.3	66.3	69.99
2	1ms	.52	520	296.4	192.4	88.4	99.76

Notes. Monitor is .26mm dot pitch shadow mask. Based on minimum viewing distance of 34 cm. Formula for Velocity:

$$= \text{arc sin } [.5 \frac{R}{D}]$$

Where: V = Velocity (deg/s); R= rate (mm/s); and D = Viewing distance (mm).

Table B3

Target Critical Detail (Gap) Visual Angle (B) in Minutes in Current and Prior Studies

Gap Size (mm) Current Study	B (minutes) Current Study	B (minutes) Prior Studies*
.26	2.6	2.3
.52	5.3	3.4
.78	7.9	4.6
1.04	10.6	5.7
1.30	13.1	6.8
1.56	15.8	9.8
1.82	18.4	11.4
2.08	21.0	13.7
2.34	23.7	17.4
2.60	NA	19.0
2.86	NA	26.7
3.12	NA	31.8
3.38	NA	43.2

Note. Computations for current study used the formula b = {arc tan (s/d)} 60 which is an algebraic derivation of the formula presented by Schiffman (1990). In this formula b = visual angle in minutes, s = physical size of the target, d = viewing distance, 60 = a correction factor applied to translate degrees into minutes. The visual angles of targets presented in the "prior studies" column reflects the sizes used by Long and Riggs (1991) and Long and Roarke (1989). Although the ranges of target sizes in the current study is similar to the ranges used in prior studies, the increments between target sizes in the current study are equal, whereas the sizes used in earlier studies was more sensitive at the smaller target end of the scale. 4. These sizes are computed based on a minimum viewing distance of 34 cm using a 17" .26mm dot pitch monitor.

Appendix C: Detailed Instructions to Participants:

(Actual computer text displayed in **bold** type)

When initiating the program, the computer povided the following technical information to verify display settings:

mode is <graphics mode type>
max scrn size in pixels = <xmax> x <ymax>
press return to continue

SCREEN CLEARS
DISPLAY CHANGES TO LEFT HALF WHITE, RIGHT HALF BLACK AND WAITS FOR A KEY TO BE PRESSED

This split screen display was used to calibrate the luminance of the target and background at the beginning of each session.

SCREEN CLEARS

The computer then prompted the experimenter for the following information for the data base:

Please enter subject number:
Please enter the last name of subject:
Please enter the first name:
Please enter SSN (nnn-nn-nnnn):
Please enter the age of subject:
Please enter the gender [M/F]:
Please enter the session number:
Will this be fixed [1] or random [2]?

IF '1' OR '2' IS NOT ENTERED, THE FOLLOWING IS DISPLAYED:

Must select either 1 or 2

SCREEN CLEARS

The experimenter then adjusted the hieght of the adjustable chair to raise each participant to the common viewing height of 129.5 cm above the floor, which corresponded to the center of the computer moniter.

The experimenter supplemented the computer instructions, emphasizing four ponts:

1) The purpose of the horizontal bar is to prevent you from getting too close to the screen and "cheating", however, it is to your advantage to be as close to the screen as the bar will allow.

2) The input mechanism is the arrow keys, and most people found it to be easiest to use their index finger to input "left", their ring finger to input "right, and their middle finger to discriminate between "up" and "down".

3). The experimenter will remain in the room in case the computer malfunctions or the participant has questions.

4) The session would begin with some practice rounds to ensure you feel comfortable with the task and the input mechanism. Once you feel comfortable with the task and have entered at least three decisions, let me know, and I will switch the computer to the test mode.

The computer then initiated the static familiarization round:

********** INTRODUCTION **********

The target for all visual testing on this computer program is the letter 'C'. The gap in the letter 'C' will be pointed in one of four directions: towards the top, bottom, right, or left of the computer screen.

Your task is to determine the direction in which the gap is pointing, and input your decision via the keyboard using the arrow keys. The computer will first present the largest 'C', and continue to present smaller 'C's until it determines the smallest 'C' you can correctly identify.

Press the Return (or Enter) key to continue

SCREEN CLEARS

The computer will beep approximately one second before each target appears. The computer will wait to present the next target until you input your answer for the current target. Therefore, you must guess. Accuracy is more important than

speed. Do the best you can.

Press the Return (or Enter) key to continue

SCREEN CLEARS

************ Static Threshold Practice ************

For this test, the 'C' will appear briefly in the middle of the screen and will not move. This practice round will familiarize you with the task.

The horizontal bar near your forehead will ensure you view the screen from no closer than 29 cm. It is to your advantage to be as close to the screen as the bar will allow. You may rest your forehead against the bar.

If you have any questions, please contact the experimenter now.

Press the Return (or Enter) key to continue with the practice round.

SCREEN CLEARS

FOR EACH ROUND BEGINNING...

You have <number of rounds left> rounds remaining

IF ONLY 1, IT SAYS

'round'

Press the Return (or Enter) key to resume.

SCREEN CLEARS AND C IS DISPLAYED

IF THE ANSWER WAS CORRECT

Correct!
Press the Return (or Enter) key to continue

OTHERWISE

Incorrect.
Press the Return (or Enter) key to continue

...FOR EACH ROUND END

SCREEN CLEARS

Once the participant indicated that they were comfortable with the task, the experimenter switched the computer to the test round, and supplemented the computer instructions, emphasizing two points:

1) Unlike the familiarization round, the testing will be conducted in three rounds, and the computer would provide no feedback after each guess. Instead, the computer would continue to present Cs untill it establishes the smallest C you can correctly identify.

2). Feel free to take a break in between rounds (whren there is text on the screen). Do not take a break during a round (when the computer is presenting Cs), or you may miss one.

