Peripheral Dynamic Visual Acuity Under Randomized Tracking Task Difficulty, Target Velocities, and Direction of Target Presentation

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Peripheral Dynamic Visual Acuity Under Randomized Tracking Task Difficulty, Target Velocities, and Target Direction of Presentation

By
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(ABSTRACT)

Dynamic Visual Acuity (DVA) in the visual periphery has not been extensively studied. DVA is a measure of an observer’s ability to resolve critical details in a target when there is relative motion between the target and the observer. This dissertation examined static and dynamic acuity in the 25-55 deg region of retinal eccentricity under a variety of conditions. Functionally, this region of the visual field is just beyond the “blind spot,” but not yet in the “far” visual periphery of 60-90 deg of eccentricity. Traditionally, DVA research has been confined to the assessment of DVA for the foveal (or “central”) visual system. However, the peripheral (or “ambient”) visual system provides very important information content for the visual and neuro-vestibular systems. This peripheral visual information content is also used to create a sense of ego motion (termed “vection”), and for alerting the visual system to targets entering or leaving the field of view. Past findings involving visual acuity in the peripheral retina have demonstrated that peripheral acuity performance has components related to the notion of “attention” as well. This is particularly true if the peripheral vision research results are to be applied to visually and attentionally complex and/or dynamic real-world environments.

In this experiment, the 25-55 deg eccentric region of the retina was tested for DVA in 50 observers. This study used a mixed four-factor research design with Eccentricity (25, 35, 45, 50, 55 deg) as a between-subjects factor. Tracking Difficulty (monitor only, easiest, moderate, most difficult tracking levels), Landolt C Target Velocities (0.0, 4.88, 14.62, and 24.40 deg/s), and Target Direction ( “F/R:” fixed or random direction of target appearance) were used as within-subjects factors. A computer presented the Landolt C ring targets under the stated conditions in a random fashion. Acuity was determined for each trial by a modified descending method-of-limits approach with the Landolt C ring target gap widths utilized as the determinant for the acuity measure. The Tracking Task was designated as the primary task, with the secondary task being to indirectly observe the orientation (up, down, right, left) of the Landolt C rings being presented under the various conditions of Target Velocity and Target Direction in the retinal periphery.
The resulting Analysis of Variance (ANOVA) revealed significant differences (p < 0.05) for each of the main effects of Eccentricity, Tracking Task Difficulty, Velocity, and Target Direction (F/R). Only two of the two-way interactions were found to be significant (p < 0.05) -- those of Tracking Difficulty x Target Velocity and Target Velocity x Target Direction interactions. The results are discussed in terms of the psychophysical, attention, and “tunnel vision” like models of peripheral visual performance, along with other related human factors literature in the domain of “situation awareness” that are relevant to this general problem area.

The results of a separate follow-on mini-study are discussed using a Two-way Contingency Table analysis across all of the treatment conditions when verbal intrusion was embedded in the previously described experimental conditions. This mini-study revealed a significant association (p < 0.05) with not seeing the peripheral targets as accurately when intrusion was present, versus when there was no verbal intrusion. This effect was more pronounced at the highest velocities (14.62 and 24.40 deg/s) as compared with the slower ones (0 and 4.88 deg/s) in terms of the strength of the association, as assessed by a Kappa test statistic.

Taken all together, and with consideration given to the relatable scientific literature, these results indicate that the more “busy” a person is with cognitive, visual, or motor-skills tasks, the more likely an individual will show degradation in static or dynamic peripheral visual acuity tasks. Peripheral vision often serves as a “warning” or “status” sensory modality for what is occurring in the local task environment, separate from the foveal visual system. Future research is suggested given the sensitivity of the peripheral visual system to these factors, particularly with regard to how factors involving the notion of attention may affect such “peripheral visual awareness” issues. These issues in turn may play an important role from a human factors and safety perspective in a variety of person-rated vehicular domains. Specific areas that are highlighted for future research in the domain of attention and “peripheral visual awareness” include the low-altitude high-performance flying realm, the flying environment more generally, and in other dynamic multi-task vehicular environments such as that encountered while simultaneously driving and using a car cellular phone.
The final document was substantially improved due to the time my various committee members took to provide a critique of this work. I am very grateful to them for sharing their expertise and insight. There are several individuals that are deserving of mention that were integral to the accomplishment of this study. Dr. Woodrow Barfield provided many hours of thoughtful review and insight into this project with respect to how the peripheral visual system performs, and has become a valued mentor and key advisor in the human factors and vision research community. My previous Master’s advisors in systems engineering, Professor (Col) Paul Kemmerling and Dr. Robert Dryden, thankfully stayed on this Ph.D. project as committee advisors. I cannot thank my Master’s degree in Systems Engineering Chairman, Professor (Col) Paul Kemmerling, enough for remaining on this committee as a crucial advisor for this dissertation work. Dr. C. Patrick Koelling offered advice or other project help whenever it was needed, even while off-site at another assignment. Dr. Albert Prestrude provided the laboratory space and many participants for this study. Dr. Robert Beaton provided a critique of the draft that improved the final product. Mr. Bron Duncan’s fine graphics support has been appreciated.

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INTRODUCTION

Optimal foveal and peripheral visual performance is important for most human tasks, including operating air- and land-based vehicles, working at command/control consoles (such as found in Air Traffic Control or for weapons systems on ships/aircraft), and when using a variety of display systems to enhance situation awareness. Tests of visual acuity have typically involved the use of static targets, while the “real world” that the visual system must perform in is replete with a wide variety of both static and dynamically moving targets. Considering these factors, and with thoughts toward addressing deficits in the scientific literature, this study examined the dynamic acuity performance of the peripheral visual system (25-55 deg of visual eccentricity) as a dependent variable at a variety of Target Velocities, Target Directions of travel, and Tracking Task Difficulty levels.

Concepts about what factors affect visual performance have evolved dramatically over the past 150 years since Hueck’s (1840) and Volkmann’s (1846) early remarks about the peripheral visual field. Aubert and Forster’s (1857) research on Static Visual Acuity (SVA) research revealed that visual acuity declines as a target moves into the retinal periphery. In a classic study, Wertheim (1894) undertook a detailed examination of SVA in the retina from the central to peripheral fields of vision that has been cited extensively and is available more recently in translation (Dunsky, 1980). SVA declines quickly as one moves from the fovea to the retinal periphery for approximately the first 5 deg, after which decrements in SVA continue, but at a slower rate of decline. Refer to Figure 1 from Woodson (1954) that combines data from historic and modern researchers in the peripheral vision/retina studies area.

Static acuity measures have been employed by researchers since the earliest vision work as the predominant method utilized to assess visual performance. By the late 1950’s, the minimum angle of resolution measure of SVA came into widespread use that expressed visual acuity in terms of the degrees (or mins) of visual angle that the discriminating aspect of the test target subtended. This “minimum angle of resolution” metric has become one of the most utilized methods that vision researchers have adopted for use since that time in order to give easy-to-understand meaning for the acuity values found (Weymouth, 1958). This study follows the same convention by reporting acuity measures as an angle of resolution in minutes of visual
Figure 1. The distribution of rods and cones along a horizontal meridian with a superimposed relative visual acuity index [from Woodson (1954); Rod and cone density data for figure derived from Osterberg (1935)].

angle (60 mins = 1 deg of visual angle).

The world that humans perceive is not static. Scenes and targets appear and disappear continuously within the field of view. For this reason, studies of Dynamic Visual Acuity (DVA) are important from a psychophysical and human factors engineering standpoint. DVA is defined as a visual acuity measure obtained from a target with relative motion in the observer’s field of view. Scientific work on DVA began in the late 1940’s, and has continued since (for a broad sampling of this literature see Ludvigh, 1949; Miller and Ludvigh, 1962; Morrison, 1980; Shevlin, Prestrude, and Shevlin, 1997). The majority of DVA research has focused on the evaluation of foveal (or “central”) acuity characteristics.
Visual information is processed from both the foveal and peripheral retinal areas. Since the foveal and parafoveal regions sample only a small fraction of the total visual field ($\sim \leq 4.5$ deg of visual angle; Williams, 1995a), the peripheral areas of the retina also should be regarded as important contributors to the functional performance of the visual system in terms of object detection, vection, and for inputs to the neurovestibular-related control systems (Barfield, Bun, and Kraft, 1989; Leibowitz, Johnson, and Isabelle, 1972). Because the foveal and peripheral visual systems provide different inputs to the brain’s visual and vestibular signal processing regions, particularly with regard to the perception of motion, target detection, and postural equilibrium in the case of the peripheral visual system-- it is reasonable to study the responses of the retinal periphery to a variety of stimuli. Kraft, Barfield, Busey, Williams, and Qualy-White (1993, p. 181) summarizing other researchers’ thinking (Held, 1970; Leibowitz and Post, 1982) have noted that the foveal and peripheral visual systems can be described in the following manner:

Visual scientists have found it advantageous to describe the visual system with two elements: a foveal (focal) and a peripheral (ambient) subsystem (Held, 1970; Leibowitz and Post, 1982). The focal subsystem generally performs such tasks as pattern recognition and requires well-lighted, high contrast stimuli for maximum performance. Alternatively, the ambient system principally provides information on observer orientation, direction, and velocity of movement. The ambient subsystem is accomplished by the peripheral areas of the retina, and does not require higher illuminance, contrast, or resolution.

Thus, the foveal and peripheral visual systems can subserve different visual functions.

Prestrude (1987) noted that of approximately 250 published papers on DVA, foveal DVA was studied more often than peripheral DVA. He commented that it was possible that DVA in the retinal periphery might correspond best to performance measures in some tasks such as flying, driving, and athletic activities. Webster and Haslerud (1964, p. 272) have made similar observations:

Rather it is necessary, whenever the peripheral region is being utilized, to determine the specific effect on peripheral perception of the presence of a second task. In such areas as driving, athletics, and flying, where peripheral vision is important there are definite practical applications.
Problem Statement

Compared to foveal DVA, only a few researchers have examined peripheral DVA. Low (1947a) presented Landolt C targets at up to 60 deg eccentricity from fixation, but utilized only one target speed (15 deg/s). Hoogerheide’s (1964) study used a single subject to 90 deg of retinal eccentricity with several velocities represented from 6-60 deg/s. Later, Brown (1972a) examined peripheral DVA up to 10 deg of retinal eccentricity with target velocities from 0-50 deg/s. Collectively, these works appear to be the most important contributions to the peripheral DVA research literature. With only minor variations at very slow velocities, the papers noted above found decreasing peripheral DVA with increasing target velocity for each area of the peripheral retina that was tested. Increasing the visual eccentricity of moving targets also resulted in poorer peripheral DVA. The differences among these studies are related to different target types, target contrast differences, target presentation formats, plane of motion, and the targets’ travel-paths. All of these studies used foveal fixation to assess peripheral DVA function.

Low (1947a) observed that DVA values obtained from moving targets out to as far as 20 deg of visual eccentricity were affected by the retinal “blind spot.” Accordingly, the present study examined DVA in the peripheral visual field from 25-55 deg of visual eccentricity. This research effort tested a variety of Target Velocities and Target Directions of Landolt C target presentation, unlike the previously noted studies. Furthermore, the present study assessed this peripheral DVA performance under various levels of Tracking Task Difficulty, or primary task loading.

Peripheral vision is a major factor with regard to target detection, orientation, and motion sensation (Berthoz, Pavard, and Young, 1975; Brandt, Dichgans, and Koenig, 1973; Dichgans, Held, Young, and Brandt, 1972; Malcolm, 1984; Yantis and Jonides, 1984). However, the vast majority of previous work into the nature of the response of the peripheral visual system with regard to acuity and detection thresholds for a variety of stimuli has not allowed for the effects of other visual processing occurring simultaneously. Specifically with respect to peripheral DVA, vision has not been tested in a “generalizable” task-oriented motor-skills scenario where the participants’ foveal vision was occupied while tracking some object as the peripheral DVA responses were being assessed (e.g., Anstis, 1974; Weymouth, 1958). With these factors in mind, Ikeda and Takeuchi (1975; p. 255) wrote:
However, these data state only the lower limit of peripheral response capability, because in these experiments subjects merely fixated centrally while attempting to detect peripheral stimuli. This kind of situation rarely occurs in daily life, since the retina is never unstimulated. The influence of the central task upon peripheral vision is, therefore, a basic issue for which different investigators have reported conflicting experimental reports.

While the previously highlighted studies provide interesting psychophysical results for a fixated visual system, they have not addressed peripheral DVA from a more “ecological” visual perspective (in the real world, the eyes are moving and constantly tracking targets for various periods of time, similar to this study). Such an approach better assesses peripheral DVA performance relative to a “real-world” scenario under levels of cognitive/visual workload and non-stationary foveation (such as might be the case at when driving or flying). Indeed, the National Research Council (NRC; 1982, 1985) has indicated that DVA studies could be an important contributor for obtaining a better understanding of how visual processes are utilized in a real-world environment, and indicated that it might be the case that DVA would be more highly correlated to some aspects of flight performance/driving skills than SVA.

This dissertation research sought to address such weaknesses in the literature from a psychophysical and human factors perspective. Specifically, participants were instructed to visually fixate on a target for 25% of the time, and were engaged in a foveal Tracking Task 75% of the time. There were four levels of Tracking Task Difficulty presented to the participants at four Target Velocities in their visual periphery. As noted earlier, all of the previously cited peripheral DVA studies used a fixed, known area of origin for the moving targets. Not knowing precisely from where a target will appear on the display screen corresponds more closely to many instances where peripheral DVA might be utilized in a real-world vehicular environment (Shevlin, 1996). This dissertation tested peripheral DVA when the target appeared either from a fixed, or four randomly-varying Target Directions of travel. The four randomly-varying directions of target travel were in the form of an “>,” where the Landolt C targets moved from one of the four corners of the “>” in a straight line toward the opposite corner of the “>” (left to right starting from the left-most positions, and beginning from the right and moving up or down and to the left).

Previous scientific investigations of the peripheral visual system have been challenging from a technical standpoint, such that peripheral DVA data were difficult to obtain. Under such
conditions, investigators were often able to test only a few experimental participants, or were able to obtain relatively few replications across experimental conditions. This dissertation study utilized computerized platforms that were fast enough to get 10 different participants at each peripheral eccentricity tested in a relatively short period of time of only 1.5 hours, including preliminary visual testing and breaks. Five retinal locations were tested from 25-55 deg of visual eccentricity. Thus, each participant had an opportunity to be presented with all Tracking Difficulty levels, Target Directions of travel, and Velocities of Landolt C movement for a significant degree of within-subjects data point replication at each of the eccentricities tested.

