# TEXT ORIENTING CUES: ENHANCING DYNAMIC VISUAL ACUITY FOR TARGETS OF UNKNOWN ORIGIN

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Dynamic Visual Acuity (DVA) refers to an observer's ability to resolve a critical detail in a visual target given relative motion between the observer and the target (Ludvigh & Miller, 1958). Prestrude (1987) abstracted three reviews of DVA literature (Hoffman, Rouse & Ryan, 1981; Miller & Ludvigh, 1962; Morrison, 1980) that encapsulate the DVA research since the concept was first introduced in 1937. This introduction discusses the major findings from this DVA literature. The introduction culminates with an in-depth review of research by Shevlin, Prestrude, and Shevlin (1997) because this dissertation programmatically extends this earlier study. The introduction is therefore organized into six sections.

Section 1: DVA Factors and Mechanisms

Section 2: DVA Versus Static Visual Acuity (SVA)

Section 3: Conventional Apparatusses and Procedures

Section 4: DVA: Capacity Versus Ability

Section 5: Shevlin et al. (1997)

Section 6: Implications and Hypotheses

## Dynamic Visual Acuity: Factors and Mechanisms

Target movement aids in target detection (determining the presence of a target); but generally impairs acuity (resolving a critical detail in the target). DVA generally deteriorates with increased target velocity and decreased target exposure duration (Morrison, 1980; Prestrude, 1987); decreased target illuminance (Miller & Ludvigh, 1962) and decreased target contrast (Brown, 1972b). Based on Miller's (1958) research, DVA appears to deteriorate similarly when stationary observers view vertically or horizontally moving targets, or when observers are rotated in a horizontal plane about stationary targets.

Increases in target velocity are generally accepted to 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 degrees per second (deg/s), followed by a marked deterioration as velocities increased beyond that point. Other researchers vary in opinion concerning the velocities at which DVA deteriorates. Brown (1972a) suggested 25-30 deg/s; Prestrude (1987) suggested 50 deg/s. These differences in opinion may simply reflect differences in experimental conditions and methods. Ludvigh and Miller (cited in Long & Roarke, 1989) illustrated a routine example in which target velocities exceeded 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 depicting these 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 factor. 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). Ludvigh and Miller (1958) discussed several mechanisms that may affect DVA (For a review of Miller and Ludvigh's early research on DVA, see Miller and Ludvigh, 1962). These mechanisms include inadequate speed of voluntary eye movements, extra-foveal retinal imaging, movement of the image on the retina, and inaccurate 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 attained velocities up to 500-600 deg/s during smooth pursuit movements. The upper limit of target velocity studied by Ludvigh and Miller was 170 deg/s, substantially less than the velocities demonstrated by Adler. DVA deteriorated at even slower velocities (Ludvigh and Miller, 1958).

Ludvigh and Miller (1958) also discounted extra-foveal imaging as a possible explanation for DVA by imaging static and dynamic targets on a retinal region 2 deg from the fovea. Although extra-foveal imaging degraded static acuity from 20/20 to 20/25, the additional impact of target velocity of only 10 deg/s further reduced acuity to 20/40 in the same (2 deg) extra-foveal region. Therefore, Ludvigh and Miller reasoned that extra-foveal imaging was a minor factor in DVA. Instead, they concluded the major factor was the movement of the image on the retina.

Ludvigh and Miller (1958) proposed imperfect pursuit movements of the eye may maintain the image in the vicinity of the fovea, but provide a moving image on the retina that reduces visual acuity. This moving image results in the eye receiving a lower intensity gradient than if the image were stationary. Ludvigh and Miller further reasoned that this hypothesis was supported by research showing that DVA performance improves with increased target illumination. Decreasing illumination levels yield the same effect as moving images – a reduced intensity gradient leading to decreased visual performance. Ludvigh and Miller further 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 errors. He defined velocity error as the difference between the angular velocities of the eye and target during the last smooth pursuit movement in the sample period. He described position error as the mean position of the target's image on the retina relative to the fovea during the last smooth pursuit movement in the sample period.

By measuring eye movements, Brown (1972a) demonstrated that during each successive smooth pursuit movement in a trial, the velocity mismatch between the eye and the target was reduced. 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 other words, as target velocity increased, the eyes required less time to make subsequent corrective movements. 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). In Brown's study, target exposure was limited to 450 ms, which may have been insufficient for the eyes to further reduce the velocity error.

Brown (1972b) suggested that the control of oculo-motor pursuit increases with increased target size, increased background illumination, and increased target contrast. These factors together may serve to vary the efficiency with which the eye can summate available energy. Brown (1972a, p. 320) accordingly concluded "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."

Dynamic Visual Acuity Versus Static Visual Acuity

DVA proponents contend measures of Static Visual Acuity (SVA) inadequately assess visual performance in real-world tasks. Because DVA is poorer than SVA, observers require larger targets for resolution under dynamic conditions. Daily activities such as walking, running, driving, participating in athletics, and operating equipment, involve visual tasks under conditions of relative motion. Measures of SVA are designed to optimally measure the refractive error of the visual system (Prestrude, 1987) and to optimize performance [National Research Council (NRC), 1982] by using "easy" (static, high contrast) targets. In contrast, DVA appears to measure visual performance not assessed by standard visual screening procedures. For example, individuals with identical SVA scores using Snellen Letters varied considerably when performing a DVA task (Morrison, 1980).

The NRC (1982, 1985) indicated DVA may be an important, practical measure of acuity in part because it is more closely related to flight performance and automobile operation than SVA. For instance, DVA correlated negatively with the accident frequency for bus and truck drivers. Long and Kearns (1996) tested observers for DVA using street signs as targets, and similarly reported negative correlations between DVA and motor vehicle accident rates. Consequently, the NRC declared DVA to have "real potential for the assessment of vision" (NRC, 1985, p. 24).

Because traditional measures of SVA inadequately assess this important aspect of vision, the NRC (1982) included DVA among several critical visual functions not assessed by visual examinations required of military and commercial pilots. Deterioration of these critical visual functions can 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 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)

## Conventional Apparatuses and Procedures

DVA has not been widely integrated into visual screening since the NRC's 1982 recommendation in part due to constraints imposed by the existing DVA measurement apparatuses (Shevlin et al., 1997). These apparatuses are large, complicated to use, and by no means portable. The concept behind this type of apparatus has not changed much since introduced by Ludvigh and Miller in 1958 (e.g., Long & Kearns, 1996). The observer views a target reflected either from a rotating front surface mirror or directly projected onto a hemicylindrical screen. Target velocity is created by rotating either the mirror, or the projector at a designated angular velocity. Burg and Hulbert (1961) and Burg (1966) provided photographs; whereas, Brown (1972c) provided 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 has limitations (see Appendix A: Derivation of Velocity and Size).

This apparatus design constrained target presentation to a single linear direction, typically from left to right. The conventional procedures required observers to focus on a fixation point. These apparatuses and procedures ensured that observers knew when and from where their next target would appear and were well suited for documenting DVA as an isolated sensory capacity. Yet, very often in real world applications, we are not aware of the origin of our next relevant visual target. DVA under real world conditions involves more than the simple refractive capability of the eye.

## DVA: Capacity vs Ability

In 1958, Ludvigh and Miller suggested "The value of an individual's dynamic visual acuity is dependent chiefly on the efficiency of the entire ocular pursuit mechanism..." (p. 805). Recent research conceptualizes DVA not as a limited sensory capacity, but as an integrated ability involving more than just the refractive capabilities and oculo-motor mechanisms of the eye. The NRC (1982, p. 748) concluded "Modern pilots can not be evaluated in terms of their physical skills; they must also be considered as managers of complex information systems."

If DVA is an integrated ability, training should improve DVA performance. Miller and Ludvigh (1962) reported a practice effect (multiple trials) that reached asymptote after 15-20 trials. Other researchers (Long & Rourke, 1989; Long & Riggs, 1991) reported significant improvement with training well beyond the 15-20 trial asymptote. To further approach DVA as an ability, researchers have called for DVA studies using unpredictable targets (Long & Riggs, 1991; Prestrude, 1987). The introduction of unpredictable targets may further distinguish DVA from SVA, increasing the benefit of including DVA screening in test batteries (Long & Riggs, 1991; NRC, 1982).

Unpredictable target use furthers the approach to DVA as an integrated ability, rather than as a sensory capacity, by including the cognitive, motor, and visual dimensions observers must orchestrate to detect and resolve real world DVA targets. Real world DVA tasks involve two components. First, the observer must locate the target. Once the target is located, the observer must then track and resolve the moving target. In short, real world DVA involves a visual search task followed by a task that combines visual tracking and acuity. Conventional apparatuses and procedures circumvented the initial search portion of the DVA task. Shevlin et al. (1997) took an initial step in answering the call for unpredictable targets by developing a computer platform that assessed DVA. The current study logically extended this earlier work.

<u>Shevlin et al. (1997)</u>

Shevlin et al. (1997) investigated the effects of random linear target presentation on DVA using binocular free-head viewing. In addition to conventionally presenting and moving targets from a single fixation point along a common path from left to right (fixed targets), this computer application randomly presented and moved successive targets from any of six locations in six linear paths (random targets). As hypothesized, DVA for random targets was poorer than for fixed targets (by as much as 6.005 [+/- 1.09 min], see Figure 1).

When observers knew a target's origin, the generally accepted DVA relationship was supported: slower targets were easier to resolve (see Figure 2, left panel). However, for briefer durations, when the observer was unaware of the target's origin, increased target velocity actually <u>*enhanced*</u> DVA. Note in the right panel of Figure 2 that DVA improved (thresholds decrease) for the 170 ms targets as velocity increased. Specifically, thresholds at 22 deg/s significantly exceed thresholds at 45, 70, and 100 deg/s. This finding was contrary to expectations and the consensus in the DVA literature.

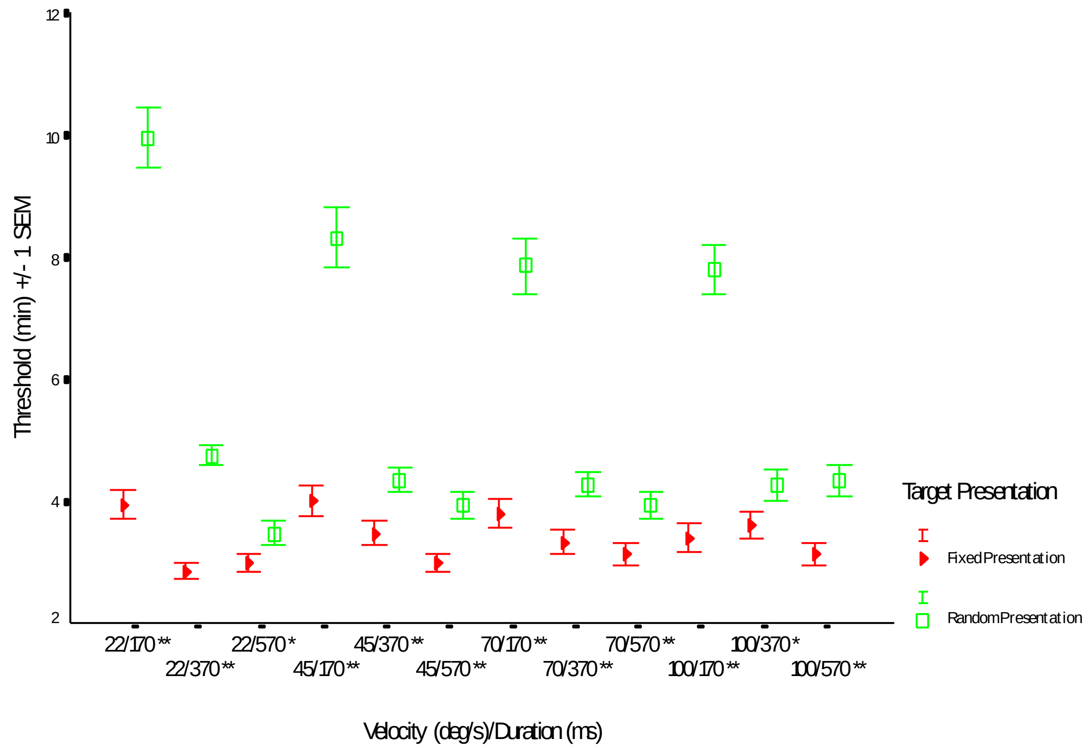


Figure 1. Comparison of mean acuity thresholds (Shevlin et al., 1997) for 15 target velocity/ duration [(deg/s)/(ms)] parameters for fixed (left to right) or random (six possible) target presentation conditions (n =10 per condition over four sessions). Mean differences obtained by subtracting $M_{fixed}$ from $M_{random}$ for each parameter. Mean differences for parameter significant at $p < .05$* or $p < .01$**. Error bars denote +/- 1 SE of the mean.