The computer then initiated the static test round, displaying:

************ Static Threshold Test ************

For this test, the 'C' will appear briefly in the middle of the screen and will not move. This test is conducted in three rounds.
NOTICE: The testing round will not give any indication as to correct or incorrect, but will proceed to the next 'C'.

The horizontal bar near your forehead will ensure you view the screen from no closer than 29 cm. It is to your advantage to be as close to the screen as the bar will allow. You may rest your forehead against the bar.

If you have any questions, please contact the experimenter now.

Press the Return (or Enter) key to continue with the threshold testing round.

SCREEN CLEARS

FOR EACH ROUND BEGIN...

You have <number of rounds left> **rounds remaining**

IF ONLY 1, IT SAYS

'round'
Press the Return (or Enter) key to resume.

SCREEN CLEARS AND C IS DISPLAYED

...FOR EACH ROUND END

=

SCREEN CLEARS

Once the participant completed the static testing, the experimenter switched the computer to the dynamic familiarization round. Participants in either the fixed or random target direction conditions recieved instructions relevant to their respective tasks. The experimenter supplemented the computer instructions, emphasizing the following points:

1) This is a slightly different task. Again, you will be provided with some practice trials to familiarize yourself with the task. Let me know when you feel comfortable with the task, and I will switch the computer to the test mode. You must complete a minimum of three decisions.

The computer then initiated the dynamic familiarization as follws:

********** **Moving Threshold Practice** **********

This test is similar to the static test, except the 'C'

(FIXED DIRECTION)

will be moving across the screen from your left to your right.

OR (RANDOM DIRECTION)

will be moving across the screen in any one of six directions - horizontally:

left to right
right to left

diagonally:

top-left to bottom-right
top-right to bottom-left
bottom-left to top-right
bottom-right to top-left

AND BOTH TARGET CONDITIONS

Your task is the same as in the preceding test. Input the direction of the gap in the 'C' via the keyboard. This practice session will familiarize you with the task.

Press the Return (or Enter) key to continue

SCREEN CLEARS

The horizontal bar near your forehead will ensure you view the screen from no closer than 29 cm. It is to your advantage to be as close to the screen as the bar will allow. You may rest your forehead against the bar.

Again, you must guess, and accuracy is more important than speed. Do the best you can.

Press the Return (or Enter) key to continue with the practice round.

FOR EACH ROUND BEGIN...

You have <number of rounds left> **rounds remaining**

IF ONLY 1, IT SAYS

'round'

Press the Return (or Enter) key to resume.

SCREEN CLEARS AND C IS DISPLAYED

IF THE ANSWER WAS CORRECT

Correct!
Press the Return (or Enter) key to continue

OTHERWISE

Incorrect.
Press the Return (or Enter) key to continue

...FOR EACH ROUND END

SCREEN CLEARS

Once the participant indicated that they were comfortable with the task, the experimenter switched the computer to the test round, and supplemented the computer instructions, emphasizing two points:

1) Unlike the familiarization round, the testing will be conducted in three rounds, and the computer would provide no feedback after each guess. Instead, the computer would continue to present Cs untill it establishes the smallest C you can correctly identify.

2). Feel free to take a break in between rounds (when there is text on the screen). Do not take a break during a round (when the computer is presenting Cs), or you may miss one. There are 12 rounds to this test.

The computer then initiated the dynamic test, displaying:

************   Moving Threshold Test   ************

This test is similar to the static test, except the 'C'

(FIXED DIRECTION)

will be moving across the screen from your left to your right.

OR RANDOM DIRECTION)

will be moving across the screen in any one of six

directions - horizontally:
left to right
right to left
diagonally:
top-left to bottom-right
top-right to bottom-left
bottom-left to top-right
bottom-right to top-left

(FIXED AND RANDOM DIRECTION)
Your task is the same as in the preceding test. Input the direction of the gap in the 'C' via the keyboard. This test will be conducted in twelve rounds, each using a different combination of target speed and display time.
NOTICE: The testing round will not give any indication as to correct or incorrect, but will proceed to the next 'C'.

Press the Return (or Enter) key to continue

SCREEN CLEARS

The horizontal bar near your forehead will ensure you view the screen from no closer than 29 cm. It is to your advantage to be as close to the screen as the bar will allow. You may rest your forehead against the bar.

Again, you must guess, and accuracy is more important than speed. Do the best you can.

Press the Return (or Enter) key to continue with the moving test round.

SCREEN CLEARS

FOR EACH ROUND BEGIN...

You have <number of rounds left> **rounds remaining**

IF ONLY 1, IT SAYS
'round'

Press the Return (or Enter) key to resume.

SCREEN CLEARS AND C IS DISPLAYED

...FOR EACH ROUND END

Vita

Joseph P. Shevlin

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EDUCATION:

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U.S. Army Airborne School, Ft. Benning GA
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EMPLOYMENT:

1988-1990: Rifle Platoon Leader, Anti-Armor Platoon Leader, 82nd Airborne Division, Ft. Bragg NC
1990-1991: Company Executive Officer, 82nd Airborne Division, Ft Bragg NC, Saudi Arabia, and Iraq.
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- Distinguished Military Graduate
- Psi Chi
- Phi Beta Kappa
- Willard F. Rockwell and Presley L. Stevenson Scholarship Leadership Awards, Kappa Sigma.

Military:
- Bronze Star Medal
- Meritorious Service Medal
- Army Commendation Medal (x 2)
- Army Achievement Medal (x2)
- National Defense Service Medal
- Army Service Ribbon
- Southwest Asia Service Ribbon (x2)
- Liberation of Kuwait Medal
- Combat Infantryman's Badge
- Expert Infantryman's Badge
- Master Parachutist Badge
- Pathfinder Badge
- Ranger Tab