This body of research also has relevance to the notion of “paying attention to” what is happening in the visual periphery in order to properly process that information. Such concepts apply most directly to the flying and driving domains in terms of enhancing overall “situation awareness.” Recent concern expressed about car cell phone use while simultaneously driving is a possible example where distraction and channelized attention may be contributing to an increased risk for being involved in a car crash while using these devices (Redelmeier and Tibshirani, 1997). Human beings rarely collide with what they can “see and avoid” if there is enough time to take evasive action. If humans perceive the impending danger too late, due to a compromised peripheral visual system (for whatever the reason), then perhaps the “warning service” provided by that system is being compromised under some conditions. Could it be that some car and aircraft accidents where the peripheral visual system is utilized to alert—then see and avoid collision—are being caused by too few cognitive resources being available for properly attending to the visual periphery as the operator becomes more “engrossed” in the primary task at hand? Pursuing this point just a bit further, it is interesting to note that the vast majority of USAF serious mishaps that involved the loss of life or badly damaged airplanes during a ten-year window of time in the 1980’s were attributed to channelized attention, distraction, or task over-saturation as pilots hit other aircraft, collided with the ground, or made other human factors types of errors (Holland and Freeman, 1992; 1995). This was found to be true for a variety of aircraft, and relates to the broader concept of “situation awareness” (for a series of articles in one journal on this topic refer to the special edition of Human Factors edited by Gilson, 1995). From a visual information processing perspective, it seems reasonable to surmise that the less accurately one is able to “see” in the periphery that overall situation awareness might be degraded for some task environments.
LITERATURE REVIEW

General Visual Acuity Issues

Visual acuity has been defined as the ability to see the salient details in a just-resolvable target stimulus (Anstis, 1974). The cone photoreceptors are known to be the transducers of detailed visual information. Under photopic viewing conditions, the density and arrangement of the cones is an important determinant of visual resolution from a physiologic standpoint (Williams and Coletta, 1987; Yellot, 1982). Research on SVA reveals that it declines precipitously as one moves the acuity test from the fovea into the retinal periphery (refer again to Figure 1). Thibos, Walsh, and Cheney (1987, p. 2196) have confirmed previous reports by Kerr (1971) and Wertheim (1894) that peripheral visual resolution values obtained from sinusoidal gratings typically fall “…rapidly from a central value of 54 cycles/deg to just 6 cycles/deg at 20 deg of eccentricity and only 3 cycles/deg at 35 deg” of eccentricity. Under photopic viewing conditions, such decreases in visual acuity roughly parallel the declining number of cone photoreceptors (Curcio, Sloan, Kalina, and Hendrickson, 1990; Ludvigh, 1941a; Osterberg, 1935, Williams and Coletta, 1987). The decline in visual acuity performance is illustrated by Figure 2 below.

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Figure 2. A pictorial impression of the progressive coarsening of visual acuity from the fovea to the retinal periphery. According to the study’s author, with good textual viewing conditions in the original document, the letters shown should be “equally readable” when the center of this chart is fixated at any distance (Anstis, 1974).
There are factors other than cone density that affect photopic visual resolution such as optical quality (Banks, Sekuler, and Anderson, 1991; Jennings and Charman, 1981), retinal neuronal interconnections (Curcio and Allen, 1990), and retinal image blurring arising from microsaccadic eye movements (Adler and Meyer, 1935). Interestingly, the ability to “see” targets in the fovea or retinal periphery also is dependent on the allocation of “attentional” resources to the task (Jonides, 1981; Jonides and Yantis, 1988; Webster and Haslerud, 1964; Yantis and Hillstrom, 1994). Thus, acuity in the human visual system is modulated at several levels within the nervous system. The key elements of visual system behavior are reviewed in more detail in the following pages, particularly as they relate to the performance of the peripheral visual system.

The research literature most relevant to this dissertation includes historical and modern peripheral static acuity literature, as well as a brief discussion of old and new DVA studies for the foveal visual system. Peripheral DVA studies also are reviewed, with additional commentary provided from the “attentional” literature that relates to DVA performance in the retinal periphery. Commentary on issues in spatial vision that relate to the perception of targets in the retinal periphery is also offered. The studies are generally reviewed in a past-to-present sequence within each of the broader groups noted.

**Peripheral Static Acuity Measures: Historical Perspective**

Since Hueck (1840) and Volkmann’s (1846) brief comments on SVA variations with eccentricity were published, more than a handful of early researchers have attempted similar assessments under varying experimental conditions (Aubert and Forster, 1857; Wertheim, 1894). The various target types and critical dimensions that were manipulated to determine acuity at different points in the foveal and peripheral visual fields have included: a variety of gratings (Wertheim, 1894; Weymouth, Hines, Acres, Raaf, and Wheeler, 1928), vernier offsets (Bourdon, 1902, Weymouth 1958), movement detection thresholds (Basler, 1906), contour-break test objects (Adler and Meyer, 1935), the “classic” Snellen letters (Dobrowolsky and Gaine, 1876; Dor, 1873), Landolt C’s (Low, 1943), and a host of other approaches as noted by Traquair (1940).

The classic curves of peripheral acuity that Wertheim (1894) generated closely follow those shown in Figure 1 for the horizontal retinal meridian (which is the horizontal line directly to
the right and left from the foveal fixation point). Wertheim used very thin wire “gratings” as targets for peripheral visual acuity measures in the horizontal and vertical planes (see Dunsky, 1980 for a translation of T. Wertheim’s 1894 classic paper).

Traquair (1940) said that the results among different workers in the visual periphery were often highly variable, with similar comments made for the acuities found within a given study. Low (1943, p. 83) remarked on this by writing, “This suggested a more or less wide variation of peripheral visual acuity under normal conditions.” Additionally, Ludvigh (1941a) noted in his paper that few of the early laboratory experiments testing SVA at various eccentricities had experimental conditions that closely approximated those normally found in the clinical assessment of visual acuity.

The 1940’s were a time of greatly expanding research in the peripheral visual system. The first major paper of that decade in this area by Ludvigh (1941a,b) studied the “near” visual periphery under conditions corresponding closely to those found in clinical practice by using Snellen letters as the test target for acuity determination. Three subjects were tested repeatedly at eccentricities ranging from 0-10 deg of visual eccentricity. Ludvigh (1941a) was one of the first vision researchers to articulate what might be the reason for the shape of the visual acuity curve in this retinal region. Ludvigh (1941a, p. 306-307) wrote:

It appears likely that when the retinal image is located on some peripheral region of the retina there is some relationship between the visual acuity exercised by the eye and the density of cones at the same region of the retina. It might be thought that if visual acuity is dependent upon a discrimination of linear extents the square root of the number of cones would be a deciding factor, while if visual acuity is mainly dependent upon discriminations of areal extent, then the number of cones per sq. mm. would be a determining factor in the variation of visual acuity from center to periphery. It will be noted that the variation in visual acuity from center to periphery does not exactly parallel the decrease in either linear or areal density of cones from the center to the periphery. This, however, is not surprising because near the fovea the fixation tremor of the eye (Adler and Fliegelman, 1934) and the finite size of test objects may cause the acuity to remain relatively high over a range of the central region of the retina even though the density of the cones decreases and shows no corresponding quasi plateau. In the periphery on the other hand, the visual acuity of the eye is no doubt affected by factors other than the density of the retinal elements… Despite this obscurity, however, it has been suggested by some investigators (Crozier and Holway, 1939 a, b; Elsberg, 1937; Elsberg and Spotnitz, 1937;) that central nervous system processes are the dominant features of sensory thresholds.
Thus, Ludvig hinted not only at how the peripheral retina might function under photopic conditions but also foreshadowed a few of the key elements of debates that would occur in vision science for the next 50 years in terms of optical factors, peripheral processing factors, and attention issues as they relate to peripheral visual performance (Banks, et al., 1991; Eriksen and Yeh, 1995; Ikeda and Takeuchi, 1975; Williams, 1995a,b; Williams and Coletta, 1987).

Low (1943) was the first author to study the 30-60 deg region in the visual periphery under controlled conditions with a large number of subjects (n=100). Low (1943, p. 83) described his targets as “…Landolt Broken Circles (diameter equals five times width of line equals width of break) photographed and printed on the targets in the following sizes: width of [the circle] break in mm. ½, 1 ½, 2, 2 ½, 3, 4, 5, 6, 7, 8, 9, 10.” He noted that peripheral visual acuity variation was much greater than expected. Low (1943, p. 87) therefore commented:

The relative average acuity for each point as noted in figure 1 agrees in the main with the curves of Wertheim (1894). The actual variation of acuity for each individual point is of course greater than the limits of the standard deviation boxes. For example, on the up 30° point, the smallest test object identified was size 1, while 2 of the subjects could not identify size 10, the largest used. On each 60° point some individuals failed on size 10.

It is notable that the variation of the acuity for any point increased as the acuity itself decreased… central acuity is not a reliable indicator of peripheral visual acuity. This is in accord that the fact that the focusing power of the lens, which is largely responsible for central acuity, hardly functions at all beyond 30° from the line of vision...The lack of high grade positive correlation between peripheral visual acuity and other measured factors seems to justify the statement that peripheral visual acuity is an independent visual function.

The general comments by Low in his 1943 paper parallel later findings with regard to the wide variation and individual nature of performance on peripheral acuity tests (Kerr, 1971, Low, 1947a,b; Low, 1951). The later paper in 1951 by Low reviewed many of the important issues from the literature for static visual acuity tests up until that time, such as the effects of altering target duration with increasing eccentricity, and the wide variation in acuity results found between individuals in various studies.

Weymouth (1958) summarized the work of 12 authors over 100 years in terms of a measure of acuity that was just beginning to come into use at that time termed “the minimum
angle of resolution.” The minimum angle of resolution measure in mins of arc (or degrees) offered a more straightforward assessment of acuity than does the classic “1.0” (20/20 equivalent) fractional measure of acuity that many researchers used previously since the angle of resolution measure refers directly to the size of the visual angle that a target subtends on the retina (refer again to Figure 1). Weymouth noted in his 1958 (p. 102) paper that “the minimum angle of resolution (MAR), a true threshold, is now coming into general use.” This statement turned out to be prophetic.

The result of this earlier work reveals a gradual evolution in thought from considering the peripheral visual system as a “fixed” response system to one that had response plasticity associated with it based upon a variety of visual and “nervous system” issues. Additionally, researchers have begun to realize that there is significant variability among individuals with regard to their peripheral acuity abilities, even though their foveal vision might test as “normal” (i.e. 20/20). Lastly, by the late 1950’s, there was a realization that more standardized measures of acuity (such as “minimum angle of resolution”) should be adopted since the wide range of metrics used for acuity were somewhat difficult to compare across studies.

**Peripheral Static Visual Acuity: The Modern Era**

Beginning in the 1960's, investigations into the visual periphery continued with static targets, and became more sophisticated with improving technology. Target types utilized to measure SVA in the periphery again included contrast gratings (Banks et al., 1991; Daitch and Green, 1969; Thibos, et al., 1987; Westheimer, 1979), two-dot vernier acuity (Westheimer, 1982), Landolt C gap-orientation determination (Millodot, Johnson, Lamont, and Leibowitz, 1975), and Snellen letters (Anstis, 1974).

The exact nature of the loss of SVA with increasing eccentricity in those studies varied according to the type of visual task presented. For example, SVA decreases more quickly with increasing target eccentricity under foveal fixation for a two-dot vernier acuity task than for a grating resolution task, because fewer cone photoreceptors are active in the case of the two-dot vernier task, or because of spatial frequency tuning by the receptors themselves (Orban, Gulyas, Spileers, and Maes, 1987). SVA also decreased slightly more slowly at stated eccentricities for a grating resolution task as compared to a Landolt C presentation. Thus, in the visual periphery, Landolt C targets generally yielded values for the SVA case that are intermediate between the
most-easily seen gratings and the harder-to-see two-dot vernier acuity task. However, for foveal acuity tests most Snellen letters are usually slightly more difficult to see than Landolt C ring gaps.

With regard to the use of Landolt C’s or sinusoidal gratings, Kerr (1971, p. 378) concluded with these comments in her discussion section:

> It is apparent that the use of the grating test object in the present study resulted in peripheral acuities much higher than those obtained with the Landolt C by Mandelbaum and Sloan (1947). This is the opposite of the situation in the fovea, where maximum acuity for the Landolt C slightly exceeds that for the grating. At least part of the superiority of the grating in the periphery can be attributed to the redundancy provided by a repetitive pattern which can be resolved anywhere over its entire area. This redundancy is probably more important in the periphery, where receptor size and density vary less over the target area than for a comparable area in the fovea.

The comment by Kerr of “…peripheral acuities much higher…” can be interpreted to mean that the stated acuities were much “better.” Kerr’s observations that “… in the fovea, where maximum acuity for the Landolt C slightly exceeds that for the grating,” with the reverse true in the periphery—might be partially explained by the use of constructs where vision is modeled as a spatial frequency-domain analyzer (Campbell and Robson, 1968). Indeed, Bondarko and Danilova (1997) used a two-dimensional Fourier spatial frequency domain approach to analyzing the attributes of a Landolt C and Snellen E. They concluded that it is the lower-frequency components related to orientation of the Landolt C that allows for the more accurate determination of the direction of the Landolt C gap, versus the more grating-like Snellen E which has fewer low-frequency “orientation components.” Such spatial frequency domain approaches have been used as one approach when discussing the results from peripheral vision research studies.
Static Peripheral Spatial Vision

Troland (1924) termed the neural representation of an external stimulus as the “neural image.” Modern interpretations of the “neural image” often are stated in terms of spatial frequency domain analysis using Fourier Theory (Bracewell, 1965), and more recently by spatial and temporal frequency domain approaches (Watson and Ahumada, 1985). Campbell, Blakemore and Robson (Campbell and Robson, 1968; Blakemore and Campbell, 1969) popularized visual spatial frequency domain analyses as a method for evaluating the human visual system.

Whether or not the visual system functions specifically as a Fourier (linear) type of analyzer with all of its inherent non-linearities is an entirely different question. As Regan and Regan (1987, p. 2181) have stated, “The application of Fourier methods to analyzing human visual processing of patterns in two modulated dimensions assumes that there is no nonlinear interaction between visual responses to orthogonal gratings. Our research showing the existence of a strong cross-modulation term in the orthogonal-grating response violates this crucial requirement.” However, with a few disclaimers, spatial frequency domain analyses do appear to provide a reasonably good first-order descriptive output of many functional aspects of the visual system.

Banks et al. (1991) attempted to describe the performance of the visual system across many areas of the retina to 40 deg of eccentricity by assessing some of the optics, photoreceptor, and other properties of the retina from a spatial frequency domain analysis standpoint. Banks et al. noted that several factors are likely to affect performance in a host of spatial visual tasks in different ways depending upon the conditions of the visual task at hand. The factors cited by this group as critically important to spatial vision in the periphery include: the optical transfer function of the eye (Jennings and Charman, 1981), decreasing cone density (Curcio et al., 1990; Osterberg, 1935), the post-receptor processing of the cones’ signals by the retinal ganglionic cells (Curcio and Allen, 1990), and the possibility for the existence of “cortical magnification” functions having an impact on peripheral visual processing (Dow, Snyder, Vautin, and Bauer, 1981; Van Essen, Newsome, and Maunsell, 1984).