This contrary finding may have occurred because increased velocity moved the target into the visual field more quickly, where the observer was more likely to acquire the target and initiate eye movements to track and resolve the target. One may assume the initial DVA advantage for faster targets would dissipate as the detection advantage is overcome by unmanageable target velocities (in excess of those used by Shevlin et al., 1997). In the right panel of figure two, this dissipation would result in a U shape function for the top series if the data were extrapolated to faster velocities.

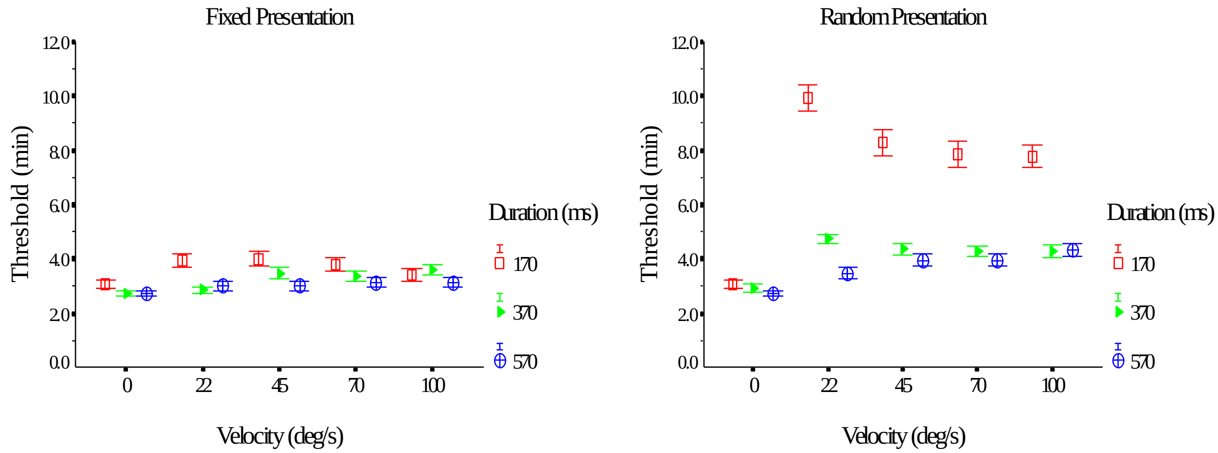


Figure 2. Three-way interaction between Presentation (Target Direction), Velocity, and Duration (Shevlin et. al., 1997). Error bars denote +/- 1 SE of the mean.

Brown's research (1972a; 1972b; 1972c) may offer partial explanations for these previous results (Shevlin et al.,1997). Brown (1972b) demonstrated that observers' eyes initially moved more quickly, and made corrective saccades more frequently and rapidly when pursuing faster targets. If Brown's research completely explained these results, one would expect faster targets to be uniformly easier to resolve when holding other factors (such as exposure time) constant. Shevlin et al. (1997), however, reported the advantage for faster targets occurred only at brief durations (170 ms). An argument of faster target movement uniformly facilitating performance is insufficient to explain these data. Exposure time appears to be a moderating factor.

The search task for unknown targets takes time. Using conventional procedures (like the fixed targets in Shevlin et al., 1997), observers know the target's origin and can "preposition" their eyes. This prepositioning eliminates the initial corrective movement required of observers viewing random targets. Consequently, increased random thresholds (relative to fixed) may also be explained as a function of the time available to acquire the target and initiate corrective tracking movements. This argument is reinforced by DVA studies using anticipatory tracking. These anticipatory tracking studies present the moving target with the critical detail initially occluded to allow the observer to acquire and begin to track the target. The observer can see and track the target, but can not see the critical detail. The critical detail in the target is then revealed and the observer must correctly identify the target. Anticipatory tracking further improves DVA performance relative to conventional procedures (Elkin, cited in Morrison, 1980).

Shevlin et al. (1997) used a race analogy to explain the DVA advantage affording by pre-positioning. Using conventional procedures, observers can focus their attentional, motor, and visual capacities at the start line. Using anticipatory tracking, observers are not only able to focus these assets at the start line, but also ensure they leave the start line at race speed. When observers are unaware of the location of the start line, they must first detect the start line, move to it, change direction, and then begin to catch up to the pack. These additional steps obviously disadvantage the racer. This disadvantage is most pronounced during very short races.

Implications and Hypotheses

The current study was designed to eliminate type of target movement as a confound from the Shevlin et al. (1997) study. In the current study, observers saw text cues prior to viewing each target. These cues either provided the observers with the point of origin of their next target, or simply advised them that another target would appear. Type of target movement was the same for all observers, regardless of their knowledge of the target's origin.

Other research, especially in aviation psychology, has demonstrated the advantage of directing observer attention using different types of cues. For example, Perrot, Cisneros, McKinley, and D'Angelo (1996) demonstrated that three dimensional (3D) auditory cues facilitated performance in a 360-deg visual search task (finding a target item among a set of distracters). 3D auditory displays provide directional cues to objects in space by either physically presenting the stimulus from the desired location, or by using headphones programmed with transfer functions to model interaural time differences. Search times improved by as much as several seconds for targets outside the field of view and by several hundred milliseconds for targets inside the field of view using 3D auditory cues. Bronkhorst, Veltman, and Breda (1996) found similar reductions in search times using 3D auditory and radar type displays in a flight simulation task. Data from the visual search literature indicate search time is substantially reduced when observers are aware of the location of a visual target. The current study used text cues, rather than auditory cues, to facilitate target search. (Text cues were easier to incorporate with the existing software). Because DVA tasks in the real world involve a visual search task, it follows that reducing search time will also facilitate DVA, especially at briefer durations.

This study examined four hypotheses **H1**: When observers are informed of the point of origin of a target, conventional DVA relationships will be supported. Specifically, DVA will deteriorate as: a) target velocity increases; b) as target exposure duration decreases; and c) as increased velocity and decreased duration interact compounding the task difficulty. **H2:** When observers are not informed of the point of origin of their target, conventional DVA relationships will be partially contradicted. Specifically, DVA will *improve* as target velocity increases, especially at briefer durations. **H3:** DVA will be poorer for observers who are uninformed of the origin of their target relative to observers who are informed. Although the magnitude of this decrement will vary based on the two-way interaction of target velocity and duration, this main effect is still relevant. The main effect of presentation will indicate that for all velocity and duration parameters in this study, text cues can be used to offset DVA degradation caused by targets of unknown origin. **H4**: DVA will deteriorate as target exposure duration decreases for both informed and uninformed observers; however, this deterioration will be more pronounced for uninformed observers due to the additional requirement of target acquisition.

## Method

### Participants

Twenty-eight freshmen at the United States Military Academy (USMA) volunteered and earned class credit for participation. Participants included 24 males and 4 females, ranging in age from 18 to 23 years (m = 19.3 years). All participants possessed binocular near SVA corrected to 20/40 or better. In many states in the U.S., this SVA level is the minimum acceptable to receive a driver's license (see Long & Riggs, 1991). The USMA Independent Review Board approved the use of human participants (Appendix C).

Variables

Targets

Positive contrast Landolt Cs (light text, dark background) served as acuity targets. Schiffman (1990) describes Landolt Cs as a ring drawn with a thickness of one-fifth its outer diameter. From this ring, a gap is removed. The width of the gap is also one-fifth the size of the outer diameter. Target and background luminance were displayed at 10 lux and 1 lux, respectively. Using the formula provided by Schiffman (1990):

$$C = (Max - Min)/ (Max + Min)$$

(where C = contrast, Max = maximum luminance, and Min = minimum luminance) the display resulted in 81.8% contrast. The critical detail (gap) in the Landolt C was randomly oriented toward one of four screen directions: top, right, bottom, and left. 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. Despite Brown's reccomendation, diagonal gap orientations were not included in the current study due to programming constraints. Miller and Ludvigh (1962) reported Landolt C split-half reliability at .99 with a 10-month retest reliability of .87.

Independent Variables

Duration. Three target exposure durations were manipulated (170, 370, 570 ms). These durations applied to the physical presentation of the target and in no way limited observer response time.

Velocity. Five target velocities were included (0, 22, 45, 70, and 100 deg/s, see Appendix A, Derivation of Measures).

Presentation. Participants viewed targets under two target presentation conditions. Prior to the computer presenting each target, observer in the "known origin" condition viewed text displayed in the center of the computer screen which indicated the origin of their next target on the screen (either "top right," "right," "bottom right," "top left," "left," or "bottom left").

Observers in the “unknown origin” condition viewed text in the same screen location; however, the text indicated only “next target.” This manipulation ensured observers in each condition performed the same visual tasks. First, each observer read the text centrally located on the screen, and then located, tracked, and resolved their dynamic target.

All moving targets (velocities > 0) originated from one of six randomly selected positions on the computer screen and moved linearly to a point 180 deg opposite the point of origin (i.e., left/right, right/left and diagonally from and to each of the screen corners). Figure 3 portrays the six target paths. Vertical movement was not included due to programming and display constraints.

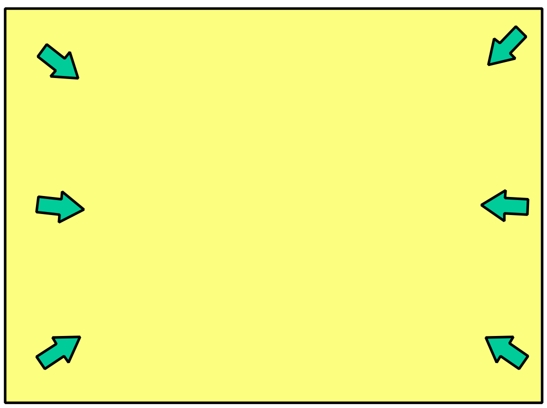

Figure 3. Target movement directions. Each time a dynamic target was presented, it moved in one of six possible randomly selected screen paths: Top left to bottom right, left to right, bottom left to top right, top right to bottom left, right to left, and bottom right to top left.