Banks et al. (1991) after a thorough comparison of human and “ideal” observers with known optical performance characteristics of the eye from a spatial frequency perspective in a variety of peripheral visual tasks concluded that the information available to the retinal ganglion
(not cone) cells explained much of the variation in spatial vision with eccentricity. This study blunted some of the arguments with regard to the existence of “cortical magnification factors” that appeared frequently in the peripheral vision research literature of the 1970’s and 1980’s. Banks et al. (1991; p. 1786) commented that:

More recent anatomical measurements, however, suggest little if any difference between retinal and cortical magnification (Curcio and Allen, 1990; Wassle, Grunert, Rohrenbeck, and Boycott, 1990). Our results are compatible with these recent measurements… Thus the greater contrast sensitivity and resolving power of the fovea may result from optical and retinal specializations only.

**The Problem of Aliasing in the Periphery.** The optics of the eye are not able to filter out the high spatial frequencies that are transmitted to the retinal surface in comparison to the relatively sparse cone density that resides there from a signal sampling standpoint. This can result in relatively too little sampling of the higher frequency signals at the retina, causing a distortion artifact known as aliasing. The phenomenon of foveal aliasing was first described by Bergmann (1858), and more recently by D.R. Williams (1985).

Thibos et al. (1987) compared their resolution limit results with the detection limit results from D.R. Williams (1985) and concluded that it was not the cone array, but under-sampling by ganglion cells that caused aliasing across a variety of retinal locations.

Veridical representation of a stimulus with a certain frequency component to the retina is possible only for spatial frequencies that are lower than the Nyquist frequency. The Nyquist frequency is the highest spatial frequency (in cycles/deg) that can be represented without aliasing. It is computed by taking the reciprocal of two times the angle of the smallest sampling interval. For the human visual system, the Nyquist frequency can be estimated from the spacing between cone photoreceptors (Williams, 1985). The formula for estimating the highest diagonal spatial frequency for the hexagonally-packed foveal cones is given by:

\[
\text{Nyquist Frequency} = \left( \frac{\sqrt{3}}{d} \right)^{-1}
\]

where \(d\) is the center-to-center spacing of cones in degrees.
According to Thibos et al. (1987), higher spatial frequency image components above this theoretical resolution limit will be sampled and “signaled” by the peripheral vision cone array, but they will be improperly perceived as aliased patterns beyond the resolution limit, but within the detection limit. Higher frequency components may be seen (detected), but misperceived in terms of the gratings’ orientation. This is referred to in Figure 3 as the region of “aliasing.” Spatial frequencies beyond the detection limit are not noticed at all. The different visual “limits” just noted for peripheral vision in terms of spatial frequency are illustrated as a function of eccentricity in Figure 3. The resolution limit curve in Figure 3 from Thibos et al. shows a sharp decline in spatial frequency resolution for the first 5-6 deg of visual eccentricity with a more gradual decline as the more eccentric retinal periphery is examined. According to Thibos et al. the decline in the resolution limit with increasing eccentricity roughly parallels the decrease in ganglion cell density across the retinal periphery, and is not simply a function of the cone cell sampling intervals. Thibos et al. (1987, p. 2196) argued that, “Instead, the aliasing appears to be the result of under sampling by the array of ganglion cells since their spacing [not the cone cells’ spacing] closely predicts the lowest frequencies for which aliasing occurs, i.e., the resolution limit.”

Thibos et al. (1987) used horizontal gratings for targets on the horizontal meridian of the right eye with the left eye occluded. They noted in their report (p. 2194) that “As performance was generally best for horizontal gratings, only these results are reported here [refer to the curves found in Figure 3].” Obliquely presented static targets (gratings, line orientation discrimination, etc.) are known to be more difficult to see than either vertical or horizontal targets in the fovea and peripherally (Vandenbussche, Vogels, and Orban, 1986) and have also been shown to vary with the meridian position in which the targets are tested (Vogels, Orban, and Vandenbussche 1984). Saarinen and Levi (1995, p. 2449) commented that, “…the oblique effect is strongest at threshold, in the fovea, and for high spatial frequencies” (for a review of the literature with regard to oblique target visibility, see Heeley and Buchannan-Smith, 1990).
Figure 3. The limiting spatial frequency for resolution (squares) and detection (circles) of sinusoidal, horizontal gratings varies with eccentricity from the fovea along the horizontal meridian in different ways for the same subject (L.N.T.). Symbols show the means of 5 determinations. Standard errors of the means are less than symbol radius in all cases. The detection value for central viewing is taken from D.R. Williams (1985). The data separate the spectrum of visible spatial frequencies into a zone of veridical perception, which lies beneath the resolution limit, and a zone of aliasing, which extends from the resolution limit to the detection limit (resolution limit data from Thibos et al., 1987).
**Dynamic Visual Acuity Studies (Foveal)**

As the world becomes dependent upon human-controlled vehicular transport, it would seem reasonable that research into the factors that affect DVA would be useful and relevant. Compared to SVA studies, DVA research began later in time and has developed more slowly over the past decades. The progression of knowledge about DVA has resulted in part from technical challenges that DVA researchers have had to surmount in order obtain meaningful measures. This section highlights the development of foveal DVA studies first and then a later section deals with the special case of peripheral DVA research.

Bourdon (1902) worked to ascertain how the minimum perceptible velocity varied from the center to the more eccentric regions of the visual field. Basler (1906) next studied the minimum path length that must be traversed for target motion to be perceived. Later, Blackburn (1937), discussed the ability of an observer to perceive the presence of a moving object, but not its details. Langmuir (1938) appears to have been the first experimenter to attempt to quantify when target blurring occurs due to faster velocities by whirling a piece of solder attached to a string above his head. Langmuir was trying to simulate the velocities of a Deer Fly. Ludvigh (1947) also considered Langmuir’s Deer Fly problem, and then extended his analyses (Ludvigh, 1948) to higher velocities (up to 175 deg/s). Ludvigh’s 1948 test objects were Landolt C’s, and he reported that foveal DVA declines most precipitously at target angular velocities greater than 75 deg/s.

Ludvigh (1947) felt that it was not the absolute value of the linear velocity, but rather the angular velocity of the target across the field of vision that causes diminishing acuities. Ludvigh (1949, p. 22) concluded his paper with these comments:

> The hypothesis is that imperfect pursuit movements, although maintaining the image in the immediate vicinity of the fovea, nevertheless result in a motion of the image on the retina which reduces visual acuity. This motion would result in the retina’s receiving less intensity contrast than it would if the eye and object were stationary. The hypothesis tends to be confirmed by observations showing that when the test object is moving, high intensities of illumination may advantageously be employed to increase visual acuity.
Miller and Ludvigh (1962) later made the following global assessments of the DVA literature up to that point:

1. After a test object attains an angular velocity of approximately 50 deg/s, the ability of the eye to pursue it is impaired [Westheimer’s (1954) research indicated that the eyes could accurately track a moving target up to about 30 deg/s].
2. The absolute values of the DVA thresholds may vary as a function of apparatus, procedure, test objects, and the refractive characteristics of the subject’s eyes.
3. Movement along a vertical meridian is perceived slightly better than movement along a horizontal meridian. No differences were noted for left/right or for up/down motion.
4. If an observer is relatively “velocity resistant” to horizontal motion, that person will very likely be resistant to vertical motion as well (“velocity resistant” means that higher target velocities do not affect DVA values obtained as much—refer to Figure 4).
5. DVA deteriorates most rapidly for circular movement and least rapidly for vertical movement. Horizontal movement deteriorates at a rate in between the vertical and circular rates; however, the general form of the deterioration-- Acuity=a+bx^3 (where x is the angular velocity, and a, b are constants)-- is preserved for each of the three directions of target motion.
6. Because the eye is capable of movement at velocities greater than 500 deg/s, it is therefore the imperfect control of eye movement while tracking a target that produces the retinal image smear that results in DVA degradation with increasing target velocities.

*Individual and Population Differences.* Miller and Ludvigh (1962) commented on the notion of “velocity sensitive” versus “velocity resistant” persons. Velocity sensitive individuals exhibit acuity losses more quickly with increasing target speeds than do velocity resistant people. Figure 4 from Miller and Ludvigh’s paper highlights the differences in DVA between two individuals, one of whom is velocity sensitive and the other velocity resistant.
While an individual may be velocity sensitive or resistant, other patterns emerge from large populations of individuals examined for DVA abilities. Miller and Ludvigh (1956) tested 1000 US naval aviation cadets and results clearly showed a fairly tight pattern of variance at target speeds of 20 deg/s angular velocity, with a much wider distribution for much higher velocities including 110 deg/s. The results from the naval cadet data at 20 and 110 deg/s revealed curves that were not quite normally distributed, and somewhat resembled a Poisson distribution (although they were not completely Poisson in character, either).

**Figure 4.** A comparison of two experimental participants, “R” and “T.” Person “T” appears to be more affected by increasing target velocities, or “velocity sensitive,” while “R” is less susceptible to higher target velocities and is known as being “velocity resistant” (from Miller and Ludvigh, 1962).
In a larger sample (n=17,500) from a diverse civilian population, Burg (1966) found a closer-to-normal distribution for the DVA results obtained at any given velocity. Given the evidence from many studies, it appears that as the target velocity increases, there is more variation in a population’s response to those velocities. Similarly, it appears that some individuals are more sensitive to degrading effects on DVA from increasing target velocity than others.

The question is whether or not a reasonable global explanation can be used to describe foveal DVA results, given the data noted. Brian Brown’s (1972b) remarks provide a reasonable commentary:

DVA is not a fundamental visual attribute but depends on sensory and motor components of the visual response and on the complex feedback systems which link them. The relation between DVA (min of arc) and target angular velocity (deg/s) is approximately linear for targets with velocities up to 90 deg/s. The decrease of acuity with increasing target angular velocity is produced by increasing position and velocity errors of the target image on the retina.

Other recent reviewers of the DVA literature (Hoffman, Rouse, and Ryan, 1981; p. 881; Morrison, 1980) agreed with Brown’s assessments by commenting that “DVA reflects the efficiency of integration of the entire oculomotor system as well as non-visual factors such as attention and practice effects.” The various review authors also remarked that other “human attributes” involved in DVA are the resolving power of the retina, peripheral awareness, and the psychological ability of the individual to interpret what is seen. Taken together, it is likely that a combination of factors including psychological, oculomotor system practice-related, and social all combined to yield the age and gender differences found in the earlier literature (Burg, 1964; Burg, 1966; Burg and Hulbert, 1961). This author would suggest that such outcomes may have occurred because in that period of time because males drove vehicles more often, flew more aircraft, and played sports that helped to develop and hone the fine oculomotor control that underlies DVA performance in the populations tested than did the females at that time.

Another factor that seems to improve foveal DVA includes having anticipatory warnings as short as 0.2 s (Elkin, 1962). Anticipatory eye tracking of targets originating from known locations also supports Brown’s (1972b) foveal study’s general conclusions, and further supports the notion that foveal DVA performance has anticipatory components.
Recently, anticipatory factors have been shown to play important roles in foveal DVA research findings. Shevlin et al. (1997) showed that across all velocities (22, 45, 70, and 100 deg/s) and durations (170, 370, 570 ms) examined, that a random direction of moving target presentation was worse in terms of DVA measures than the fixed direction of presentation case. This anticipatory effect, was described by Shevlin et al. (1997) allegorically as follows:

The observer’s [foveal] DVA task is analogous to a race. 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 they also ensure they leave the start line at race speed. When observers are unaware of the start line, for a random direction of presentation they must first detect the start line, move to it, change direction, and then begin to catch up to the pack [the moving target].

As noted previously, Brown (1972b) felt that foveal DVA began to suffer for obliquely oriented Landolt C target angular velocities of 25-30 deg/s, while Long and Garvey’s (1988) work with moving gratings showed a change in the degradation rate at approximately 30-40 deg/s. Prestrude (1987) summarized results from six DVA studies, including his, and offered an opinion that “marked degradation” of foveal DVA occurs at angular velocities of greater than 50 deg/s.

The question with regard to peripheral DVA research is, “to what degree does knowing where to concentrate (anticipate) attention in the peripheral visual field affect the outcome measures of peripheral DVA studies?” The relevant “attention” literature for peripheral DVA studies will also be reviewed later to facilitate a discussion of these peripheral vision/attention factors.

**Foveal DVA Practice Effects**. Miller and Ludvigh (1962) reviewed previous DVA literature (including their own) and were interested in evaluating the effect of practice on DVA acuities since it appeared that foveal DVA might be considered a skill due to the complexities of oculomotor control upon which good DVA task performance depends.

Miller and Ludvigh’s (1962) results are shown in Figure 5. Twenty successive DVA thresholds were determined for 20 deg/s targets, and 20 additional thresholds were determined at the higher target velocity of 110 deg/s. The effect of practice appears to be considerable at the
faster 110 deg/s presentation velocity, while only a minor amount of improvement related to
practice was noted with increasing practice trials (n=20) at 20 deg/s. Miller and Ludvig (1962;
p. 102) commented that over 50 percent of the total improvement in the 110 deg/s velocity
condition had taken place upon the completion of Trial 4, and “…that the difference between
the means obtained between trials one and two was examined and found to be significant beyond
the 0.01 level of confidence.” Considering a sizable population of DVA responses to practice,
Miller and Ludvig (1962, p. 102) stated: “However, there are a large amount of individuals
who demonstrate a negligible amount of improvement in dynamic acuity as a result of practice.
Likewise, there are those individuals who show a considerable amount of improvement in acuity
and who seem to learn with exceptional rapidity.”

Anecdotally, that pattern of learning was also seen during the data collection phases for
this study, although the mechanisms involved in foveal DVA and peripheral DVA are quite
different. Peripheral DVA, and peripheral vision results in general, appear to have much greater
attentional/tasking components, and relatively little oculomotor control components as the main
contributor to performance. Whether individuals that are “velocity challenged” (velocity
“sensitive” to use foveal DVA terminology as seen in Figure 4) in the visual periphery are
affected by attentional, task environment, mental strategy, previous lack of practice at similar
tasking in recent or longer term time periods, etc. is unclear. The reverse comment may be made
as well. For those individuals that perform exceptionally well on peripheral DVA tasks-- to what
extent is that performance due to better allocation of attentional resources, learning ability,
practice at similar tasks, and an efficient mental strategy used to optimize the task? These are
questions that have not been thoroughly investigated in past peripheral DVA studies.

The question of longer-term practice effects has been examined for foveal DVA studies.
Miller and Ludvig (1962) evaluated how eight experimental participants performed on a foveal
DVA task after 180 trials over a three-week period. This body of research showed that the
critical DVA detail resolvable after approximately 180 trials was not significantly lower than the
values found on the 15-20th trial results. Miller and Ludvig (1962, p. 104) commented that, “It
was found further that about 92 percent of the total improvement which took place upon the
completion of 20 thresholds had been achieved by the end of the 10th threshold [trial]. We may
conclude, therefore, that after 10 threshold determinations at 110 deg/s angular velocity of test
object, the learning curve is probably asymptotically approaching its final value and not merely a temporary plateau.”

Ludvigh and Miller (1955) investigated the effect of transfer of training on DVA. Surprisingly, no significant improvement in foveal DVA measures occurred for the 20 deg/s condition after practice with target presentations at 110 deg/s. Thus, cadets receiving the faster 110 deg/s targets first reached their final asymptotic values more quickly if the slower 20 deg/s condition was presented second. As might be expected, practicing at the 20 deg/s, then testing at the faster 110 deg/s led to no significant improvement in DVA for the faster presentation velocities.

The potential for a similar practice effect was given consideration as a part of the research design for this experiment, so that the observers were well practiced before the actual data collection phase began.

Figure 5. Miller and Ludvigh (1962) DVA as a function of trial number for two Landolt C target velocities. Exposure times were 250 ms, with a target illumination of 268.75 lx.
Later researchers’ studies (Long and Riggs, 1991; Long and Roarke, 1989), challenged Miller and Ludvig’s (1962) earlier review assessment of 10-20 trial asymptotic results, in favor of significant training effects well past the 20 trial number. The studies accomplished in Long’s laboratory using fixed- or free-head viewing conditions found that the practice effect was most important for those participants initially demonstrating the poorest performance with briefer exposure times and faster velocities on the DVA task. Long and Riggs (1991) commented that if training effects exist, foveal DVA might be thought of as a skill that can be nurtured in tasks where DVA has important performance components (e.g., flying, athletics). Shevlin (1996) and Shevlin et al. (1997) also tested if practice improved DVA, particularly if fixed then random targets were presented, and found that there was an absence of any such training effect. Shevlin et al. were careful to note that the absence of a training effect in their data should not be construed as minimizing the Long and Riggs study since the Shevlin et al. target size increment of 2.6 min of arc was probably too coarse to resolve the 2 min of arc practice effect improvement found by Long and Riggs in their foveal DVA research.

A summary of other factors relevant to foveal DVA results can be found in Appendix A. The Appendix includes commentary on the reliability of target types, target orientation effects, and other factors that affect foveal DVA outcomes including fixed- versus free-head viewing of DVA targets.

Recent research by Heinen and Watamaniuk (1998) on foveal DVA in terms of the spatial integration of human smooth pursuit contains ideas that may have a bearing upon peripheral DVA research. Smooth pursuit is a voluntary eye movement that aids in the stabilization of a moving object on the retina, thereby creating a clearer image by reducing image “slip” on the retina. These authors suggested that spatial summation occurs in the visual system’s motion processing system. When peripheral visual areas are engaged with foveal ones, and when the target motion in the periphery is in the same direction as the foveal image, they note that the motion information from the parafoveal and peripheral retina would help the eye’s oculomotor control system to better “track” (pursue) a large stimulus. Heinen and Watamaniuk showed this in their experiment, and commented further that the eye’s smooth pursuit improvement with bigger targets is because of a larger number of motion detectors that are summed or integrated. Heinen and Watamaniuk (1998; p. 3792-3793) wrote:
In addition, Verghese and Stone (1995) found that adding multiple small moving stimuli over the visual field improved speed discrimination. These past results as well as our own are consistent with a motion processing system that averages motion information across the visual field. To account for the present data, such a system would require subunits that are smaller than the area that is being averaged across to feed into a summing junction. These results are consistent with current computational models of motion processing that incorporate spatial summation [many references cited], and suggest that the behavior of the smooth pursuit system can be used to explore characteristics of human motion processing.

These authors’ comments are directed toward the spatial-temporal integration of signals involved in the smooth pursuit function of the foveal moving target visual performance when the peripheral visual system is also stimulated. Later, comments will be made in the Discussion section relating to evidence for another spatial-temporal integration/summation process being at work with regard to the determination of Landolt C gap orientation for moving targets in the peripheral visual system as well.
Peripheral DVA Research

Pre-1970 Peripheral DVA Research. There is comparatively little information on how the peripheral retina performs with respect to DVA measures. Low (1947a) systematically investigated DVA in the peripheral retina. Low used Landolt C targets swinging at 15 deg/s along a horizontal meridian. Both eyes were tested separately under conditions of foveal fixation. Low began by testing Landolt C orientation determinations at eccentricities of 30-45 deg, 45-60 deg, and 60-75 deg in the periphery. Using a 1s target exposure time, he found that Landolt C thresholds were approximately 37’ of arc at 30-45 deg, with 78’ of arc in the 45-60 degree condition. Low’s targets were not large enough in the 60-75 deg region of eccentricity to obtain meaningful results. Based upon his data, Low (1947a, p. 127) remarked, “Thus it may be said that when a peripherally perceived object is moving [on the horizontal meridian] toward or away from the line of vision, the innermost 5° of its excursion is the critical area for perception of its form [acuity].”

Low (1947a) also presented observers with moving Landolt C targets at exposures of only 0.20 s. This brief exposure resulted in the Landolt C target travel path being only 3 deg of visual angle. Surprisingly, Low’s reported that despite this much shorter path length and exposure time (3 deg visual angle subtended by the moving target) there was little peripheral DVA loss. He noted that this shortened path resulted in DVA decrements that were not significantly different than the full 15 deg travel-path (1s) exposure condition (refer to Figure 6 on the following page).

The variation between observers’ peripheral DVA abilities was noticed by Low and commented upon. He stated that of 200 trials (n=50 subjects), 1 participant failed to identify the largest Landolt C gap orientation at the 30-45 deg position, 32 failed at 45-60 deg of eccentricity, and there were 144 failures to discern the largest Landolt C target orientation at 60-75 deg of visual eccentricity (resulting in a failure rate of 72% at 60-75 deg). There is a fair amount of variation in Low’s data as Figure 6 illustrates. As a reference, the “failures” just noted would correspond to values on the y-axis of greater than 10 mm Landolt C gap sizes. The implication for the current peripheral DVA study is that a substantial amount of between-subjects variation is to be expected in the acuity values obtained at a given eccentricity.
Figure 6. Average and standard deviations of peripheral motion acuity scores for 50 observers. Vertical bars show the standard deviations around the means. In and out refer to the direction of the Landolt C target movement along the horizontal meridian. The 4 groups with only 3° of target visual angle exposure (labeled as 33-30; 30-33 for each eye) were timed at 1/5 second (data directly from Low, 1947a). “Acuity” (y-axis) refers to the Landolt C gap size in mm. The acuities presented for 1 s converted to mins of visual angle would average out to be 37 min at 30-45 deg of eccentricity, and 78 min of visual angle at the 45-60 deg condition.
McColgin (1960) evaluated 10 airline pilots’ (ages 30-45) ability to detect the motion of an aircraft dial-like pointer in the visual periphery. The absolute thresholds for motion detection at a particular pointer movement rate are illustrated in Figure 7 and extend approximately twice as far on the horizontal axis as on the vertical axis. McColgin (1960) used only a single rotating pointer for the study. Other researchers (Gordon, 1947; Leibowitz et al., 1972) have found that different target shapes presented in the periphery yield different motion thresholds, but the general elliptical pattern seen in Figure 7 of threshold motion-detection is preserved under photopic visual conditions.

The implications of these works are that peripheral DVA cannot be assessed unless, and until, the target is first detected. The general pattern of the threshold isograms’ contours correspond roughly to the visual acuities found for static targets in the peripheral retina by Wertheim (1894; translation by Dunskey, 1980).

As Low (1947a) had discussed, and the various acuity and motion threshold isograms imply, presenting Landolt C targets along the horizontal meridian stimulated a wide variety of cones/ganglion cells with quite different densities along that meridian (and therefore presumably changing resolving power). Hoogerheide (1964) attempted to surmount this receptor density problem by having the target move downward in a perpendicular direction to the horizontal eye meridian in the temporal visual field (refer to the isograms in Figure 7 to see how this applies).

Hoogerheide’s (1964, p. 141-142) target also was somewhat unusual and he described it with the following commentary:

The subject(s) had to discriminate between two objects (0), the one being a luminous square and the other consisting of two luminous bands, separated by a dark one. The latter, called parallel bars, formed a square the size of which was equal to the square formed by the other object. Care was taken to ensure that both objects emitted the same total of light energy.

The luminance of the test object was 4 ½ cd/m². The contrast with the background was approximately 100%. The angular velocity (v) of the movement varied from 0 deg/s to 60 deg/s. Viewing time varied with target velocity in such a way that the length of the motion path was kept constant at 6 deg….Samples were taken from the temporal visual field from 15 deg to 90 deg periphery. The dynamic visual acuity was measured in minutes of arc being the width of the dark band of that object which could be discriminated from the corresponding square in 80% of the presentations. The experimental data were obtained from one subject.
Figure 7. Absolute threshold isograms for detecting rotary movement in the periphery of the visual field. The numbers on the ellipses represent the pointer movement in revolutions per minute. The central crosshair region inside the 2 rev/min isogram indicates the point of foveal fixation. To the right is “90 deg” and to the left of fixation is labeled “270 deg” (McColgin, 1960).
Hoogerheide commented that for his single observer, static acuity measures were in close agreement with Wertheim’s (1894) values. Hoogerheide’s work showed that at velocities of 6 deg/s and 10 deg/s, SVA and DVA measures were similar to each other from approximately 20 deg of eccentricity to 90 deg. At a velocity of 20 deg/s, from 15 deg until 70 deg of eccentricity, DVA was less accurate than SVA. However, beyond 70 deg of eccentricity, DVA for a 20 deg/s target was better than SVA. For a velocity of 60 deg/s, Hoogerheide’s observer performed far poorer in a DVA test than for the static target presentation case until approximately 80 deg of visual eccentricity was reached (see Figure 8).

Figure 8. Four panels showing peripheral visual acuity values at a variety of eccentricities and target velocities. The solid line labeled represents a static acuity measure. Each panel has a different velocity that was tested associated with it, and this is denoted in each graph by a dashed line. The velocities used to test DVA are 6 deg/s, 10 deg/s, 20 deg/s, and 60 deg/s (from Hoogerheide, 1964).
Previous research in the near-periphery on contrast threshold measurements also have demonstrated some degree of improved acuity in the periphery for slowly moving targets as compared to stationary ones. Ercoles and Zoli (1968) used Landolt C targets to evaluate the parafoveal region of 1 and 2 deg of eccentricity with contrast thresholds. Their data revealed that contrast sensitivity was greatest for Landolt C’s moving at 2-3 deg/s, and contrast sensitivity was greater at 2 deg of visual eccentricity as compared to the fovea for targets moving at this speed.

The peripheral retina is known to exhibit the “Troxler Effect.” Clark and Belcher (1962) studied the phenomenon of peripheral non-moving targets “disappearing” at low background luminances or contrast when foveal target fixation occurs. In a study by Pirenne (1958) involving a peripheral detection task at low intensities, the participants found that to achieve the best results, they had to move their eye around just a bit within a few degrees of visual angle, thereby avoiding foveal fixation (as is the case in this study the majority of the time). Researchers also found that targets drifting slowly into the deeper periphery were “lost” more easily than targets moving into the more central areas of vision from eccentric positions, particularly under conditions of visual fixation.

**More Recent Peripheral DVA Studies.** In two experiments, Brown (1972a) studied the near-periphery DVA at 0-10 deg eccentricity by stimulating a “heterogeneous population” of visual receptors in his first experiment (see Figure 9), and a “more homogeneous receptor population” in the second experiment (see Figure 10). Brown did this by choosing the geometry of the Landolt C target travel paths in the visual periphery (see p. 296 in Brown’s 1972a paper for details on how he approached this). His experiments used visual fixation upon a central (0 deg eccentricity) target. Brown (1972a, p. 296) stated that the observer “…was specifically instructed that no eye movements were to be made during the target exposure…Judgements [sic] were made monocularly with the right eye.” He used four male observers for the study at visual eccentricities of 0, 2.5, 5.0, 7.5, and 10 deg. Brown used target velocities of 0, 5, 10, 20, 30, 40, and 50 deg/s presented in random order. Each of the four observers in Experiment 1 (Figure 9), or five observers in Experiment 2 (Figure 10), had thirty peripheral DVA threshold measures made at each eccentricity and Landolt C target velocities. Both experiments showed that at target velocities beyond 10 deg/s there was a general worsening of peripheral DVA at nearly all of the eccentricities tested.
Brown also found that beyond approximately 5 deg of eccentricity, at all velocities, the results of the two experiments became more similar as Figures 9 and 10 reveal. At the maximum eccentricity Brown studied (10 deg), the results obtained from the two experiments were virtually identical. Some of Brown’s (1972a) curves, particularly at eccentricities of 7.5 or 10 deg, show better peripheral DVA at a velocity of 5 deg/s. This result of Brown’s with regard to slow targets being more easily seen than stationary ones relates closely to Ercoles and Zoli’s (1968) work revealing increased sensitivity to slow target motion in the near periphery. Brown (1972a) chose a Landolt C target exposure time of 180 ms, with a mean luminance of the targets noted as 93 cd/m$^2$, and a screen luminance of 14 cd/m$^2$, thereby yielding a Michelson target contrast of 74%.

Brown (1972a, p. 289-299) commented upon the differences between his experiments noting that in the second experiment due to the manner in which the Landolt C rings were presented, “The interaction between target velocity and specified eccentricity is not significant. This is expected since the mode of target presentation was designed to reduce this interaction.” This comment is in opposition to the first experiment, where a “more heterogenous” population of peripheral receptors were stimulated by choosing a Landolt C target travel path that traversed a faster-changing density of peripheral receptors.

Brown (1972a, p. 296) wrote, “The method of limits was used…as the psychophysical method because preliminary experimentation had shown that there was too much variation in the threshold data both between and within subjects to allow the method of constant stimuli to be used.” Brown (1972a, p. 296) commented further that, “Criterion threshold was two incorrect responses (descending series) or two correct responses (ascending series).” Other researchers have chosen a modified descending method of limits technique with a staircased procedure for DVA studies in order to better “bracket” the average response of the visual system for a given set of experimental conditions (see Shevlin et al, 1997; Shevlin, 1999). Following along the lines of previous DVA research procedures, this study utilized a descending method of limits with a staircased procedure to better “bracket” the actual peripheral DVA values obtained given all of the additional constraints inherent in data collection, such as the time available for data collection and fatigue effects.
Figure 9. Brown’s (1972a) Experiment 1. Visual thresholds for Landolt targets as a function of angular velocity. The data are averaged at each data point over four participants. The parameter labeled “SE” is the specified eccentricity of target presentation in degrees. These data reflect acuities determined from a more “heterogeneous” density of visual receptors (cones/ganglion cells) across the targets paths, based upon experimental geometry and design considerations (see text).
Figure 10. Brown’s (1972a) Experiment 2. Visual thresholds for Landolt targets as a function of target angular velocity. The data are averaged at each point over five participants. The parameter labeled “SE” is the specified eccentricity of target presentation in degrees. These data reflect acuities that were determined from a more “homogeneous” population of visual receptors (cones/ganglion cells), based upon experimental geometry and design considerations.
**Peripheral Visual Processing Factors**

Bursill (1958) appears to be the first to discuss a “funneling” of the visual field of awareness with degraded peripheral target recognition as higher temperatures and more humid environmental conditions were introduced. This “funneling” phenomenon has been referred to as a contraction of the field of vision, or “tunnel vision.”