Dependent Variable

In each session, 15 threshold scores (min) were recorded for each observer. These scores reflected the 15 factorial combination of the three durations (170, 370, and 570 ms) with the five target velocities (0, 22, 45, 70, and 100 deg/s). Figure 4 portrays these 15 factorial combinations. Thresholds were obtained using nine target gap sizes (23.7, 21.0, 18.4, 15.8, 13.1, 10.6, 7.9, 5.3, and 2.6 min). Smaller threshold scores indicate better visual performance. For reference, SVA of 20/20 equates to a threshold of 1 min. These dependent measures are the same measures used by Shevlin et al. (1997), and demonstrated test–retest reliability, depicted in Table 1, ranging from .78 to .87 (Shevlin, 1996). Appendix A details the derivation of these measures.

| | Static Targets | | | Dynamic Targets | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 deg/s | | | 22 deg/s | | | 45 deg/s | | | 70 deg/s | | | 100 deg/s | | |
| | 170 ms | 370 ms | 570 ms | 170 ms | 370 ms | 570 ms | 170 ms | 370 ms | 570 ms | 170 ms | 370 ms | 570 ms | 170 ms | 370 ms | 570 ms |
| Known Origin | | | | | | | | | | | | | | | |
| Un-known Origin | | | | | | | | | | | | | | | |

Figure 4. Dependent variable matrix. Reflects the 15 factorial combinations of 3 target durations (ms) and 5 target velocities (deg/s). Static Targets (0 deg/s) were displayed in the center of the computer screen. Dynamic targets moved in any of 6 random directions. Prior to the computer presenting each target, observers viewing "Known Origin" targets saw text indicating the origin of their next target (i.e. "top right"); whereas, observers viewing "Unknown Origin" targets saw text that indicated only "next target."

Table 1

Dynamic Visual Acuity (DVA) Test-Retest Reliability from Shevlin (1996)

| | Session | | | |
|---|---|---|---|---|
| Session | 1 | 2 | 3 | 4 |
| 1 | 1.000 | | | |
| 2 | .834 | 1.000 | | |
| 3 | .868 | .798 | 1.000 | |
| 4 | .868 | .870 | .780 | 1.00 |

Note: Test-retest reliability obtained for 20 observers over four separate sessions. No two sessions were completed on the same day, and all four were completed over a 14-day period. Each participant's session score reflects the sum of individual thresholds (min) for 15 thresholds. These 15 thresholds reflect the factorial combination of 3 target durations (170, 370, and 570 ms) and 5 target velocities (0, 22, 45, 70, 100 deg/s).

Apparatus

The computer program (DYNAQUE 4, Shevlin, Shevlin, & Prestrude, 1998) ran on a 100MHz Pentium (tm) computer. A Princeton Graphic Systems Ultra 70f (dx 17) .26 mm flat screen 1280 x 1024 non-interlaced monitor, set at 1280 x 1024, 256 colors, and 75 MHz vertical refresh rate displayed the targets. Participants entered responses via a standard keyboard. Screen luminance was calibrated using Pasco Scientific OS-8020 photometer prior to each session. The monitor rested on a table, with the bottom of the screen 112 cm from the floor. A horizontal bar (e.g., Long & Riggs, 1990) placed 135 cm from the floor parallel to the computer screen prevented observers 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. Seated observers viewed the screen from 34 cm. The monitor, table, and horizontal bar remained stationary throughout the study. All sessions occurred in an Auditory Chamber (#10992, manufactured by the Industrial Acoustics Company) to prevent distractions. All windows in the chamber were occluded to control light levels. The chamber was illuminated with 15-watt incandescent light reflected from the side wall to prevent screen glare.

Procedure

Randomly assigned participants viewed targets using either the “known origin” or “unknown origin” presentation condition during their initial session. Participants viewed targets under the remaining presentation condition on their second session. No participant completed two sessions in a single day, and all participants completed the second session within 10 days of their initial session. Figure 5 portrays this experimental design. Each participant was screened for 20/40 or better binocular near SVA (corrected) using the Armed Forces Vision Tester during their first session only. The participant sat in an adjustable height chair, positioned so the participant comfortably rested their forehead on the horizontal bar and viewed the center of the screen. Once the chair height was adjusted, each participant began the computerized vision training and testing. Each session consisted of static training and testing followed by dynamic training and testing. Appendix B outlines the detailed directions issued to each participant.

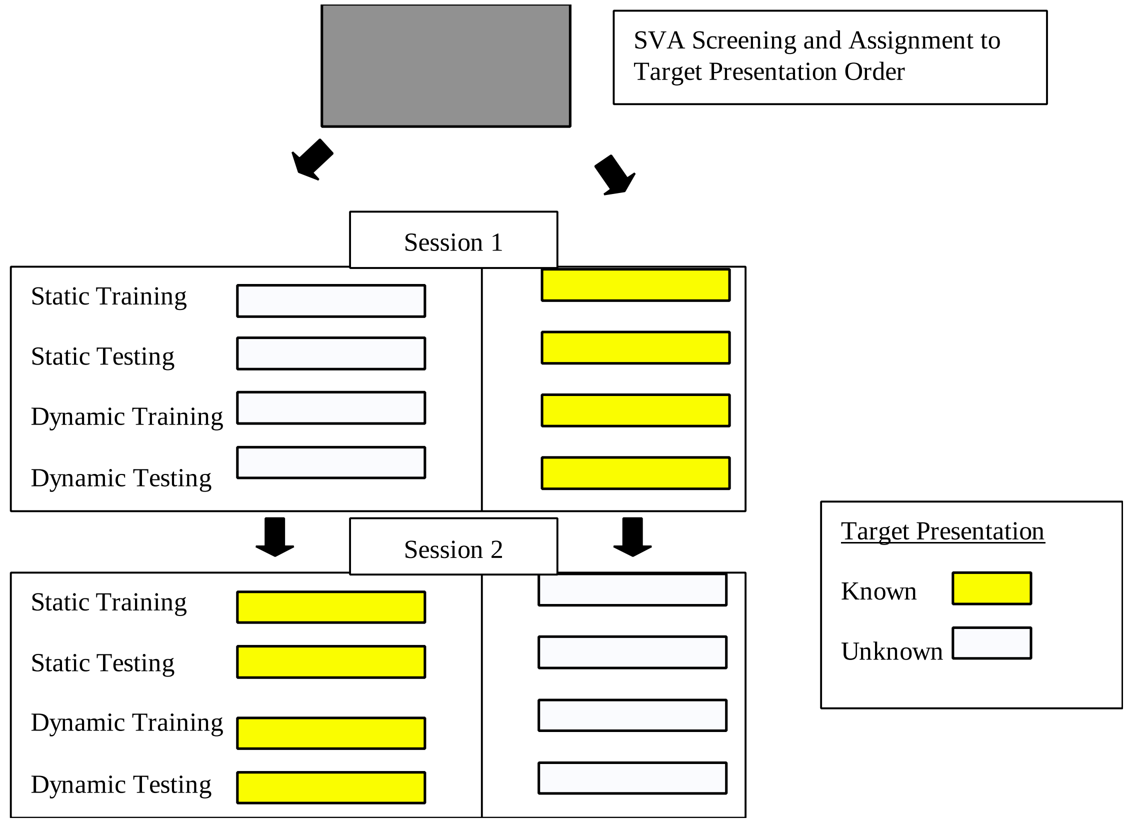


Figure 5. Experimental design. Known origin targets were preceded by text indicating the origin of the next target. Unknown origin targets were preceded by text indicating "next target." Each of the 28 observers participated in two separate sessions, with the sequence of target presentation counterbalanced between the two sessions.

Static Training and Testing.

Static (0 deg/s) training began with the largest target displayed in the center of the computer screen for one of the three durations (randomly chosen by the computer). Once the observer indicated the target gap orientation, the computer displayed appropriate text ("correct" or "incorrect") for that response. Following a correct response, the target size was incrementally reduced. Participants practiced until they indicated comfort with the task (minimum of three targets), and then began static testing.

The computer randomly assigned the static parameter testing sequence [(0 deg/s) x (170, 370, 570ms)] and recorded a threshold (min) using a modified descending method of limits procedure. The computer sounded a warning tone 1s prior to presenting each target. Static testing began with the largest target displayed in the center of the screen. The observer again indicated the gap orientation; however, the computer provided no text feedback during testing.

Once the observer correctly reported the gap position for the largest target, incrementally smaller targets were presented until an incorrect response was entered. At this point, the computer presented the next larger target. If the participant answered correctly, the computer reduced the size of the subsequent target. If the participant answered incorrectly, the computer again presented the next larger target. This procedure continued with targets being made smaller after correct responses and larger after incorrect responses until the observer erred twice for the same target size. The computer then recorded the next larger size as the observer's threshold for that parameter. Observers had to correctly resolve the smallest target twice within the same trial to achieve the smallest threshold.

Dynamic Training and Testing.

Once a threshold score (min) was recorded for the participant for the three static parameters, that participant proceeded to dynamic training and testing. Dynamic training proceeded similarly to the static training, except the computer presented targets by presentation condition (known origin, or unknown origin). Participants received verbal and computerized directions unique to their respective target condition for that session (See Appendix B for detailed directions to participants). During dynamic testing, the computer randomly generated the testing sequence for the twelve dynamic parameters [(22, 45, 70, 100 deg/s) x (170, 370, 570 ms)], and recorded thresholds (min) using procedures described above. Each session yielded 15 thresholds (3 static and 12 dynamic) for each of the 28 participants within their given target condition (see Figure 4).

## Results and Discussion

All hypotheses were tested at $\alpha = .05$. Data were analyzed using a 2 x 3 x 4 (Presentation x Duration x Velocity) within-subjects repeated measures ANOVA (Table 2), with Huynh-Feldt corrections applied. Significant interactions and main effects relevant to the hypotheses were further tested using Tukey's Honestly Significant Difference (HSD) procedure to isolate differences within the parameters (Tables 3 and 4). Tukey's HSD is a more conservative multiple range test (MRT) than Duncan's, however analysis with Duncan's MRT did not substantially alter the findings. Mean differences for each of the 12 parameters were tested between known and unknown target parameters using one-tailed paired $t$-tests, with the Bonferroni correction applied (Table 5). The results of all analyses are presented and discussed in the order hypothesized.

Table 2

Repeated Measures Analysis of Variance, Dynamic Visual Acuity

| Source | df | Huhyn-Feldt Epsilon | SS | MS | F |
|---|---|---|---|---|---|
| Presentation (P) | 1 | 1 | 46.78 | 46.78 | 9.67** |
| Error | 27 | | 130.55 | 4.84 | . |
| Velocity (V) | 3 | .99878 | 3.53 | 1.18 | .77 |
| Error | 81 | | 253.58 | 3.13 | |
| Duration (D) | 2 | 1 | 717.55 | 358.78 | 110.70** |
| Error | 54 | | 177.02 | 3.24 | |
| P x V | 3 | .82928 | 64.32 | 21.44 | 4.83** |
| Error | 81 | | 359.26 | 4.44 | |
| P x D | 2 | 1 | 50.16 | 25.08 | 4.95** |
| Error | 54 | | 273.38 | 5.06 | |
| V x D | 6 | .81722 | 248.45 | 41.41 | 10.80** |
| Error | 162 | | 621.03 | 3.83 | |
| P x V x D | 6 | 1 | 26.41 | 4.40 | 1.29 |
| Error | 162 | | 633.06 | 3.41 | |

Note. Huyhn-Feldt correction applied to F values when Huyhn Feldt Epsilon is less than one.
** F Values are significant at $p < .01$.

Table 3

Comparison of Mean Acuity Thresholds (min) for Velocity by Duration as a Function of Target Presentation

| Target Presentation | Duration (ms) | | Velocity (deg/s) 22 | 45 | 70 | 100 |
|---|---|---|---|---|---|---|
| Combined | 170 | M | 9.13a | 7.59b | 7.59b | 6.79b |
| | | SD | 3.04 | 2.13 | 2.13 | 1.18 |
| | | SE | 0.46 | 0.28 | 0.30 | 0.25 |
| | 370 | M | 5.04a | 5.42ab | 5.80ab | 6.03b |
| | | SD | 1.85 | 1.85 | 1.70 | 2.12 |
| | | SE | 0.25 | 0.24 | 0.22 | 0.28 |
| | 570 | M | 4.76a | 5.66b | 5.89b | 6.08b |
| | | SD | 1.72 | 1.70 | 2.19 | 1.58 |
| | | SE | 0.23 | 0.22 | 1.57 | 0.21 |
| Unknown | 170 | M | 10.26a | 8.29b | 8.29b | 6.42c |
| | | SD | 3.13 | 2.23 | 2.23 | 2.01 |
| | | SE | 0.59 | 0.42 | 0.40 | 0.39 |
| | 370 | M | 4.99a | 5.46a | 5.84a | 5.56a |
| | | SD | 1.96 | 2.16 | 2.08 | 1.81 |
| | | SE | 0.37 | 0.41 | 0.39 | 0.34 |
| | 570 | M | 5.09a | 6.03ab | 6.58b | 6.13ab |
| | | SD | 1.90 | 1.58 | 2.43 | 1.76 |
| | | SE | 0.35 | 0.29 | 0.46 | 0.33 |
| Known | 170 | M | 8.02a | 6.89a | 6.88a | 7.16a |
| | | SD | 2.54 | 1.80 | 2.31 | 1.57 |
| | | SE | 0.48 | 0.34 | 0.44 | 0.29 |
| | 370 | M | 5.09a | 5.38a | 5.67a | 6.51b |
| | | SD | 1.76 | 1.52 | 1.25 | 2.33 |
| | | SE | 0.33 | 0.28 | 0.24 | 0.44 |
| | 570 | M | 4.42a | 5.27a | 5.18a | 6.03b |
| | | SD | 1.47 | 1.77 | 1.69 | 1.39 |
| | | SE | 0.28 | 0.33 | 0.32 | 0.26 |

Note. Means in the same row not sharing a common letter differ at $p < .05$ in the Tukey's HSD comparison.

The predicted three-way interaction among velocity, presentation, and duration was not significant $\underline{F}_{(6,162)} = 1.29$ (Table 2), in large part due to a single mean threshold value (22 deg/s velocity, 170 ms duration, known origin). This single mean threshold value primarily impacts the first hypothesis. The expected three-way interaction theoretically distinguishes the first and second hypotheses, and must be reviewed to interpret the current findings.  Prior to considering the current results, consider the hypothesized nature of this three-way relationship.  Hypothetical data presented in Figure 6 demonstrate the three-way relationship expected in the current study.

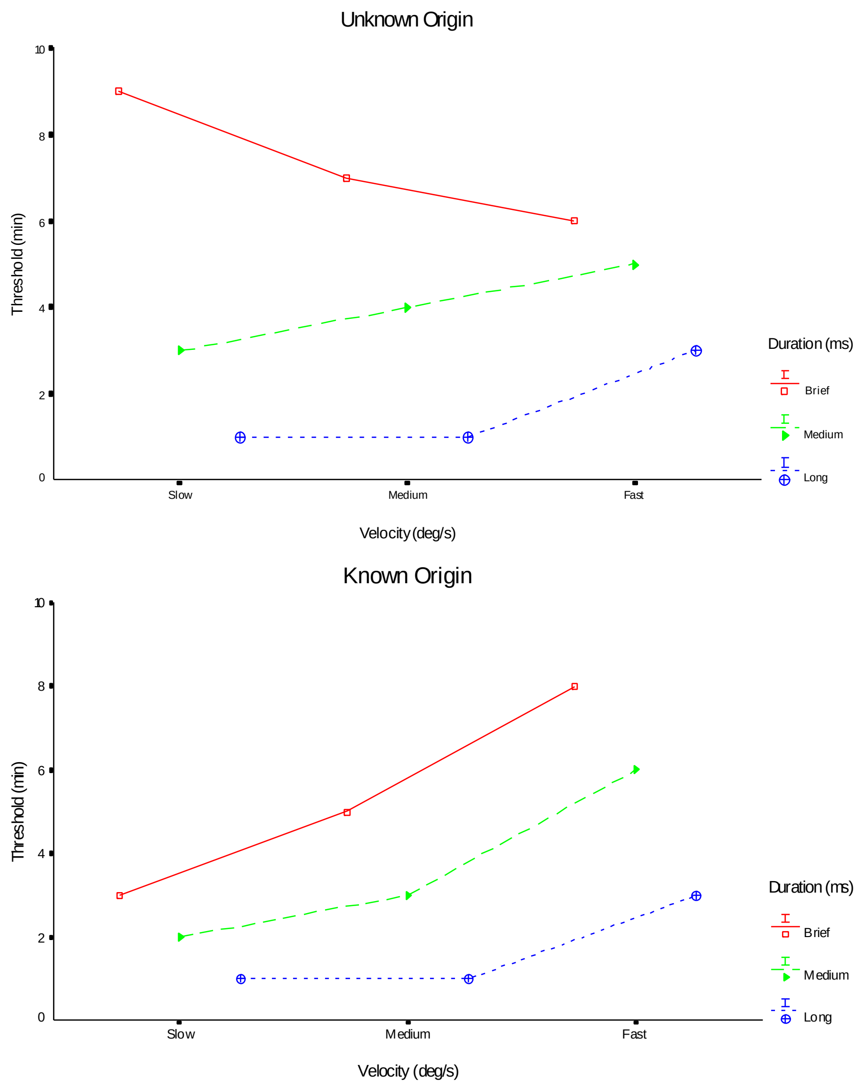


Figure 6.  Hypothetical DVA data for targets of known (bottom panel) and unknown (top panel) origin.

The bottom panel in Figure 6 portrays a hypothetical data set when observers know the origin of their target (as in H1 of the current study). This relationship is well supported in the DVA literature. Briefer targets should be more difficult to resolve; faster targets should be more difficult to resolve; and velocity and duration should interact indicating increased difficulty as faster targets are displayed more briefly. This relationship is best described as three lines of positive slope that diverge with increased velocity (Figure 6, bottom panel).

The top panel of the hypothetical data set in Figure 6 depicts the relationship expected when observers are unaware of the origin of their targets as documented by Shevlin et al. (1997). Specifically, velocity and duration should significantly interact, indicating slower targets are more difficult to resolve at brief durations. This relationship is described as three lines where the top and bottom line have opposite slope and converge towards the middle line as velocity increases.

The three-way interaction from the current study is depicted in Figure 7. Data from the unknown target condition fit the theoretical pattern in Figure 6. Data from the known origin target condition fit the hypothetical pattern with the exception of the contrary mean threshold value (22 deg/s 170 ms, circled in Figure 7). This mean threshold value is higher than expected and prevents the 170 ms series from having a positive slope. Although slope analysis indicates the 370 ms and 570 ms series are positively sloped [$F_{(110)} = 10.13$, $F_{(110)} = 12.53$; $p < .01$ for both series], the 170 ms series is statistically flat. Theoretical justification of this anomaly will follow presentation of the results for each of the four hypotheses.

Hypothesis 1

Recall H1: *When observers are aware of their target's origin, conventional DVA relationships will hold.* This hypothesis contains three major components and is grounded in the conventionally accepted relationship between target velocity and duration for dynamic targets. Specifically, DVA will deteriorate: a) as target velocity increases; b) as target exposure duration decreases; and c) as velocity and duration interact indicating increased difficulty when faster velocities compound with decreased duration. These relationships are depicted collectively in the top panel of Figure 7.

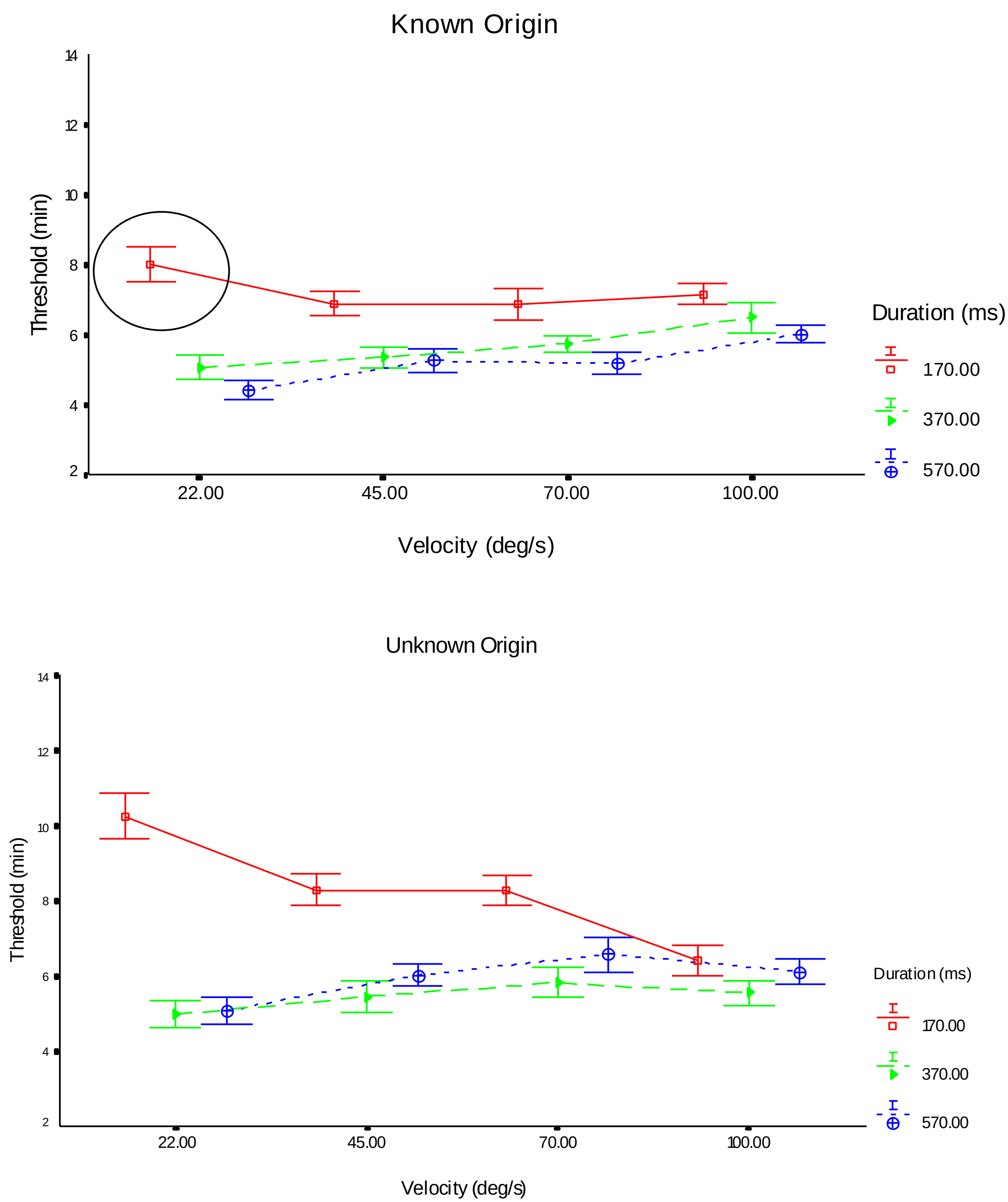


Figure 7. Three-way interaction among presentation (known, unknown) velocity, and duration. Observers (n = 28) viewed targets under both presentation conditions on separate days. In the known origin condition, observers received text cues indicating the origin of their targets (top panel); whereas, observers in the unknown presentation condition (bottom panel) received only notification that a target would be presented. Contrary mean threshold value circled in top panel. Error bars denote +/- 1 SE of the mean.

The data do not support H1a. When collapsed across duration for known origin targets, faster targets were not significantly more difficult to resolve (see Figure 8). The results of Tukey's HSD procedure on these known threshold means are reported in Table 4 (thresholds at all four velocities are not statistically different). The contrary mean threshold value at 22 (deg/s)/170 ms (see Figure 7, top panel) elevates the mean in the 22 deg/s velocity condition above predicted levels.