Mackworth (1965, p. 67) described the “functional field of view” decreases he measured as “tunnel vision.” For many of the studies along this line of research, the “functional field of view” corresponds to the foveal and parafoveal regions of up to approximately 4-5 deg of visual eccentricity (Williams, 1989).

Many other researchers have noted that performance on secondary peripheral vision tasks is often degraded when compared to the same peripheral task performed in the absence of a cognitive or foveal load (Webster and Haslerud, 1964; Williams, 1982; Williams, 1988, Williams, 1995a). The vast majority of peripheral tests are tasks such as attending to new peripheral targets, searching for a target among foils, or some other dependent measure of static peripheral visual performance (e.g., Chaikin, Corbin, and Volkmann, 1962; Edwards and Goolkasian, 1974; Engel, 1974; Holmes Cohen, Haith, and Morrison, 1977; Ikeda and Takeuchi, 1975).

Some studies (Bacon and Egeth, 1994; Hillstrom and Yantis, 1994; McKee and Nakayama, 1984) have addressed the question of the detection of motion in the visual field, and how such motion affects “attentional capture,” which is the ability of a target to elicit attention from the visual-perceptual system. Yet other authors such as Bursill (1958) and Teichner (1968) have presented notions that there are some “attentional field sensitivities” to environmental and stress reaction pressures.

Several models have been used to describe attributes of visual attention in terms of a “zoom lens” type of model (Eriksen and St. James, 1986), or modeling visual attention as a modality-specific resource that may be “spread out” over the relevant locations in the visual field (Eriksen and Hoffman, 1972; Jonides, 1983; Shaw and P. Shaw, 1977, Williams, 1988). Yet other researchers such as Wickens (1991) have modeled the allocation of attention as a finite processing resource that may be allocated to different tasks, both visual and non-visual.

There were several studies in the 1950’s evaluating peripheral visual performance in the presence of a concurrent foveal visual task. One study by Bahrick, Fitts, and Rankin (1952) had
participants engaged in a central tracking task while attending to a variety of stimuli, while the later work of Burshill (1958) already noted, under hot experimental conditions, revealed that peripheral stimuli at further eccentricities were missed. Burshill was apparently the first to write about a “funneling” of the field of awareness. Mackworth (1965) and Sanders (1966) are credited with two of the earliest arguments for a “functional” field of view where the performance of the visual system was somewhat plastic, depending upon the visual/cognitive task environment at hand. Mackworth appears to be one of the first researchers to understand that the retina acts as a dynamic functional entity, and that there seemed to be an interaction between the fovea and more eccentric parts of the retina from an information processing standpoint. Mackworth (1965; p. 67) described the functional field of view as:

The area around the fixation point from which information is being briefly stored and read out during a visual task. When there is too much information, the useful visual field contracts to prevent overloading of the visual system. The useful field is therefore varying in width from moment to moment according to the amount of information in the display. The useful field cannot exceed the normal physiological limits set by the ordinary visual acuity limits.

This effect has been referred to as “tunnel vision,” a term applied by Mackworth to the observed contraction of the visual field.

Other researchers in the 1960’s such as Webster and Haslerud (1964) reported that static peripheral visual perception was adversely affected by a visual or auditory counting task. The peripheral areas tested were from 4 deg in the temporal visual field to 14 deg of eccentricity in the nasal visual field. They also remarked that foveal task loading and auditory counting tasks had an equally adverse effect on peripheral visual perception. Webster and Haslerud (1964, p. 27) stated, “If only the foveal [visual] task had produced an adverse effect, it could have been argued that retinal peripheral inhibition was the cause [for the peripheral decrements].” However, their results indicated that the peripheral visual system had an overlay of “attentional” or cognitive components to some aspects of its function as well. Authors such as Burshill (1958) and Teichner (1968) have presented similar evidence for visual “attentional fields” and have discussed some aspects of attention in the visual periphery as they relate to the task environmental demands. During roughly the same period of time, Leibowitz and Appelle (1969)
showed that as the foveal task complexity increases, performance of visually presented stimuli is impaired in terms of requiring higher luminance thresholds for peripheral target identification.

The introduction of a variety of stressors has also been detrimental to, or has been shown to interfere with, peripheral target acquisition (Baddeley and Fleming, 1967; Bahrick, Fitts, and Rankin, 1952; Bursill, 1958; Easterbrook, 1959; Hockey, 1970a, 1970b; Weltman and Egstrom, 1966; Weltman, Smith, and Egstrom, 1971). Many of the research studies of this time began to refer to “perceptual narrowing” or notions of wide versus narrow attention attributes (Wachtel, 1967) while completing a wide variety of tasks.

**More Recent Peripheral Visual Field Processing Research**

*The Question of Attention.* Beginning in the 1970s and 1980s, resource or capacity models began to evolve to explain a variety of spatial vision results that seemed heavily related to visual “attentional” issues. In this context, allocation of attention to different regions in the visual field (Eriksen and Hoffman, 1972; Jonides, 1983; Shaw and Shaw, 1977), or shared resources among different tasks (Kahneman, 1973; Wickens, 1980), were often used as theoretical models that addressed a finite processing capability. Or, stated slightly differently, that there is a certain allocation of attention resources that is divided among the visual or related cognitive resources.

Other researchers have also investigated how visual processing can be facilitated by the specific allocation of attention resources (Eriksen and Yeh, 1985; Jonides, 1983; LaBerge and Brown, 1989; Posner, 1980; Yantis, 1988). These experiments, which often involved some sort of precueing or biasing of attentional capacity in a particular direction, show that a host of cognitive variables affect how the functional visual field performs.

Several models have been proposed to account for the general visual attributes of allocation of attention and visual “narrowing.” The “zoom lens” analogy implies that as the attention field size increases, the available processing resources within the visual field decrease. The reverse is true as well. Just as a camera zoom lens “sees” more detail when highly focused, less area is available to be processed in the peripheral field of view. Eriksen and Yeh (1985) and Eriksen and St. James (1986) tended to favor this “zoom lens” analogy of visual attention within and around the field of focal attention. A variety of researchers (Jonides, 1983; LaBerge and Brown, 1989; Williams, 1982; Williams, 1995b) have shown that the size of the attentive visual
field can vary depending upon the task at hand. Additional research by Williams (1995b) highlighted that special populations of persons may be more resistant to visual degradation in the periphery while under various states of workload than others. He reasoned and demonstrated that since aviators are often required to rapidly and accurately process large amounts of foveal and peripheral information, they might be less susceptible than nonaviators to a “tunnel vision” effect that Williams (1985) had previously shown to exist in nonaviators. To an extent, this difference might access a daily “practice effect” in the task lives of some of these special populations. This ability likely reflects both a practice effect at transferable tasks, and the training they had already undergone so that they could successfully complete those specialized tasks.

*Other Factors Affecting Peripheral Visual Performance.* Other factors, such as visual noise in the visual search-target detection types of experiments tends to cause poorer performance with regard to accurate target detection in the periphery. As the size/shape of similarity among targets or foils increases in the periphery, performance suffers, particularly for those targets located deeper into the visual periphery (Bloomfield, 1972; Bouma, 1971; Chaikin, et al., 1962; Engel, 1974; Mackworth, 1965; Sanders, 1966).

A relatively limited amount of dual-task studies in which subjects concurrently perform a primary foveal task and secondary task in the periphery have been accomplished (always with a static, non-moving peripheral test target). Despite the variation in these studies of the tasks both being visual or mixed-modality, cognitively or visually complex, etc.—the investigators have reported a performance decline in the peripheral visual task as compared to the no-foveal or no-cognitive load condition. As Williams (1982) has noted, most of the studies have not attempted to differentiate between the complicating effects (peripheral performance dependent measure results) of increasing the cognitive or visual loading. The distinction between increasing cognitive or foveal loading is important, depending upon the application and task environment to which the research results might be applied. These areas might include cockpit display design or modifying a training syllabus’s aerospace human factors information content to accurately reflect the state-of-the-art knowledge base to aid in accident prevention.

Important research by Ikeda and Takeuchi (1975) showed that subjects performed more poorly on a peripheral visual task where a target was presented among a set of ambiguous background patterns as the perceptual load of the foveal task was systematically increased. More
detailed conclusions were difficult to derive from their study since the foveal manipulation was confounded by the numbers of foveal visual targets, and the visual angle subtended by the foveal items.

**Tunnel Vision Versus General Interference Models.** In spite of a large amount of variation among all of the studies attempting to assess peripheral visual performance (most often as a secondary task), the majority of researchers have found that the peripheral visual system performs more poorly when cognitive and/or foveal visual task loading increases. Typically in these studies, the peripherally presented targets tested have been stationary ones within approximately 10 deg of retinal eccentricity. This dissertation research probed the 25-55 deg region of visual periphery with static and moving targets under conditions of increasing workloads.

The nature of the decrement of acuity with increasing workloads has been a topic of some research interest. Ikeda and Takeucki (1975) and Holmes et al. (1977) discussed two different models of visual functional field decrements with eccentricity. The “tunnel vision” model, strictly interpreted, postulates that as the load/complexity of the primary task increases, peripheral visual performance should get increasingly worse as the more eccentric visual periphery is probed. The “general interference” model, on the other hand, assumes that as the primary visual/cognitive task loading increases, then peripheral visual performance is degraded approximately equally at all locations with increasing eccentricity (refer to Figure 11 for examples of each).

These two contrasting models have serious implications for human performance in a variety of vehicular environments. For example, if fighter or low-level attack pilots are becoming more cognitively/visually task loaded (perhaps even “task saturated”) during low-altitude flight-- and if the “tunnel vision” model of visual performance were true-- it would be best to try and off-load any extra cockpit tasking from the pilot to avoid creating an additional peripheral vision decrement that can lead to wingmen colliding or altitude and terrain awareness being lost. This author suggests that preventing such dangerous situations from developing requires, at least in part, a highly functioning peripheral visual system. The development of such dangerous situations is very contextual and related more generally to the notions of avoiding task oversaturation, channelized attention (cognitive and visual), and unwanted distracting influences.
Figure 11. Peripheral visual acuity as a function of retinal eccentricity according to the General Interference Model (Top Panel), or the Tunnel Vision Model (Bottom Panel). The two solid lines represent the theoretical effect of two different levels of workload as a parameter. The bottom line in each panel represents a lower level of cognitive workload than does the upper line. The lower panel representing a “tunnel vision” model of visual performance would be more likely to show an interaction between tasking and eccentricity.
In other words, there is a requirement for pilots to maintain a high degree of cognitive and visual “situation awareness. Perhaps one aspect of maintaining this level of situation awareness in some task environments is being able to keep the peripheral visual system performing at an optimal level.

LaBerge and Brown (1989) have proposed a gradient model where peripheral visual performance decreases from the center of attention in a general interference type of pattern. Holmes et al. (1977) also largely favored a general interference type of approach for describing the peripheral visual system, although their experiment was designed in a manner that would have tended to support such a model since they imposed a fairly easy foveal-cognitive load on their observers.

Williams (1988) has tested visual performance to approximately 4.5 deg of eccentricity and found that it is essentially dependent upon the type of tasking placed upon the observers, and that a high cognitive load, focused attention strategy, and speed stress can induce a tunnel vision effect upon visual performance in the “near-periphery” (also referred to as the para-foveal region). As Williams (1982, p. 182) remarked:

> The fovea typically contains data that is unusually pertinent or important. Because of the processing priority already assigned to the fovea, allocating additional resources to a foveal region where information processing is already operating at near optimal levels will add very little. On the other hand, any redistribution of attention that deletes even small amounts of resources from nonfoveal areas may have profound detrimental effects on peripheral information extraction.

The “redistribution of attention” that Williams referred to involved manipulating the experimental instruction set in a way that forced participants to more fully concentrate, or attend to, the foveal region (in Williams’s second experiment in his 1988 paper). When the observers were allowed to distribute their attention as much as possible (as in Williams’s first experiment in this paper), a peripheral pattern more like that of a general interference type of effect in the near-periphery was seen. Interestingly, William’s (1985) previous work to 9 deg in the retinal periphery had produced a tunnel vision like pattern of peripheral vision performance. In that work, Williams varied the foveal load of the primary task, and the peripheral visual task was to
determine the correct orientation of a stationary line target placed at 3, 6, and 9 deg of retinal eccentricity.

In general, taking all of the results from previous studies into consideration, it appears as though peripheral visual performance on a given task is extremely contextually dependent. The primary task variables that may influence peripheral performance include, but are not limited to, foveal (visual) task requirements/complexity, cognitive task requirements/complexity, training and experience in related tasks, visual displays/conditions used by the primary task, and the set of instructions (or “mission rules”) that accompany the task to be performed. This serves to create the “attention bias” utilized by the participant to optimize combined cognitive and visual performance. This as been referred to as developing an optimal “mental strategy.”

Gopher, Brickner, and Navon (1982) considered a broad spectrum of divided attention, dual-task literature from a multiple resources perspective and have noted that it is important to evaluate both the level of difficulty and task emphasis when assessing human performance output from dual-task studies. This author would agree that similar commentary could easily be offered with respect to dual-task studies involving the peripheral visual system.

Williams (1995a,b) has in fact showed that aviators were generally more resistant to a tunnel vision type of effect than were non-aviators (as might be expected), although even the aviators showed “moderate susceptibility” to cognitively induced visual tunneling when the foveal task presented to them was sufficiently difficult, and their reaction time limited (speed stress). Results like this tend to also support a contextual approach for considering, or predicting, how certain populations’ peripheral visual system will perform under task loading. In this regard, the cliché “practice makes perfect” hints at the better performance of the pilots’ peripheral visual systems under certain task loading that is relatable to flying duties as opposed to non-aviators under the same task loading. Certain brain regions in the pilots subserving visual information processing areas are therefore more “practiced” at multi-tasking and attending to stimuli in the retinal periphery, since in part, piloting performance depends upon “paying attention” to what is happening in the periphery. This is the case whether it is flying with reference to instruments, low-altitude flight, traffic pattern operations, or takeoffs and landings. A more detailed explanation of what is meant by “paying attention to” events occurring in the visual periphery will be offered in the Discussion section of this dissertation.
Recently, evidence from a study involving “anatomo-functional” Magnetic Resonance Brain Imaging (fMRI) of different “mental strategies” in pilots lends some credence to the general notion of measurably different visual-spatial processing in the brains of novice versus experienced pilots. This was the first study where “mental strategy” via brain activation patterns has been assessed and differences in strategy/attention were seen by fMRI techniques during real-time in novice and experienced pilots (Peres, Moortele, Pierard, Lehericy, Satabin, Bihan, and Guezenec, 2000). The study’s authors predicted that a tracking task relatable to flying would reveal different brain activation areas for pilots of high versus low expertise levels. Peres et al. (2000; p. 1224) noted “…that the detected cerebral activity (size of activated surface and activation ratio) was greater in novice pilots than experienced pilots since the mental effort was more intense in less experienced subjects [pilots].” The authors further stated that the novice pilot has a poorer mental model of what is happening in the tasking, is operating in a less predictive and more reactive mode to changing task demands, and therefore has less efficient attentional resources to cope with a dynamic task environment. These concepts and attributes are very close to describing what has been labeled as “situation awareness” by some authors (Endsley, 1995). The Peres et al. (p. 1229-1230) team concluded:

However, the likely mental strategy in the two groups of subjects studied may be extrapolated from the pattern of results from the scan findings and the subjective information collected after the fMRI experiments. We support our conclusion that greater expertise in aviation tasks appear to be characterized by complex cognitive behaviors involving interactions and interplay between related areas in higher mental functions, such as visual working memory, planning, attention, and decision making. In expert pilots, working memory, in association with selective attention, provides the mechanism by which an active representation of the best flight path is held on line over a brief period during which period one learns to keep a course. This executive network subserves automated visuomotor coordination and anticipation of a flight path, leading to good test performance. Because of their inadequate expertise in aviation tasks, the novice pilots are impaired on the track-following task. The defective attention processes shifting at high speed are associated with a lack of image maintenance and image transformation of the flight path in working memory, leading to defective planning and anticipating actions.

It is likely that the mechanism that leads to high performance in the tracking task is established during the acquisition of expertise, corresponding to a progressive reduction of the cerebral activity which ends in selection of a network of specialized functions from visual through multiple
prefrontal areas regarding perceptual and mnemonic processing. This economy corresponds to sufficient cerebral resources being allocated to processing information for optimum task performance with a minimum of conscious effort, and presumes the ability of dividing attention in order to manage a workload increase. By contrast, novice pilots who tend to be overloaded by a suboptimal workload during the tracking task, present a predominant activity in a nonspecific perceptual processing without subsequent representation of selective information in working memory.
Figure 12. Representation of the cerebral regions exhibiting significant task-related activity (expressed as percent activation ratio) during the simulated track-following task in expert (top) and novice (bottom) pilots, as projected on a lateral and mesial view of the right and left brain hemispheres (from Peres et al., 2000).
Objectives of this Dissertation

The general objectives of this dissertation and summary rationales (in parenthesis) based upon the literature review for each general area follow:

1) To assess peripheral DVA under a variety of workload levels in the 25-55 deg region of visual eccentricity with an off-the shelf “desktop” personal computer apparatus. (The literature review highlighted the weakness in the literature in this regard.)

2) To assess peripheral visual acuity for moving and fixed- versus random-direction of target origination. (This relates to the body of literature discussed with regard to the attention-related and anticipatory factors of peripheral visual performance).

3) To derive a better understanding of how various levels of Tracking Task Difficulty affect peripheral DVA. (This relates to the literature discussed with regard to how the peripheral visual system performs under various task loadings.)

4) To evaluate how factors such as fixed or random (F/R) Target Direction of Presentation, Tracking Task Difficulty, and Velocity interact with each other at a variety of visual Eccentricities. (This leads to an assessment of how visual acuity in the periphery is degraded or enhanced under these conditions, and under what combination of conditions peripheral visual performance is augmented or degraded. Choices about these factors and the levels thereof were based upon the review of relevant literature and pilot studies.)

5) To evaluate the human peripheral visual system with static and dynamic targets from a more real world, or “ecological” perspective, and not purely a psychophysical one as most previous studies have done. (Since this study assessed the performance of the peripheral visual system under Tracking Task loading, with and without central visual fixation—these results may be more generalizable to certain environments outside the laboratory than previously published purely psychophysical studies).

In the remainder of this dissertation, when reference is being made to a specific experimental factor as a noun (or levels within that factor with specific reference to the factor), the factor named will be capitalized. Examples are Eccentricity, Velocity, Target Direction (of presentation), and Tracking Task Difficulty.
Specific Research Questions (RQ) Evaluated

Given the many factors affecting peripheral DVA noted in the preceding literature review, and the overall objectives of this study, this research was designed to specifically evaluate the following research questions. For clarity, and as a foreshadowing of the results to be discussed in detail, the answers derived given the analyses in the following sections to the questions posed in this study are noted in parentheses with a “yes” (found to be statistically significant and/or the data analyses indicate such a likelihood), or “no” (found not to be statistically significant and/or the data examined do not support the statement).

RQ1: A computerized test of DVA in the visual periphery will be largely in agreement with past research, or extensions of the literature, such that DVA thresholds will:

a) increase with increasing Eccentricity (yes);
b) have some change in the variance with increasing Eccentricity (yes);
c) result in an interaction between Eccentricity and the fixed/random Target Direction of presentation (no);
d) result in an interaction of Eccentricity by Tracking Difficulty such that targets in the farther visual periphery are harder to see (no). (Note: This is a test of the “tunnel vision” hypothesis of visual performance with increasing Eccentricity; the possibility exists that a “general interference” type of model for peripheral performance with increasing Eccentricity might be a better choice for these data);
e) result in an interaction of Eccentricity by Target Velocity (no).

RQ2: Targets presented with a random Target Direction of motion (“>” pattern of target tracks) versus a fixed Target Direction of motion (only left to right) will:

a) be harder to see (i.e., have increased mean visual acuity thresholds) (yes).
RQ3: Increasing Tracking Task Difficulty will:

a) result in decreased DVA performance in the visual periphery in general (threshold mean acuities will increase)(yes);
b) result in an interaction between Tracking Difficulty and F/R Target Direction of presentation (no).

RQ4: Increasing Target Velocity will:

a) result in acuity for the slowest moving targets (4.88 deg/s) that may in fact be better than that of static targets in the retinal periphery (no);
b) result in more difficult to see targets in the visual periphery (yes);
c) have an interaction with Target Direction of presentation (yes);
d) result in an interaction with Tracking Task Difficulty (yes).
METHOD

Participants

Students at Virginia Polytechnic Institute and State University and other individuals in the Roanoke Metropolitan Area participated in this study. Participants were college and graduate school students or university staff with ages 18-39 years old (average age 23.4 years; 32 females and 18 males). Participants were paid $5.00 per hour for their time or given extra credit for a psychology class at Virginia Polytechnic Institute and State University as compensation for their time and effort to complete the experiment.

Participants were screened for normal visual acuity, normal stereopsis, red-green color vision deficiency, and peripheral vision by a four-quadrant confrontation test for each eye. This last test was used to detect gross abnormalities in peripheral visual function. Vision was tested in the nasal, temporal, superior, and inferior visual fields by a standard clinical face-to-face confrontation test. One participant was excused from the experiment due to a suspected left upper quadrant peripheral field deficit and was referred to a local ophthalmologist for a follow-up examination. Near and distant visual acuity was screened for 20/25 or better in the worse eye with a Snellen eye chart. Although red-green color blindness was assessed, no participants tested exhibited this defect. Normal bilateral muscle control of gaze for the six cardinal eye positions with no signs of clinically detectable strabismus was required for participation in the experiment. Participants were asked to follow the examiner’s finger through the six eye positions to test for normal oculomotor control of gaze in the six cardinal positions.

Participants that reported feeling less than a “6” out of “10” in terms of physical fatigue and/or illness and mental well-being (sleep; sickness; undistracted by school/life issues) were excused from participating in the experiment. (The subjective scale utilized for screening was: 1-- I feel extremely fatigued/very sick or extremely distracted by other issues; 10-- I feel very well-rested, completely healthy and totally undistracted.) This type of screening was accomplished since the experiment required extensive attentional resources to complete effectively. Several potential participants reported fatigue and/or distraction due to recent or impending academic tests, life issues, etc., so these individuals were asked to return later after rest, etc. as soon as possible to participate in the experiment.
Equipment

The primary tracking task was derived from a modified version of the NASA/COMSIC software package. This Multi-Attribute Task (referred to as “MAT”) Battery software was driven by an IBM personal computer (IBM, Model 466DX2/D) operated in MS-DOS (version 4.00.950). A scan converter (Altech, Model PSC 1106) was used to convert the personal computer Video Display Terminal (VDT) output to a NTSC video signal for display on a 6.35 cm Liquid-Crystal-Display (LCD; Casio, Model EV-510; addressibility 112x94; RGB spot widths: V .0197mm; H: .0236mm). A screen stabilization program (MS-DOS command, C:\PSC1106\movescr.com) was employed to prevent screen rolling given that the Tracking Task output was in a VDT format, which was converted to an NTSC signal format used by the LCD “TV” device. The NTSC signal was fed through a signal Modulator (Radio Shack, RF Modulator Model 15-1244) that converted the outputted computer video signal to a TV format that the antenna of the “hand-held” Casio LCD TV could pick up and process.

An A/B Rotary Data Switch was used to move the NASA MAT Tracking Task signal from a standard computer VDT screen to the smaller LCD screen. The standard computer VDT screen was “blanked-out” so that the Tracking Task only appeared on the smaller LCD screen during the practice and data collection trials. The LCD screen was one of the smaller commercially available screens that met the requirements for the Tracking Task, given the constraints to keep the physical size and display presentation of the LCD small enough to not “intrude” into the physical/visual peripheral space of the other peripheral DVA display that supported the moving Landolt C ring targets. The room illumination in the plane of the display surface was 110 lx. The on-screen luminance of the primary display device was set at 30 cd/m$^2$.

A second computer was used to generate and move the DVA Landolt C targets in the visual periphery (ASTVision 7L, Model 824 Advantage; 133 MHz Pentium processor). Software written in C++ was created and tested in an interative fashion for this study.

The VDT (ASTVision 7L) used to display the peripheral DVA targets was operated in a 639 x 349 VGA mode, at vertical refresh rate of 85 Hz. The dot pitch was 0.28 mm for this monitor (see Appendix F for details). A high value of on-screen luminance contrast for the lighted Landolt C target was deemed important for this study based upon previous research results (Brown, 1972a, c). The peak luminance of the lit secondary task screen area was set at 65 cd/m$^2$ with the use of a photometer in the display plane (Minolta, Model: Luminance Meter 10,
The luminance of the “dark” portion of the screen was measured as 0.2 cd/m\(^2\). This combination resulted in a well-defined Landolt ring target on the screen, without noticeable “smearing” of the target on the display screen as it moved across the screen in the peripheral field of vision. Medium short-persistence phosphors were the light-generating visual elements. The room illumination at eyepoint was 116.9 lx. On-screen illumination was 104.3 lx.

The update rate on the Tracking Task from joystick input to presentation response had no discernible control-response delay. The Tracking Task was accomplished with an off-the-shelf joystick (Garvis, Model: PC Pro). There was sufficient deadspace around the null position to prevent inadvertent joystick activation.

Pilot work with 80 participants over a four-month window was undertaken to determine the optimal control/display sensitivities in the MAT software such that the four levels of Tracking Difficulty were distinguishable by users and challenging, yet still able to be accomplished to the research protocol criterion by participants at the hardest level of Tracking Task Difficulty. Accordingly, a control/display sensitivity setting of “40” within the modified MAT software was selected for this experiment. During this period of time, as well as prior to this, the peripheral display device target parameters were tested and refined, as were the experimental protocols.

**Experimental Design**

The experiment used a mixed-factor research design with a total of 50 participants tested in five groups of 10. Each participant was exposed to all of the Tracking Difficulties, Target Velocities, and Target Directions of presentation in a random fashion, but only to one Eccentricity. Thus, Eccentricity was a between-subjects factor, while the within-subjects factors levels were Tracking Task Difficulty (4), Target Velocity (4), and Target Directions (2). A total of five right temporal field locations were tested at five locations in the visual periphery at 25, 35, 45, 50, and 55 deg of visual Eccentricity for the population of participants used in this study. Figure 13 shows the experimental design for the peripheral DVA study. The design had a total of 1599 degrees of freedom.
Figure 13. Experiment design for the peripheral dynamic visual acuity study.

10 participants received each of these treatment conditions at 25 degrees of visual eccentricity. The experimental treatments were randomly presented.

Another group of 10 participants received the conditions at 35 degrees of visual eccentricity.

Another group of 10 participants received the conditions at 45 degrees of visual eccentricity.

Another group of 10 participants received the conditions at 50 degrees of visual eccentricity.

Another group of 10 participants received the conditions at 55 degrees of visual eccentricity.
At the assigned eccentricity, participants were exposed to Target Velocities (0.0, 4.22, 14.62, and 24.40 deg/s), Target Directions of presentation (F/R: fixed or random), and Tracking Task Difficulty levels (monitor, easiest, moderate, hardest). Eccentricities were computed for the right temporal visual field. The right eye was placed in a position directly in front of the Casio LCD screen and 56 cm from the center of the moving target tracks on the peripheral display screen. A plastic ruler held the observer’s head at the proper distance (56 cm) from the Casio LCD primary display screen. Cellophane tape was used to position the ruler on the temporal portion of the left orbit so that the desired eye-to-screen distance and geometry was maintained during the practice and actual data collection trials. The participant’s chair position was adjusted so they could comfortably maintain the desired geometry. A place to rest the lower arms was also available.

The Tracking Task was presented at four levels of difficulty, including an “automatic” mode where the participant simply focused on the center of the primary display device (refer to Figure 14). The remaining Tracking Task difficulty levels were: easy (low difficulty); moderate (medium difficulty); and hardest (high) difficulty. These levels were built into the MAT software and were selected by the experimenter with keyboard control (Comstock and Arnegard, 1992).

Task Description. The primary visual task was to attend to a compensatory workload Tracking Task on the Casio LCD device. The participants moved the ever-changing position of the “error” oval toward the fixed central cross-hair “target” with the joystick controller. The Tracking Task used in this experiment was derived from the NASA/Cosmic Multi-Attribute Task (MAT) Battery, which provides a benchmark set of tasks for use in laboratory studies of operator performance and workload (Comstock and Arnegard, 1992). The Tracking Task was separated from the other MAT functions so that it could be used in a stand-alone fashion for this work.

The original MAT task battery was designed to be a “generic” one with applications to aviation-like tasks, without requiring all of the specific skills that aviation does. The original NASA-MAT task battery incorporates tasks analogous to activities that aircraft crew members perform in flight, while providing a high degree of experimenter control, performance data on each subtask, and the freedom to use non-pilot participants (see Arnegard and Comstock, 1991 for a full description of the tasks in original software).
Figure 14. Experimental geometry and setup for the peripheral DVA study.
For the purposes of this experiment, the foveal region of the observer was kept “busy” by performing the compensatory Tracking Task for three-quarters of the time, while the participants focused on the central cross-hair target region on the Casio LCD display one-quarter of the time (refer again to Figure 14; a “blow up” of the small central cross-hair region, error oval and rectangular region is presented on the normal-sized VDT screen directly in front of the observer). Observers performed the Tracking Task at only one level of Difficulty for a given target exposure. When the participants were tracking, this protocol kept the eyes moving within a rectangle subtending approximately 0.3 x 0.5 deg of visual angle in the center of the “required” rectangular tracking region on the LCD display. Such a small area is within the “foveal region” when the central cross-hairs of the LCD display are visually fixated.