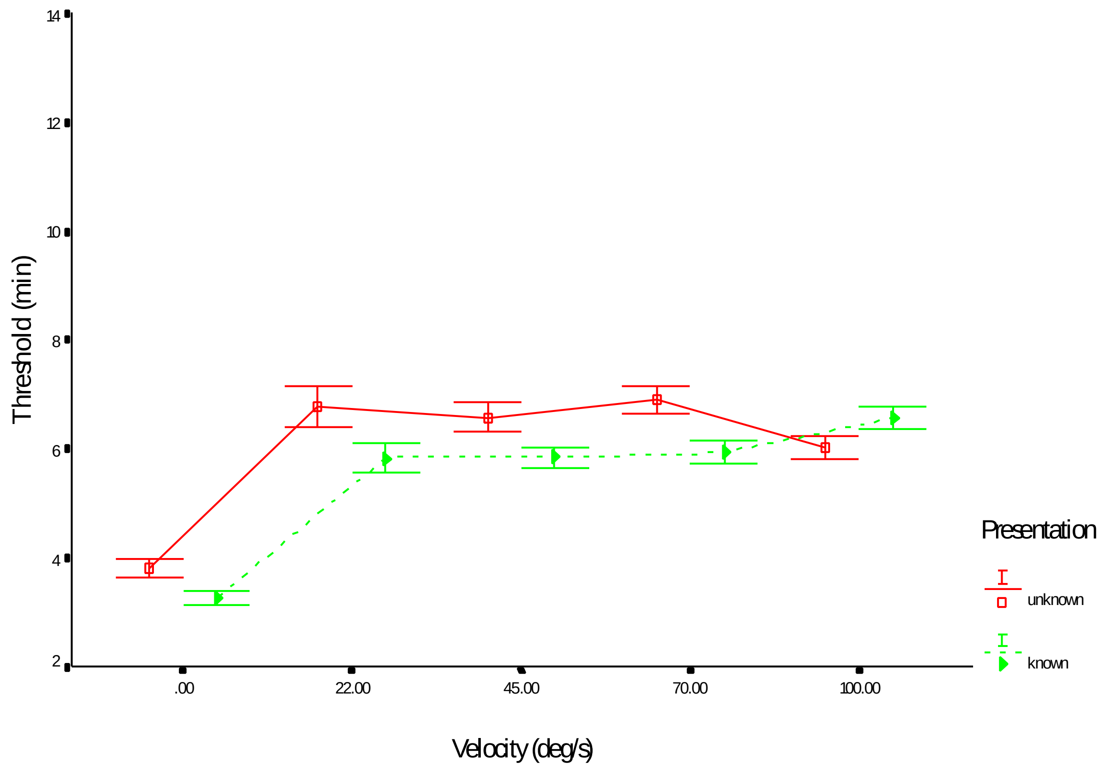


Figure 8. Two-way interaction between velocity and presentation. Error bars denote +/- 1 SE of the mean.

The data provide some support for H1b. Targets exposed more briefly were more difficult to resolve. As indicated in Table 4, when collapsed across velocities for known origin targets, the mean threshold for 170 ms targets (7.24 min) was significantly greater than the thresholds for the 370 ms and 570 ms targets (5.68 and 5.23 min, respectively) using Tukey's HSD procedure. This relationship is presented graphically in Figure 9.

Table 4

Comparison of Mean Acuity Thresholds (min) for Duration and Velocity as a Function of Target Presentation .

| Target Presentation | | Duration (ms) 570 | Duration (ms) 370 | Duration (ms) 170 | Velocity (deg/s) 22 | Velocity (deg/s) 45 | Velocity (deg/s) 70 | Velocity (deg/s) 100 |
|---|---|---|---|---|---|---|---|---|
| Combined | M | 5.60a | 5.58a | 7.78b | 6.31a | 6.22a | 6.43a | 6.30a |
| | SD | 1.87 | 1.91 | 2.51 | 3.03 | 2.13 | 2.23 | 1.89 |
| | SE | 0.12 | 0.13 | 0.17 | 0.23 | 0.16 | 0.17 | 0.15 |
| Unknown | M | 5.96a | 5.47a | 8.31b | 6.78a | 6.60a | 6.91a | 6.04a |
| | SD | 1.99 | 2.00 | 2.76 | 3.43 | 2.33 | 2.42 | 1.91 |
| | SE | 0.19 | 0.19 | 0.26 | 0.37 | 0.25 | 0.26 | 0.21 |
| Known | M | 5.23a | 5.68a | 7.24b | 5.84a | 5.85a | 5.95a | 6.57a |
| | SD | 1.67 | 1.83 | 2.12 | 2.51 | 1.84 | 1.92 | 1.85 |
| | SE | 0.16 | .017 | .020 | 0.27 | 0.20 | 0.21 | 0.20 |
| Difference | M | 0.73 | -0.22 | 1.07 | 0.94 | 0.74 | 0.96 | -0.53 |
| | SE | 0.28 | 0.30 | 0.31 | 0.40 | 0.26 | 0.36 | 0.28 |
| | t | 2.61 | -0.73 | 3.41 | 2.34 | 2.85 | 2.71 | -1.93 |
| | p | 0.01 | 0.23 | 0.01 | 0.01 | 0.01 | 0.01 | 0.04 |

Note. Difference is obtained by subtracting $M_{known}$ from $M_{unknown}$. Means in the same row and viewing condition (duration or velocity) not sharing a common letter difeer at $p < .05$ in the Tukey's HSD comparison, All t-tests are one-taile (right) with df = 27.

The data do not support H1c (Increased velocity and decreased duration should interact compounding task difficulty). Tukey's HSD data in the bottom panel of Table 3 indicate that for known targets, thresholds at both 370ms and 570 ms increased with increased velocity (Thresholds at 22, 45, 70 deg/s < thresholds at 100 deg/s). No significant differences existed between velocities for the 170 ms known origin targets. This may again be due to the contrary mean threshold value at 22 (deg/s)/170 ms in the known condition (Figure 7).

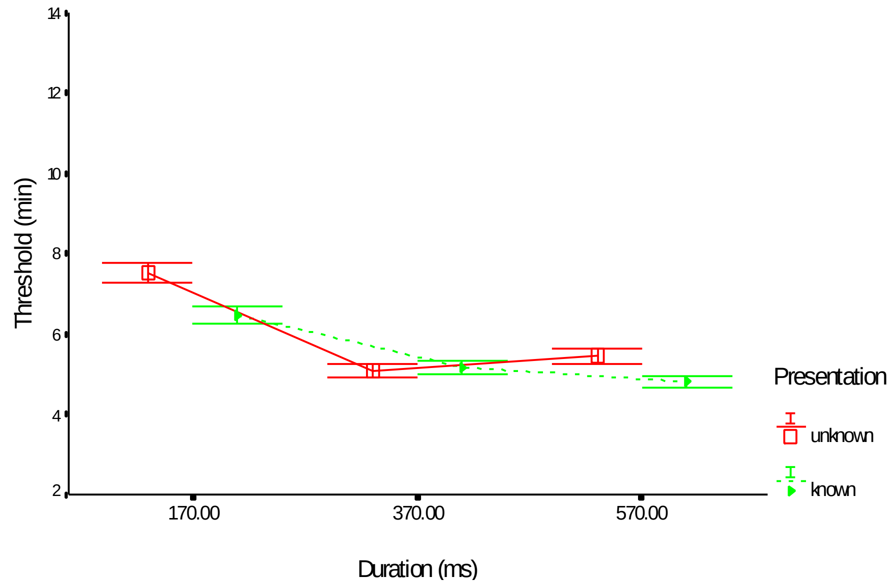


Figure 9. Two-way interaction between duration and presentation. Error bars denote +/- 1 SE of the mean.

Hypothesis 2

The data support H2. When observers are unaware of a target's origin, conventional DVA relationships were partially contradicted. Slower targets were more difficult to resolve at brief durations. This relationship is portrayed graphically in the bottom panel of Figure 7. Tukey's HSD data (Table 3, center panel) show that for 170 ms targets, DVA improved with increased velocity (thresholds at 22 deg/s > thresholds at 45 and 70 deg/s > thresholds at 100 deg/s). At 370 ms durations, no significant differences are indicated. At 570 ms, DVA deteriorated with increased velocity (thresholds at 70 deg/s > thresholds at 22 deg/s). This pattern of data is as predicted in the hypothetical data set (Figure 6, top panel). The three lines are of different slopes and converge with increased velocity. The 170 ms series is negatively sloped, $F_{(110)} = 31.03$, $p < .01$; the 570 ms series is postively sloped, $F_{(110)} = 4.42$, $p < .05$; and the slope of the 370 ms series was not statistically significant. These data are congruent with the findings from Shevlin et al. (1997) that contradicted the conventional DVA relationships. For targets briefly exposed, slower targets are *more difficult* to resolve than faster targets when observers are unaware of their target's origin. The consensus in the DVA literature suggests slower targets are *easier* to resolve. These conventional findings are intuitive, however, are in part due to conventional apparatuses and procedures. These conventional devices and procedures circumvented the visual search task that precedes most real world DVA tasks. Both the visual search task and the DVA task take time. When viewing time is brief, observers unaware of their target's origin consume much of the available time searching for, rather than resolving their target.

Hypothesis 3

H3 received some support from the data. Of the twelve dynamic parameters, five show a significant observer advantage for DVA targets of known origin relative to targets of unknown origin. These differences are portrayed in Figure 10. When using the Bonferroni correction to diffuse $\alpha = .05$ across the 12 separate comparisons, only the difference at [22(deg/s)/170 (ms)] remains statistically significant at the conservative .004 level ($t_{27} = 2.94$, $p = .003$). The 95% confidence interval for this difference is 0.68 to 3.79 min. This effect is markedly less than the 6.005 min [+/- 1.09 min 95% confidence]) effect demonstrated at [22(deg/s)/170 (ms)] in Shevlin et al. (1997).

Hypothesis 4

The data support H4, which predicted the significant two-way interaction between duration and presentation $F_{(1, 54)} = 4.95$, $p = .01$ (Table 2). Figure 9 graphically depicts this relationship. Mean acuity thresholds for observers were significantly poorer for targets exposed more briefly (thresholds at 170 ms > thresholds at 370 and 570 ms) under both known and unknown viewing conditions. This deterioration was more pronounced for observers in the unknown condition (Table 4) between both the 170 ms (1.07 min) and 570 ms (0.73 min) durations.

The computer additionally recorded the information about the relationship between gap orientations and observer responses. These data included the frequency with which each of the 4 gap orientations was presented as well as the number of correct and incorrect reponses for each of these orientations. These data are portrayed in Table 6. Using Tukey's HDS procedure, left gap orientations were more difficult to resolve relative to left, right, or up orientations. Despite the large $n$, these data should be interpreted cautiously because orientation is confounded with several other variables, to include target size and direction of movement.

A post-hoc one-way ANOVA indicated that path length (physical distance the target travels, see table A2 for calculations) is insufficient to explain DVA performance in the current study. If path length explained DVA performance, (longer physical disrtances facilitate DVA), one would expect DVA thresholds to relate inversely to path length when rank-ordered. The data in Table 7 do not support this inverse relationship. DVA performance is better explained by the relationships among velocity, duration and target presentation parameters in the hypotheses tested above.