Using the joystick, the participants were instructed to keep the wandering target touching the center of the cross-hairs on the display, and at a minimum, to keep the moving oval target at least within the small rectangular area during a trial (Appendices C, E contain the Introduction to Study and Participant Instructions). All participants whose results were used for the experimental database were able to accomplish this Tracking Task with preliminary practice to the primary task criterion just noted by the completion of the practice trials. The primary task for the participants as noted was to accomplish the compensatory Tracking Task, while secondarily attending to the peripheral display device in the right temporal visual field. The participant simultaneously performed the secondary task of reporting the orientation of Landolt C targets. The participants were instructed that attending to the peripheral display was a secondary task, and that they were not to directly view the Landolt C target display device (refer again to Figure 14).

Participant performance on the primary Tracking Task was monitored by the experimenter to make sure that the observer was not “cheating” on the Tracking Task in order to enhance their performance on the secondary PDVA Landolt C ring orientation determination task. Primary Tracking Task performance during the experiment was also monitored by the experimenter sitting directly next to the observer to ensure that the participants kept the moving oval target within the small rectangular area on the primary display device 100 % of the time during the data collection phase of the experiment. All of the participants selected for inclusion in this experiment were able to accomplish this task completely to criterion after the numerous practice trials, even at the “most difficult” level of Tracking Task Difficulty. Optimal Tracking
Task control/display ratios were experimented with during pilot studies so that the desired criterion was achievable even at the most difficult level of the Tracking Task for the vast majority of the test participants. Nonetheless, two out of 52 participants that were screened as physically qualified to participate in the experiment were unable to keep the oval target in the small rectangular region 100% of the time at the end of the second half of the practice trials, and were therefore excused from further peripheral vision testing. Accordingly, since they could not accomplish the primary Tracking Task 100% of the time to criterion, none of their results entered the database.

Because the Target Direction of movement was a within-subjects factor in the experimental design, the moving Landolt C targets originated from either a fixed or random Target Direction at one of the four randomly selected Target Velocities. A “fixed” Target Direction of presentation means that the Landolt C target moved from right to left along a horizontal meridian across the peripheral display screen. A “random” Target Direction of presentation means that the target moved along the paths in any direction as defined by the symbol “>.” (the four possibilities for target travel paths were: upper left to lower right; lower left to upper right; upper right to lower left; lower right to upper left).

**Choice of Target Warning and Duration.** There is a body of research literature previously cited (e.g., Eriksen and Yeh, 1985; Eriksen and St. James, 1986) that relates to the importance of “attentional factors” and being prepared for cues as they occur in the visual system (see also Eriksen and Rohrbaugh, 1970). With this in mind, an auditory tone alerted participants approximately 1 sec before the Landolt target appeared somewhere in the visual periphery.

A 0.5s target duration of presentation was chosen for all Landolt Cs irrespective of Target Velocity or Target Direction of travel. This presentation time resulted from the tradeoff of giving the participant a chance to see the target in the periphery without resorting to a target that was on the screen so long that it traveled “off” the VDT screen at the higher velocities. Also considered in the target speed and duration choices was the fact that in order to test a certain area in the periphery, the higher speed targets could only “last” for so long, or the Landolt C target would quickly traverse nearly half of the visual periphery. The selection of a 0.5s target duration was considered the best trade-off for the velocities being investigated, with consideration given from the previously cited literature also (Brown 1972a; Hoogerheide, 1964; Low 1947a, b).
fastest moving peripheral target traversed less than one-half of the peripheral display during this period of time. There is always a trade-off in DVA studies with respect to how long a target should be exposed to a participant. A too-brief target duration results in participants’ receiving a “flash” DVA presentation. Targets presented for “too long” at the faster speeds traverse so much of the periphery that it is difficult to draw firm peripheral acuity conclusions at a given eccentricity-- since a relatively wide “slice” of the retina is being tested.

**Procedure**

The experiment began with each participant reading Appendix C: Introduction to the Study. Next, the visual screening described in the Participants section was completed. The participants then read and signed an Informed Consent form (Appendix D). The Participant Instructions: Appendix E was read last.

**Participant Instructions.** “Your participation in this experiment will require careful attention to the tasks that you are asked to do, such that the data collected will be meaningful. You will be asked to perform a series of tracking tasks with a hand-held “joystick” that is often used to play computer games with. After a warm-up period, you will be asked to accomplish the tracking task on a small active-matrix Liquid Crystal Display (LCD) that is 2.5 inches wide. This is your primary task to accomplish, and it should take precedence over all others. With the hand-held controller, you must attempt to keep the moving, circular target, on the crosshairs at the center of the screen. At a minimum, try to keep the target inside the small rectangular window on the screen that surrounds the crosshairs. You will note that there will be several levels of difficulty as you perform the tracking task. You will be given a chance to try each of the tracking task levels, not only to become familiar with the tracking task itself, but also to test your baseline performance at each level of the tracking task without any other secondary tasks to divide your attention. Do not become concerned if it may seem difficult to keep the target centered on the crosshairs since this is simply one aspect of the experiment. Just do the best you can.

After a warm-up (practice) period, while you are performing the tracking task, the VDT screen to your right will present several objects moving across the screen known as LANDOLT C’s. These C’s will be in one of four orientations with the open part on the C pointing to the
right (as in a normal “C”), or with the open part of the C facing either up, down, or to the left. Before each of the C’s is presented to you, a tone will be heard approximately one second before the C is presented on the screen. The C will be moving at a variety of speeds and from several directions on the screen. You are to tell the experimenter which direction the C was oriented. You must inform the experimenter if you are “unsure” (or “don’t know”) if you are not 95% sure of which direction the target was oriented. YOU ARE TO USE ONLY YOUR PERIPHERAL VISION TO TRY TO ASCERTAIN WHICH DIRECTION (UP, DOWN, LEFT, or RIGHT) THE C’S ARE ORIENTED. PLEASE DO NOT USE YOUR CENTRAL VISION BY MOMENTARILY GLANCING AT THE SCREEN THEN RETURNING BACK TO THE TRACKING TASK.

Always keep your eyes focused on the primary tracking task, but try to “see” the Landolt C orientation with your peripheral vision. You will be given an ample number of practice trials to feel comfortable with the experiment. During the real trials, the experimenter will record your responses for you after you tell the experimenter which direction the Landolt C was oriented in. Keep performing the tracking task at all times during the experiment while the experimenter records the data and sets up the computer software for each trial.

You will receive 5 min rest breaks after 15, 30, and 45 mins of participation in this experiment. Feel free to ask the experimenter any questions you have now or at any time during the experiment. Let the experimenter know when you are ready to begin.”

There are two other factors that deserve brief mention that often play a role in peripheral visual performance for some populations, and were controlled for in this experiment. The first is smoking, and the second is fatigue (Behar, Kimball, and Anderson, 1976). This is particularly true for those involved in the flying and driving vehicular control domains. Both populations occasionally suffer from fatigue during the performance of their tasks. The smoking population apparently has the additional burden of a decrement in their ability to “see” as well in the periphery as compared to their non-smoking cohorts (Krippner and Heimstra, 1969; Scoughton and Heimstra, 1973). While this study did not test these conditions specifically, smoking was not allowed during the short breaks provided during the experiment in order to guard against potential retinal vascular bed vasoconstriction with the attendant peripheral visual performance confounding it might bring Johnston (1965). And, the experiment was designed so that a fatigue effect during the experiment was not a factor since rest breaks were provided and the participants
were under experimental conditions for less than an hour. Generalized fatigue was also mitigated as a factor in this experiment due to screening the participants prior to participation in the experiment for being reasonably well rested.

**Practice Trials**

To reduce the practice effects and to familiarize participants with the use of the joystick and the environment in which the experiment was to be conducted, each participant received 26 trials at the following Tracking Task Difficulties. Each trial below went to the threshold determination level for the randomly selected Landolt C Target Velocity presented. Thus, in ONE TRIAL, an observer may have seen 2-12 (or more) Landolt Cs before a threshold value was selected by the computer based upon that participant’s acuity performance (see “Method of Limits” section for details on why this was the case).

- **Trial 1, 2** Monitor the autopilot mode. Report Landolt C orientations and the perceived difficulty level to the experimenter. Fixed Direction.

- **Trial 3, 4** Tracking Task at easiest level of Difficulty. Report Landolt C orientations and the perceived difficulty level to the experimenter. Fixed Direction.

- **Trial 5, 6** Tracking Task at the middle level of Difficulty. Report Landolt C orientations and the perceived difficulty level to the experimenter. Fixed Direction.

- **Trial 7-10** Tracking Task at the hardest level of Difficulty. Report Landolt C orientations and the perceived difficulty level to the experimenter. Fixed Direction.

- **Trial 11, 12** Tracking Task at the middle level of Difficulty. Report Landolt C orientations and the perceived difficulty level to the experimenter. Fixed Direction.

- **Trial 13, 14** Tracking Task at the lowest level of Difficulty. Report Landolt C orientations and the perceived difficulty level to the experimenter. Fixed Direction.
Trial 15, 16  Monitor the autopilot mode. Report Landolt C orientations and the perceived difficulty level to the experimenter. Fixed Direction.

Trial 17, 18  Tracking Task at easiest level of Difficulty. Report Landolt C orientations and the perceived difficulty level to the experimenter. Random Direction.

Trial 19, 20  Tracking Task at the middle level of Difficulty. Report Landolt C orientations and the perceived difficulty level to the experimenter. Random Direction.

Trial 21, 22  Tracking Task at the hardest level of Difficulty. Report Landolt C orientations and the perceived difficulty level to the experimenter. Random Direction.

Trial 23, 24  Tracking Task at the middle level of Difficulty. Report Landolt C orientations and the perceived difficulty level to the experimenter. Random Direction.

Trial 25, 26  Tracking Task at the lowest level of Difficulty. Report Landolt C orientations and the perceived difficulty level to the experimenter. Random Direction.

For these trials, the fixed-direction case for Target Direction of presentation was utilized first. This was a familiarization and training approach for getting acquainted with the visual and motor tasks to be performed. Ten complete practice trials of the random Target Direction of presentation condition to threshold were also given to the participants. This was an attempt to familiarize the participants with the visual environment and tasking environment for the random Target Direction presentation case as well.

Experience during pilot studies showed that it usually took participants several practice trials to get acquainted with the experimental task demands that involved paying attention to targets presented in the visual periphery while performing the primary Tracking Task. The increasing Tracking Task Difficulty levels allowed participants to practice the task at increasing levels of Tracking Difficulty, and to practice reporting the direction of the Landolt C targets and estimating the Tracking Task Difficulty levels. While this Tracking Task battery software has been validated by the team at the Langley Research Center that developed it-- this experiment
tested this assumption by obtaining subjective observer reports of the estimated Tracking Task Difficulty after they had become adept at accomplishing the task (Scale: 1; very easy, almost no difficulty; 10, the task is impossible to complete according to the criteria stated. A score of 5 would be interpreted as being able to keep the small error oval touching the cross-hairs about 50% of the time). The observers’ estimates of the perceived difficulty to accomplish the task was recorded and evaluated. These results are discussed and presented later as Figure 18. Based upon these data collected during the latter “practice phase” of the experiment, four separable Tracking Task levels were obtained by the software control/display setup chosen for this experiment from the original pilot studies. The data represented in Figure 18 is therefore the subjective estimated Tracking Task Difficulty plotted against the actual Tracking Task Difficulty level present.

**Method of Limits**

The actual assessment of the minimum size of the Landolt C target that could be seen was accomplished by programming the software with a variation of the Method of Limits as suggested by Brown (1972a) for his peripheral DVA studies. Brown (1972a, p. 296) commented in his peripheral DVA work to 10 deg of eccentricity that, “The method of limits was chosen as the psychophysical method because preliminary experimentation had shown that there was so much variation in the threshold data both between and within subjects to allow the method of constant stimuli to be used.” Shevlin et al. (1997) more recently also chose this approach in their foveal DVA research.

The Method of Limits (staircased) approach was applied in the coding of the peripheral DVA software in the following manner. As the participant reports the correct Landolt C gap orientation (up, down, left, right), the computer assigned a smaller and smaller gap orientation to be seen (at the same velocity). When the participant missed a target orientation, the computer then presented the next larger Landolt C target (at that same velocity). If the participant then answered that target orientation correctly, the computer next presented a slightly smaller target. This selection procedure continued in an iterative fashion. When two errors were eventually made for the same target size, the value reported as the observer’s threshold visual acuity was the next larger target size at that particular Velocity and Direction of presentation condition that was correctly identified. (Note: This target gap size had already been correctly identified previously
since the Method of Limits algorithm had selected a smaller Landolt C target to test--2 pixels in
gap size smaller--below the “correctly” perceived target before to algorithm detected two
“misses” and increased the target gap size to be tested by 2 pixels to a larger gap size that had
already been correctly assessed. The algorithm then tests Landolt ring targets at that next
higher/wider target gap size for a correct answer until it finds a correct one on the “ascending
side” of the acuity testing). Thus, there was a limited “ascending” component to this particular
approach for acuity determination as well. The descending Method of Limits with a staircase
procedure was chosen here in part because there was not time in the experiment to use complete
ascending and descending trials for all of the treatment conditions to be presented without the
possibility of introducing fatigue effects.

Using the Method of Limits will tend to average-out the small amount of rectangular
asymmetry between left/right and up/down Landolt C target gap widths, since the orientation of
the targets presented are random to begin with, and it takes at least four separate decisions to
arrive at a final acuity value based upon the target gap width (e.g. given gap size—CORRECT
response—smaller gap size presented; INCORRECT response—same gap size again;
INCORRECT—larger gap size presented; CORRECT answer leads to this gap-size choice—the
larger gap size two pixels greater in width is selected rather than the smaller gaps sizes that were
missed). Furthermore, when the gap sizes decrease/increase by 2 pixels (not just 1) for each
level of change (based upon whether there is a correct or incorrect report like the example just
given) the result is a significant acuity threshold selection factor since the gap differences in
pixels at each tested level of 2 pixels, 4 pixels, 6 pixels … to 16 pixels are much larger than the
slight asymmetry of the pixels involved as long as the Landolt C gap orientations are presented
in a random manner. For this peripheral display, the Landolt C horizontal pixel width was
approximately 75% of the Landolt C vertical pixel height, resulting in slightly rectangular pixel
geometry.

**Target Gap Size and Velocity Computation**

A perfectly symmetrical pixel would appear as a square, with no vertical or horizontal
exaggeration whatsoever. With this consideration in mind, Table F1 in Appendix F represents
the arithmetic means of the vertical and horizontal pixel gap sizes, which were then converted to
mins of visual angle at the eye-to-screen distance of 56 cm. Computed in this manner, the Landolt C target gap sizes ranged from 6.96-55.71 mins of visual angle.

Target velocities in deg per 1 s of travel (by convention) were computed from the formula:

\[
\text{Velocity} = \arcsin \left[ \frac{0.5s}{d} \right] \times 2
\]

where \( s \) was the distance the target traveled on the screen in the 0.5 s it appeared, and \( d \) is the distance from the right eye to the peripheral display screen.