Table 5

Comparison of Mean DVA Thresholds (min) for All 15 Target Parameters

| | Target Velocity | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 22 deg/s | | | 45 deg/s | | | 70 deg/s | | | 100 deg/s | | |
| | Duration (ms) | | | Duration (ms) | | | Duration (ms) | | | Duration (ms) | | |
| Target Presentation | 170 | 370 | 570 | 170 | 370 | 570 | 170 | 370 | 570 | 170 | 370 | 570 |
| Combined | | | | | | | | | | | | |
| M | 9.14a | 5.04b | 4.76b | 7.59a | 5.42b | 5.66b | 7.59a | 5.80b | 5.89b | 6.79a | 6.04a | 6.09a |
| SD | 0.41 | 0.25 | 0.23 | 0.28 | 0.25 | 0.23 | 0.31 | 0.23 | 0.30 | 0.25 | 0.28 | 0.21 |
| SE | 0.41 | 0.25 | 0.23 | 0.29 | 0.25 | 0.23 | 0.31 | 0.23 | 0.30 | 0.25 | 0.28 | 0.21 |
| Unknown | | | | | | | | | | | | |
| M | 10.26a | 5.00b | 5.09b | 8.29a | 5.46b | 6.04b | 8.29a | 5.84b | 6.59b | 6.42a | 5.56a | 6.13a |
| SD | 3.13 | 1.96 | 1.90 | 2.23 | 2.16 | 1.58 | 2.13 | 2.08 | 2.43 | 2.09 | 1.81 | 1.76 |
| SE | 0.59 | 0.37 | 0.35 | 0.42 | 0.41 | 0.30 | 0.40 | 0.39 | 0.46 | 0.39 | 0.34 | 0.35 |
| Known | | | | | | | | | | | | |
| M | 8.02a | 5.09b | 4.43b | 6.89a | 5.38b | 5.30b | 6.89a | 5.76ab | 5.19b | 7.16a | 6.51a | 6.04a |
| SD | 2.54 | 1.76 | 1.47 | 1.80 | 1.53 | 1.77 | 2.32 | 1.25 | 1.69 | 1.58 | 2.34 | 1.40 |
| SE | 0.48 | 0.33 | 0.27 | 0.34 | 0.29 | 0.33 | 0.44 | 0.23 | 0.32 | 0.30 | 0.44 | 0.26 |
| Difference | | | | | | | | | | | | |
| M | 2.24 | -0.92 | 0.66 | 1.40 | 0.08 | 0.75 | 1.40 | 0.08 | 1.40 | -0.74 | -0.95 | 0.09 |
| SE | 0.76 | 0.62 | 0.47 | 0.58 | 0.51 | 0.41 | 0.62 | 0.46 | 0.53 | 0.38 | 0.54 | 0.46 |
| t (1 tail) | 2.94** | -.0.15 | 1.41 | 2.41* | 0.17 | 1.87* | 2.28* | 0.18 | 2.63** | -1.95 | -1.73 | 0.20 |

Note. Difference is obtained by subtracting $M_{known}$ from $M_{unknown}$. Means within a row and velocity not sharing a common letter differ at $p < .05$ in the Tukey HSD comparison. For all paired t-tests, df = 27. * denotes significance at $p < .05$

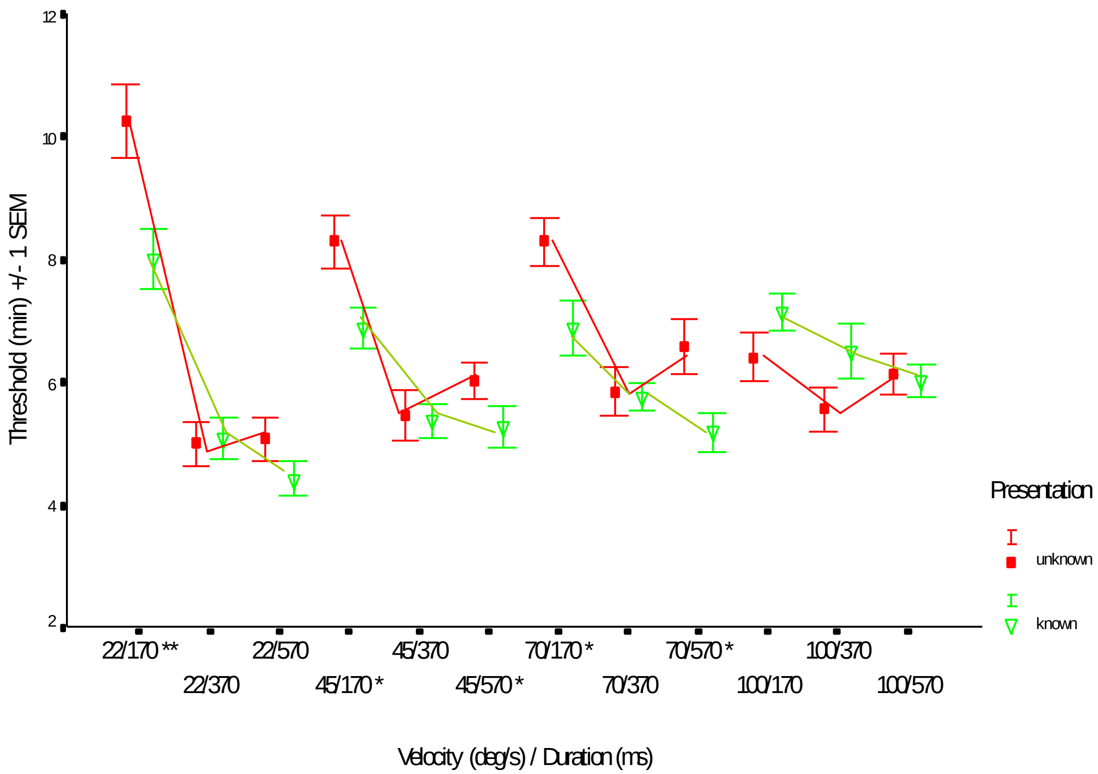


Figure 10. Comparison of mean acuity thresholds (min) or fifteen target velocity/duration parameters for targets of known and unknown origin ($\underline{n}$ = 28 observers who viewed targets in both presentation conditions). Mean differences obtained by subtracting $\underline{M}_{known}$ from $\underline{M}_{unknown}$ for each parameter. Mean differences for parameter significant at $\underline{p} < .05$* or $\underline{p} < .01$** using 1-tail paired $\underline{t}$-tests. When using the Bonferroni correction for 12 paired $\underline{t}$-tests, the only difference meeting the conservative alpha of .004 is 22/170 (deg/s)/(ms).

Explanation for Results

The data clearly support the relationships among unknown origin target thresholds, which are portrayed in the bottom panel of Figure 7. Results involving known origin targets, portrayed in the top panel of Figure 7, are somewhat different than anticipated. In order to advance testable explanations for the current findings, current results were compared with the results from Shevlin et al. (1997). Because these are different studies with different populations, this comparison was subjective and theoretical, rather than statistical.

Figure 11 compares DVA results from Shevlin et al. (1997, bottom panel) with DVA results from present study (top panel). Note the pattern of results in both studies is similar for

Table 6

Comparison of DVA Performance Among Four Landolt C Target Gap Orientations.

| Gap Orientation | Total Presented | Total Correct | M % Correct | SE % Correct | 95% CI % Correct |
|---|---|---|---|---|---|
| Down | 2,468 | 2,085 | 84.36 b | 0.10 | 82.37 – 86.35 |
| Left | 2,443 | 1,888 | 77.23 a | 0.10 | 75.29 – 79.17 |
| Up | 2,581 | 2,133 | 82.43 b | 0.09 | 80.65 – 84.21 |
| Right | 2,451 | 2,015 | 82.34 b | 0.08 | 80.81 – 83.87 |

Notes. Mean percentage correct averaged for 56 individual scores (28 observers over two separate sessions). M % scores not sharing a common letter differ at alpha = .05 using Tukey's HSD procedure.

Table 7

Multiple Comparisons of DVA Thresholds (min) Based on Target Path Length

| Path Length (mm) | Mean DVA Threshold (min) | | Velocity (deg/s) | Duration (ms) |
|---|---|---|---|---|
| 74.1 | 4.76 | a | 22 | 570 |
| 48.1 | 5.04 | ab | 22 | 370 |
| 96.2 | 5.42 | ab | 45 | 370 |
| 148.2 | 5.66 | ab | 45 | 570 |
| 144.2 | 5.80 | abc | 70 | 370 |
| 222.3 | 5.89 | bc | 70 | 570 |
| 192.4 | 6.04 | bc | 100 | 370 |
| 296.4 | 6.09 | bc | 100 | 570 |
| 88.4 | 6.79 | cd | 100 | 170 |
| 44.2 | 7.59 | d | 45 | 170 |
| 66.3 | 7.59 | d | 70 | 170 |
| 22.1 | 9.13 | e | 22 | 170 |

Note: Target Path length (mm) calculated in Table A2. Mean thresholds (ordered from snallest to largest) not sharing a common letter differ at .05 alpha in The Student-Newman-Keuls test.

the top series in each panel. These data represent the unknown origin target data from the current study and the random target data from 1997. The patterns for both lines are similar, as are the upper M threshold values in series (10.20 and 10.26 min, SD 3.83 and 3.13 respectively).

The bottom series in the top panel represents the known origin target data from the current study; whereas, the bottom series in the bottom panel represents the fixed target data from 1997. These patterns appear distinct. The data from 1997 are much flatter with mean thresholds ranging from 2.95 to 4.57 min (SD 0.95 and 1.59, respectively). The current data are more varied, with mean thresholds ranging from 5.00 to 10.26 min (SD 1.19 and 2.54, respectively). This subjective comparison indicates that observers in the known condition from the current study did not perform as well as observers in the fixed presentation condition from the 1997 study.

Data from the current study indicate that on average, when observers are presented with text cues (known origin), DVA improves relative to when observers are not provided with this information. This improvement occurred in the present study, but not to the extent predicted. The logic underlying the current study assumed that the magnitude of this improvement would be similar to the improvement in the 1997 study. Specifically, when observers knew when and from where a dynamic target would appear, DVA relationships would again approximate the conventional relationships despite the fact that the targets were moving in six different directions. This improvement would occur because observers could pre-position their eyes.

Assuming the pre-positioning occurred, the only difference (optically) between the known condition in the present study and the fixed condition in the 1997 study would be the type of target movement (six directions, as opposed to left to right). Two possibilities explain why observers in the known origin condition of the current study did not perform as well as expected. The first explanation is that the benefit afforded by prior knowledge of target origin was fully enjoyed by all observers and simply is not as effective as hypothesized. If the first explanation were correct, one would expect to see a normally distributed and modest improvement for all observers. The second explanation is that perhaps not all observers enjoyed the benefit afforded by the text cues. If the second explanation were correct, one would expect to see a diverse amount of improvement between observers. Observers who fully benefited from the cues should

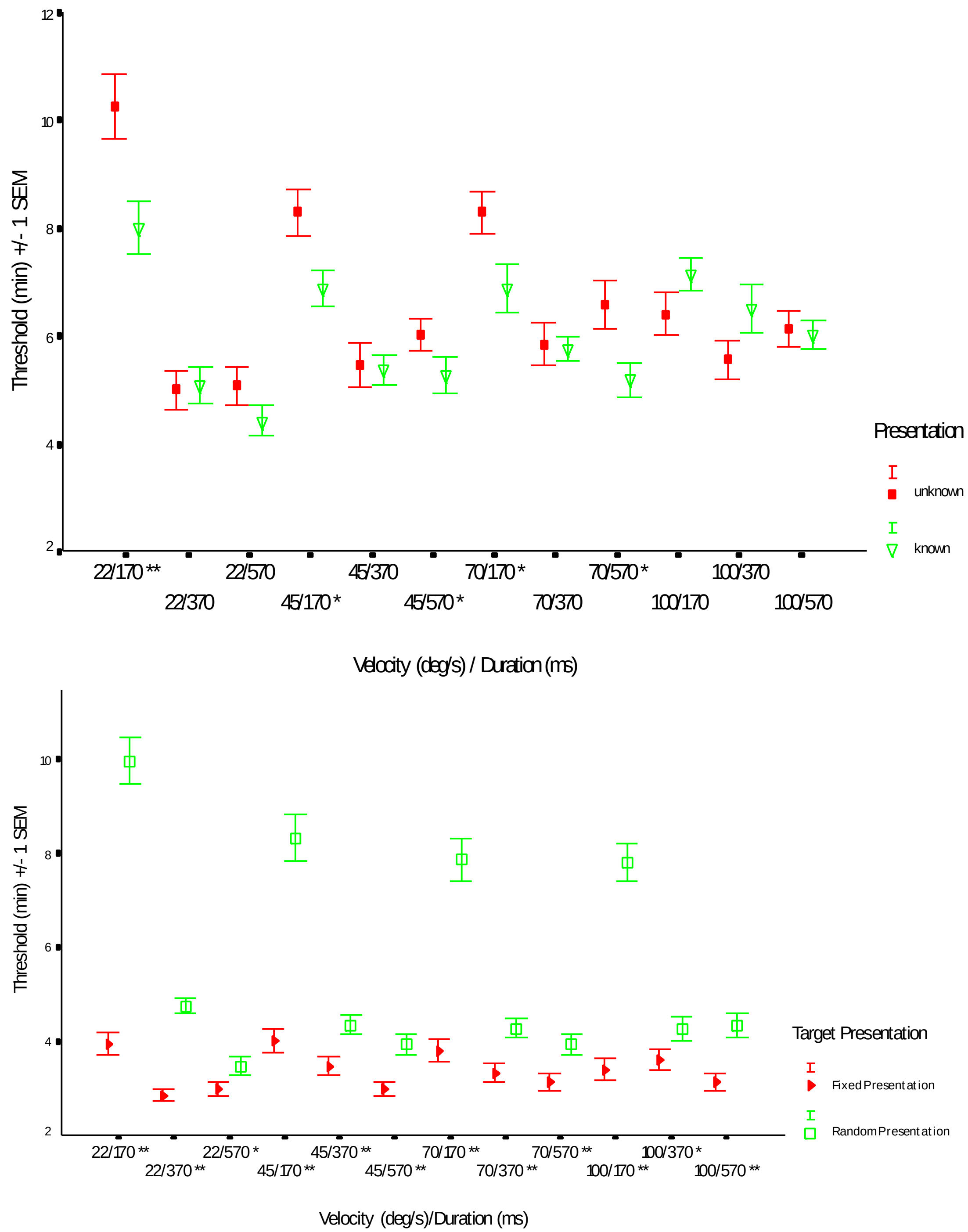


Figure 11. Comparison of DVA results from Shevlin et al. (1997, bottom panel) with DVA results from present study (top panel). Note how the random origin target data in the bottom panel approximate the unknown origin data in the top panel (Top series in both panels). The known origin thresholds in the top panel, however, appear substantially elevated relative to the fixed presentation data in the bottom panel.

show a dramatic improvement; whereas, observers who did not benefit from the manipulation would show little or no improvement. For an observer to fully enjoy the advantage offered by the text cues, the observer must complete several steps. The observer must read the text cue, correctly interpret the text cue, move his or her eyes to the target's point of origin, track, and then resolve the target. Assuming all observers in the study faithfully executed all of these steps on all trials, (the first explanation) the modest average improvement from the current study would indicate that the type of target movement matters. When targets are moved from six directions rather than in a single, predictable left to right path, DVA would deteriorate. This deterioration would be slightly diluted when observers are aware of their target's origin. Although optically the known origin task in the current study is similar to fixed task in Shevlin et al (1997), the additional steps required in the current study to effectively use the text cues entail greater observer cognitive workload.

The second explanation for the current findings is that not all observers fully enjoyed the advantage offered by the text cues. Perhaps not all viewers completed the required steps to preposition their eyes at the target's point of origin. The most dramatic difference between DVA for known and unknown targets was hypothesized to occur at ([22 deg/s] [170 ms]), the contrary mean threshold value mentioned earlier. Data from this parameter should help evaluate the viability of the two explanations. If the first explanation were correct, the pattern of improvement between observers should be modest and relatively uniform. If the second explanation were correct, the pattern of improvement between observers should be diverse, suggesting some observers enjoyed the advantage offered by the text cues more than other observers. The pattern of individual differences at this mean threshold value, reflected in Table 8, supports the second explanation.

Recall the average improvement in the current study for ([22 deg/s] [170 ms]) was 2.24 min (+/- 1.55 min, 95% CI). As indicated in Table 8, ten observers showed no DVA improvement based on the text cues, and four observers showed a decline in DVA performance. Fourteen observers improved. Of these 14 observers, 7 improved by 5.3 min or more, with 2 observers improving by 10.6 min. This distribution of individual differences suggests that the second explanation is more likely. Not all observers enjoyed the benefit afforded by the text cues. Some observers benefited by a factor of 3. This level of improvement equates to the difference between 20/20 vision and 20/60 vision for static acuity – more than the difference between normal vision and not qualifying for a driver's license. The second explanation is also supported by pilot data collected with a different population (Figure 14). These data were collected using three United States Military Academy Instructors. Although these data should be interpreted cautiously due to the small n of three, the pattern of data in the top panel portrays the hypothesized relationship for the known origin targets (three lines of positive slope, diverging with increased velocity). The instructors appear to have made better use of the text cues than did the cadets. Why might there be a difference in the effectiveness of the text cues for instructors and freshmen cadets?

Recall for the text cues to be effective, the observer had to complete the steps of reading and correctly interpreting the text cues, moving their eyes to the correct origin point, acquiring, tracking and resolving the target. As pointed out by Neisser (1967) the eye is both a parallel and serial processor of information. As a pre-attentive parallel processor, the eye can register the rudimentary presence of hundreds of items concurrently. When used to extract more detailed information from the stimulus array (as in the current acuity task), the visual system becomes a limited capacity serial processor restricted to a small field of view at a given time. The observer must focus visual attention on the object to complete an acuity task. Congruent with Neisser's logic, the text cues were designed to help focus visual attention.

Freshman cadets at the Military Academy experience a great deal of pressure during their first year. During my three years of teaching freshman at USMA, one of the biggest instructional challenges I have faced is keeping these freshmen cadets attentive and awake in class. In addition to the academic demands ordinary college freshmen face, these cadets must also bear additional burdens of academy life. Their schedules are full, and in general, they are a tired bunch.

The data for the fourteen observers who improved using the text cues (at [22 deg/s][170ms]) are portrayed in Figure 13. These data support the both the first and second explanations. The three way interaction between duration, velocity, and presentation hypothesized but not found for all observers, was significant using only the data from the observers who improved ($F_{(6, 78)} = 3.23$, $p = 0.012$), indicating that not all observers benefited from the text cues. The mean improvement (4.85 min, +/- 2.1 min 95% CI) was statistically significant ($t_{(13)} = 4.91$. $p < .01$). Even when considering only the observers who improved, however, the mean improvement in the current study is still less than the improvement (6.05 min,

+/- 1.09 min 95% CI) between the known and unknown conditions in Shevlin et al. (1997). These data suggest that when type of target movement is similar, text cues improve DVA relative to when observers are unaware of their target's origin. This improvement, however, is smaller than the improvement in the 1997 study.

Optically, the known task in the current study and the fixed task in the 1997 study are the same, with the exception of the type of target movement. Cognitively, the task in the current study requires more effort on the part of the observer to complete these steps. Although it appears not all observers benefited from the cues, even those who did benefit did so to a lesser extent than expected. The text cues did not revert DVA performance back to levels demonstrated in the 1997 study using fixed (left to right) procedures.

The task in the current study is admittedly a monotonous one. Participants were seated in a dark, quiet, and comfortable room and asked to attend to a computer screen for roughly 30 minutes during an average session. Assuming participants made no mistakes during a session, they were required to make 156 separate judgments about computerized vision targets. I observed all participants as they completed the DVA task. Many of the participants likely failed (unintentionally) to completely attend to the task. The faculty, on the other hand, appeared more interested and attentive.

The current findings suggest a revision (italics, below) to the race analogy offered by Shevlin et al. (1997). Using conventional procedures, observers can focus their attentional, motor, and visual capacities at the start line. Using anticipatory tracking, observers are not only able to focus these assets at the start line, but also ensure they leave the start line at race speed. When observers are unaware of the location of the start line, they must first detect the start line, move to it, change direction, and then begin to catch up to the pack. These additional steps obviously disadvantage the racer. This disadvantage is most pronounced during very short races. *This disadvantage may be reduced, but not eliminated, if the location of the start line is announced prior to each race. This reduction will occur only for attentive racers who hear and act on the announcement.*

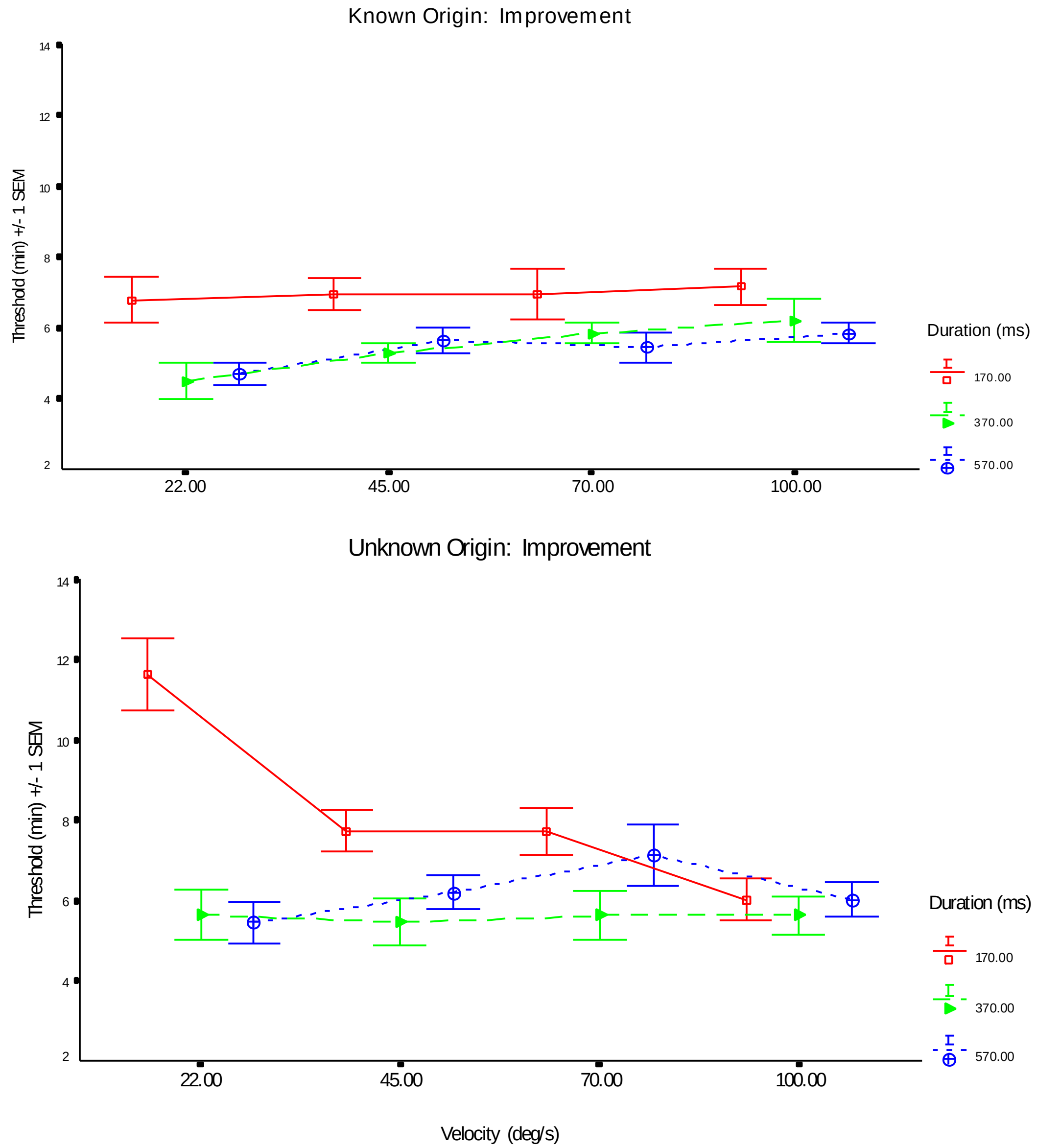


Figure 12 . Three-way interaction among presentation (known, unknown) velocity, and duration for 14 observers who demonstrated DVA improvement at ([22 deg/s] [170 ms] using text cues.

Table 8

Individual DVA difference threshold scores (min) for observers viewing known and unknown origin targets at 22 deg/s velocity and 170 ms duration

| Individual Score | | | |
|---|---|---|---|
| Unknown | Known | Improvement | Frequency |
| 15.8 | 5.3 | 10.6 | 2 |
| 15.8 | 5.3 | 10.6 | |
| 13.1 | 5.3 | 7.9 | 3 |
| 13.1 | 5.3 | 7.9 | |
| 15.8 | 7.9 | 7.9 | |
| 7.9 | 2.6 | 5.3 | 2 |
| 10.6 | 5.3 | 5.3 | |
| 7.9 | 5.3 | 2.3 | 7 |
| 13.1 | 10.6 | 2.3 | |
| 10.6 | 7.9 | 2.3 | |
| 13.1 | 7.9 | 2.3 | |
| 13.1 | 10.6 | 2.3 | |
| 13.1 | 10.6 | 2.3 | |
| 7.9 | 5.3 | 2.3 | |
| 10.6 | 10.6 | 0 | 10 |
| 7.9 | 7.9 | 0 | |
| 7.9 | 7.9 | 0 | |
| 7.9 | 7.9 | 0 | |
| 10.6 | 10.6 | 0 | |
| 7.9 | 7.9 | 0 | |
| 10.6 | 10.6 | 0 | |
| 7.9 | 7.9 | 0 | |
| 5.3 | 5.3 | 0 | |
| 10.6 | 10.6 | 0 | |
| 7.9 | 10.6 | -2.3 | 3 |
| 7.9 | 10.6 | -2.3 | |
| 10.3 | 13.1 | -2.3 | |
| 5.3 | 10.6 | -5.6 | 1 |

Note. Improvement score reflects the difference between the unknown and known scores. Negative improvement scores indicate DVA deteriorated.

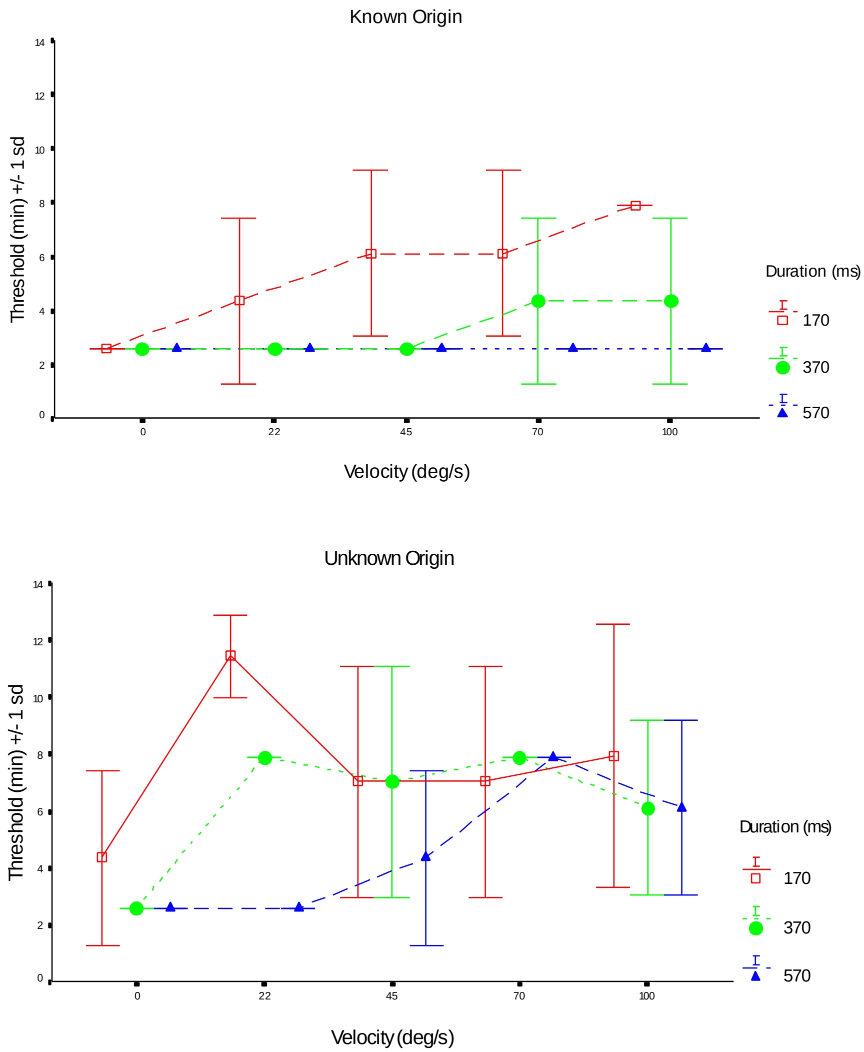


Figure 13. DVA Pilot data (3 United States Military Academy instructors as observers).

Implications and Suggestions for Future Research

The findings from the current study offer several contributions to the DVA literature. This study offers further support for earlier findings indicating that when observers are unaware of the origin of targets, DVA deteriorates (Shevlin et. al., 1997). The data also reinforce the unexpected findings from Shevlin et al. (1997) and show that when observers are unaware of the origin of dynamic targets, slower targets were more difficult to resolve at brief durations. These data partially contradict the conventionally accepted relationship between target velocity and

DVA and support the findings from Shevlin et al. (1997). The consensus in the literature suggests DVA deteriorates as target velocity increases. Data from the present study suggest when observers are unaware of the origin of dynamic targets, faster targets are actually *easier* to resolve at brief durations.

These data also support the idea that text cues may be used to offset DVA decrements when observers are unaware of their target's origin. Data from the current study indicate a modest average advantage afforded by the text cues. The text cues may afford even greater DVA improvement than demonstrated in this study. The actual advantage enjoyed by attentive observers was diluted by the performance of less attentive observers. For attentive observers, text cues may afford a substantial DVA improvement. DVA in the real world often occurs in contexts where observers are unaware of the origin of dynamic targets, and in many cases where the observer would be well motivated to resolve dynamic targets.

If future studies demonstrate a substantial DVA improvement by directing observer attention with text or some other type of cues, one still must ask if the effects are even relevant at these extremely brief durations. The most significant individual improvement in the current study was 10.6 min and was registered for targets displayed for only 170 ms. This exposure time is admittedly very brief. In the real world, one is unlikely to be required to resolve a dynamic target that is displayed for such a brief duration. In response to such criticism, it is also unlikely that a viewer in the real world would be required to search such a small piece of the visual field.

Based on the viewing distance in the current study, the computer screen subtended only 57 deg of arc on the retina. 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 observers to fixate up to 180 deg (Burg & Hulbert, 1961). The 57 deg viewing field from the current study is a small slice of the 360 arena (accessible with head and body movements) in which real world DVA targets are displayed. If text cues can facilitate DVA performance in a restricted field of view, it follows that they would have an even greater impact for targets presented in the larger visual fields required in reality. Recall Perrot et al. (1996) demonstrated that 3D auditory cues facilitated performance in a 360-deg visual search task (finding a target item among a set of distracters). Search times improved by as much as several seconds for targets outside the field of view and by several hundred milliseconds for targets inside the field of view. Data from the visual search literature indicate search time is substantially reduced when observers are aware of the location of a visual target. Consequently, text cues should offer even greater DVA improvement for dynamic targets presented in a 360-deg viewing field by reducing target search time.

Subjective interpretation of the current results indicates some observers in the present study were unable to fully benefit from the text cues due to fatigue and inattentiveness combined with a monotonous task. This study should be repeated with participants from a different population to determine the effectiveness of text cues to enhance DVA with attentive viewers. Similarly, several adjustments to the procedure might reduce the tedium of the task. The two largest target sizes, 23.7 and 21.0 min were larger than needed and could be eliminated from the procedure. This deletion would reduce the number of judgments in a session by 30. Similarly, the 45 and 70 deg/s velocity conditions could be averaged together to yield a single mid-range velocity of 57 deg/s. This combination would eliminate at a minimum, and additional 27 judgments. The static trials could similarly be eliminated, further reducing the number of observer judgments by 27. By making the task shorter, observers might be less likely to lose interest and become fatigued. By making the task briefer, it might be easier to demonstrate the actual benefit afforded by the text cues. If this benefit is documented, it will have theoretical and practical implications for designing applications in which the observer is compelled to locate, resolve, and act upon a dynamic target.

As technology advances, it would be extremely informative to superimpose existing eye movement technology on a computerized DVA test. This eye movement technology would provide an objective assessment of the effectiveness of the text cues distinct from the dependent measure. This would provide an additional measure to determine the effectiveness of text cues. Advances in technology would also allow dynamic targets to be programmed and moved over larger visual fields where text cues would offer an even greater DVA advantage. If programming dynamic targets on three or four computer screens were possible, these screens could be arrayed in a 180-deg arc around the observer. The observer would be required to coordinate eye, head, and body movements to acquire and track the targets. This process more closely approximates real-world DVA tasks. As computer and display technology improves, this DVA software will become even more useful, allowing DVA research to investigate some exciting questions with minor software manipulations. The relative effects of different types of attentional cues (i.e. auditory, iconic) could be used to enhance DVA More complex target motion paths (i.e., nonlinear paths, obliquely approaching and receding paths) could be programmed and used to investigate DVA. Additionally, real world visual tasks occur at multiple target contrast levels. Conventional high-contrast vision exams fail to capture the observer's visual ability across these differing levels of contrast (contrast sensitivity). The NRC (1982) advocated the use of contrast sensitivity as a measure of visual ability for aviators. Software adjustments might be made to the DVA program to systematically vary dynamic target contrast. These adjustments would facilitate scientific investigation of contrast sensitivity under dynamic conditions. Advances in projection technology might be used to display targets at greater physical distances than the 34 cm used in the current study.

Following the pioneering work by Miller and Ludvigh, researchers showed only "sporadic" interest in the investigation of further aspects of DVA (Long & Roarke, 1989). Once DVA had been established as a physiological capacity, DVA research tapered off despite strong suggestions from the NRC (1982) to incorporate DVA testing for aviators. The current study represents a substantial step towards fielding a reliable and portable platform to screen for DVA. Prestrude (1987) called for the development of a DVA screening test in the form of a microcomputer program that could provide a small, portable, and standardized visual screening instrument. Such an instrument might be more readily applied by flight surgeons and used to conveniently obtain normative DVA data. Obtaining such normative data would advance the possibility of incorporating DVA into existing visual screening batteries. This platform and those that follow will allow DVA to be measured more as an integrated ability than as an isolated sensory capacity, by incorporating the cognitive, motor, and visual dimensions observers must orchestrate when detecting and resolving real-world DVA targets. Prior to implementing any DVA screening measure, normative data would need to be collected on a large scale. The computer software used in the current study could readily be used at multiple locations to collect the normative data needed to further advance the possibility of using DVA as a visual screening tool.

This study represents significant departure from the constraints imposed upon DVA researchers by conventional apparatuses. As technology increases in sophistication, DVA can and should be investigated under more realistic conditions. Armed with improved display technology, future research can document DVA under diverse conditions and develop and test interventions to reduce DVA decrements in applied settings.