Further details regarding these computations may be found in Table F2 in Appendix F.
RESULTS

General Discussion/ANOVA Table

The peripheral DVA scores were subjected to a four factor, mixed-model Analysis of Variance (ANOVA) procedure. These results are presented in Table 1. Table 2A highlights the significant main effects and interactions in terms of the percentages that they contribute to the total variance. Table 2B summarizes the form of the curves from the multiple regressions on Eccentricity, Tracking Task Difficulty, and Target Velocity that best fit the data for these effects. Appendix B contains the details of the analyses that underlie these summary regression results. The results from this experiment were analyzed with statistical software from MINITAB 12.0, SPSS 7.5, and SAS JMP 3.1.

The ANOVA assumption of homogeneity of variance between treatment groups was evaluated for the results obtained in this study. This statistical assumption requires that the different treatment conditions have nearly equal variances for statistically stable means comparisons. Just as departures from normality have been shown to result in robust F tests as long as there are equal numbers in the samples (Box, 1953), Monte Carlo studies have shown that sizable differences between the variances do not appear to distort the resulting ANOVA F test distribution dramatically (Collier, Baker, Mandeville, and Hayes, 1967). Keppel has commented that violations of the homogeneity of variance are more serious when unequal treatment groups are used (Keppel, 1982). The homogeneity of variance assumption was tested for this database within each of the levels (treatment groups) of Eccentricity, Difficulty, and Velocity. The homogeneity of variance test results with Bonferroni Confidence intervals (95%) are shown in Table 3. Using Levene’s test for the homogeneity of variance across all Eccentricities, there is support for Research Question 1b, that based upon the literature review there would be differences in the variances across Eccentricity. As shown in Table 3 (Part A), the Standard Deviation (SD) reported at 25 deg was found to be 4.87 (var 23.72), while the standard deviation at 50 deg was computed as 10.40 (var 108.16). The ratio of the latter variance (50 deg) to the former variance (25 deg) is therefore 4.56 for the worst-case variance ration “mismatch” in this table.
Table 1. ANOVA Summary Table.

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<th>F</th>
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<td>&lt;0.027*</td>
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<tr>
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<tr>
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</tr>
<tr>
<td>V x S(E)</td>
<td>135</td>
<td>6105.7</td>
<td>45.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fixed/Random Direction (FR)</strong></td>
<td>1</td>
<td>1480.8</td>
<td>1480.8</td>
<td>17.66</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>FR x E</td>
<td>4</td>
<td>529.5</td>
<td>132.4</td>
<td>1.58</td>
<td>0.196</td>
</tr>
<tr>
<td>FR x S(E)</td>
<td>45</td>
<td>3772.7</td>
<td>83.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>T x V</strong></td>
<td>9</td>
<td>793.6</td>
<td>88.2</td>
<td>2.11</td>
<td>&lt;0.028*</td>
</tr>
<tr>
<td>T x V x E</td>
<td>36</td>
<td>1501.3</td>
<td>41.7</td>
<td>1.00</td>
<td>0.477</td>
</tr>
<tr>
<td>Error: T x V x S(E)</td>
<td>405</td>
<td>16935.3</td>
<td>41.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T x FR</td>
<td>3</td>
<td>224.8</td>
<td>74.9</td>
<td>1.13</td>
<td>0.340</td>
</tr>
<tr>
<td>T x FR x E</td>
<td>12</td>
<td>666.3</td>
<td>55.5</td>
<td>0.84</td>
<td>0.614</td>
</tr>
<tr>
<td>T x FR x S(E)</td>
<td>135</td>
<td>8974.5</td>
<td>66.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>V x FR</strong></td>
<td>3</td>
<td>1883.8</td>
<td>627.9</td>
<td>15.48</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>V x FR x E</td>
<td>12</td>
<td>603.2</td>
<td>50.3</td>
<td>1.24</td>
<td>0.263</td>
</tr>
<tr>
<td>V x FR x S(E)</td>
<td>135</td>
<td>5475.0</td>
<td>40.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T x V x FR</td>
<td>9</td>
<td>545.8</td>
<td>60.6</td>
<td>1.59</td>
<td>0.115</td>
</tr>
<tr>
<td>T x V x FR x E</td>
<td>36</td>
<td>1775.8</td>
<td>49.3</td>
<td>1.30</td>
<td>0.123</td>
</tr>
<tr>
<td>T x V x FR x S(E)</td>
<td>405</td>
<td>15417.5</td>
<td>38.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total E x T x V x FRS-1 =</td>
<td>1599</td>
<td>178075.6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Statistically significant effect (p < 0.05).
Table 2.
A. Percentage of the Variance Contributed by Each Significant Main Effect or Interaction from the ANOVA Table.

<table>
<thead>
<tr>
<th>Source</th>
<th>Percentage of Source Contribution to the Total Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Effects (in order from ANOVA Table):</strong></td>
<td></td>
</tr>
<tr>
<td>Eccentricity</td>
<td>32.4 %</td>
</tr>
<tr>
<td>Tracking Task Difficulty</td>
<td>0.3 %</td>
</tr>
<tr>
<td>Target Velocity</td>
<td>5.2 %</td>
</tr>
<tr>
<td>Target Direction</td>
<td>0.8 %</td>
</tr>
<tr>
<td><strong>Interactions:</strong></td>
<td></td>
</tr>
<tr>
<td>Tracking Difficulty x Velocity</td>
<td>0.4 %</td>
</tr>
<tr>
<td>Velocity x Target Direction</td>
<td>1.1 %</td>
</tr>
</tbody>
</table>

Percentage of the Total Variance Contributed by the Sources Listed Above: 40.2 %

B. Results of Multiple Regression on the Main Effects with more than Two Levels.

<table>
<thead>
<tr>
<th>Sources</th>
<th>Lowest order of Equation That Best Fits the Data</th>
<th>(R² of Best Fit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eccentricity</td>
<td>Cubic (p &lt; 0.001)</td>
<td>0.324</td>
</tr>
<tr>
<td>Tracking Task Difficulty</td>
<td>Linear (p &lt; 0.031)</td>
<td>0.003</td>
</tr>
<tr>
<td>Target Velocity</td>
<td>Quadratic (p &lt; 0.001)</td>
<td>0.052</td>
</tr>
</tbody>
</table>

Note: See Appendix B for a detailed examination of these multiple regression results by source.
Table 3.

Homogeneity of Variance Bonferroni Confidence Intervals for Standard Deviations. Standard Deviations written for Eccentricity, Tracking Task Difficulty, and Target Velocity (all values stated with 95% confidence intervals for these Standard Deviations--SD).

A. Homogeneity of Variance Computations for Eccentricity  
Levene’s Test Statistic = 28.8 (p < 0.001) for variances being significantly different

<table>
<thead>
<tr>
<th>Eccentricity</th>
<th>N</th>
<th>Lower Bound</th>
<th>SD</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>320</td>
<td>4.42</td>
<td>4.87</td>
<td>5.42</td>
</tr>
<tr>
<td>35</td>
<td>320</td>
<td>7.19</td>
<td>7.93</td>
<td>8.82</td>
</tr>
<tr>
<td>45</td>
<td>320</td>
<td>7.96</td>
<td>8.77</td>
<td>9.76</td>
</tr>
<tr>
<td>50</td>
<td>320</td>
<td>9.41</td>
<td>10.40</td>
<td>11.55</td>
</tr>
<tr>
<td>55</td>
<td>320</td>
<td>9.35</td>
<td>10.31</td>
<td>11.47</td>
</tr>
</tbody>
</table>

B. Homogeneity of Variance Computations for Tracking Difficulty Level  
Levene’s Test Statistic = 0.52 (p < 0.67) for variances being significantly different

<table>
<thead>
<tr>
<th>Tracking Difficulty</th>
<th>N</th>
<th>Lower Bound</th>
<th>SD</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitor</td>
<td>400</td>
<td>9.33</td>
<td>10.16</td>
<td>11.13</td>
</tr>
<tr>
<td>Easiest</td>
<td>400</td>
<td>9.88</td>
<td>10.73</td>
<td>11.76</td>
</tr>
<tr>
<td>Middle</td>
<td>400</td>
<td>9.68</td>
<td>10.54</td>
<td>11.56</td>
</tr>
<tr>
<td>Hardest</td>
<td>400</td>
<td>9.87</td>
<td>10.75</td>
<td>11.79</td>
</tr>
</tbody>
</table>

C. Homogeneity of Variance Computations for Velocity  
Levene’s Test Statistic = 5.09 (p < 0.002) for variances being significantly different

<table>
<thead>
<tr>
<th>Velocity</th>
<th>N</th>
<th>Lower Bound</th>
<th>SD</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 deg/s</td>
<td>400</td>
<td>8.90</td>
<td>9.69</td>
<td>10.62</td>
</tr>
<tr>
<td>4.88 deg/s</td>
<td>400</td>
<td>8.98</td>
<td>9.77</td>
<td>10.71</td>
</tr>
<tr>
<td>14.62 deg/s</td>
<td>400</td>
<td>9.43</td>
<td>10.26</td>
<td>11.25</td>
</tr>
<tr>
<td>24.40 deg/s</td>
<td>400</td>
<td>10.41</td>
<td>11.33</td>
<td>12.42</td>
</tr>
</tbody>
</table>
Several authors (Rogan and Keselman, 1977; Tabachnick, and Fidell, 1996) state that if the ratio of the largest to the smallest within-group variance of interest is near, or greater than 10, and if the observed F is close to the critical value of F chosen for the experiment, then perhaps other tests such as those based upon non-parametric statistics should be considered, since the resultant F test may then be unreliable at the stated significance level. Thus, the question of whether significant differences occur in the means for visual acuity between 35 deg (SD = 7.93), 45 deg (SD = 8.77) or 50 deg (SD = 10.31) of Eccentricity is not likely to be substantially affected when the variances of these values are so much alike (recall that the worst-case variance mismatch ratio was computed to be only 4.56). Computations in the “B” and “C” parts of Table 3 for the associated homogeneity of variance analyses all have standard deviations’ with Bonferroni confidence (95%) intervals fairly close in value to one another across each of the factors (Tracking Task Difficulty, Target Velocity) and treatment levels concerned. Levene’s Test results also are included in each part of Table 3 to assess if the variances are different statistically from one another within each of the main effects highlighted. Given the previous statistical commentary, and that commentary which follows in the next section with consideration for the equal sample sizes and values obtained in this randomized design— it is a reasonable conclusion that the resultant multiple comparisons tests in this study were not substantially affected by the slight non-homogeneity of variance seen in the Eccentricity and Velocity data. Recall that Low (1947a) detected a similar trend of changing variances with increasing eccentricity and commented on them (refer back to Figure 3).

The within-subjects portion of this database (Tracking Task Difficulty, Target Velocity, and Target Direction of presentation) was subjected to the Greenhouse-Geisser and Huynh-Feldt procedures to assess and compensate for any violations of independence among repeated measures. The Greenhouse-Geisser correction revealed a small (non-material) effect that resulted in F-test ratio changes to the second place after the decimal in the most extreme case. The resulting p-values therefore were not affected in any relevant manner. As might be expected given this minimal result for the quite conservative Greenhouse-Geisser test, the Huynh-Feldt procedure revealed no violations for independence among the within-subjects factors.
Additional analyses were performed on this dataset by removing the higher order interactions from the model and subjecting the data to ANOVAs with the reduced model(s). First, the four-way interaction was removed, and next all of the three- and four-way interactions were removed. No material changes to the ANOVA results were found with the removal of these higher-order interaction terms. This speaks to the lack of importance of the higher-order interactions in this dataset and the “stability” of the underlying data structure for the main effects and two-way interactions.

Since 18 males and 32 females participated in this study, a Welch t-test was performed as a post-hoc comparison to see if there was a significant difference between the males’ and females’ peripheral acuity performance in the study collapsed across all of the other factors. The females performed just slightly better overall (p < 0.048) than did the males in the study (see Table 4). The difference in acuity performance was 0.9 min of visual angle lower (better) for the females than for the males given the tabled values below.

### Table 4.
Comparison of Males and Females Overall Performance Collapsed Across all Treatment Conditions.

<table>
<thead>
<tr>
<th>Sex</th>
<th>N Observations</th>
<th>Mean Acuity</th>
<th>SD</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>608</td>
<td>27.4</td>
<td>10.8</td>
<td>.44</td>
</tr>
<tr>
<td>Females</td>
<td>992</td>
<td>26.5</td>
<td>10.4</td>
<td>.33</td>
</tr>
</tbody>
</table>

Welch t-test: T - 1.67; df (adjusted) = 1250; F < M (F better acuity overall), p < 0.048.

### Multiple Comparisons Tests

The problem with analyses using some Multiple Comparisons (MC) tests is that seemingly significant results may occur more often than expected by chance alone (inflated alpha error). In this study, the Fischer LSD test was used to find any significant differences between means that might be close together. The Fischer LSD test has been termed a “liberal” MC test because it will tend to detect any possible differences between means, and may overstate the nature of those differences as the number of comparisons increases by “finding”
differences where there are none by chance. This is statistically less likely to occur if the global null hypothesis of no differences among means is rejected; i.e. significant differences among some means does exist (Hsu, 1996). This is referred to as using the LSD test under “protected” circumstances. This was the circumstance under which the LSD test was used for these data. The LSD test was cautiously applied under such “protected” circumstances in order help better assess the MC among means in this dataset. Despite this implied protection, the caveat that comes with the LSD test is that it will still tend to generate more Type 1 errors than other MCs tests.

The more conservative Sidak (1967) and Tukey tests have also been chosen for the MCs in this study (alongside the LSD test) over the often-utilized Newman-Kuels procedure. This is because some recent theoretical and Monte Carlo (simulation) research indicates that the Newman-Kuels and Duncan tests likely do not offer the stated alpha error protection levels (Einot and Gabriel, 1975; Hsu, 1996; Westfall, Tobias, Rom, Wolfinger, and Hochberg, 1999). The Sidak method is particularly useful when the comparisons are independent, as is the case for the means tested in this experiment (Sidak, 1967; Westfall et al., 1999). The Tukey test is considered a fairly “conservative” test that is also widely used.

**Main Effects**

**Eccentricity.** The main effect of Eccentricity on mean threshold acuity values was significant \( p < .001 \) and is presented in Figure 15. When collapsed across all of the other factors (Velocity, Difficulty, and a F/R Direction of presentation), each of the levels of Eccentricity in Table 5 (25 deg, 35 deg, 45 deg, 50 deg, 55 deg) is significantly different from the others using the Fisher LSD test \( p < 0.01 \) and the more conservative Tukey MC test \( p < 0.049 \) individual error rate). The results of the multiple regression on Eccentricity collapsed across all other factors reveals that the best fit curve is a monotonically increasing cubic function with a substantial linear component \( \text{F (3, 1596) = 254.6; p < 0.001} \). These combined results address the previously posed Research Question 1a-- that increasing Eccentricity leads to an increase in mean visual acuity values (meaning that worsening visual acuity occurs with increasing Eccentricity—as would be expected). The amount of variance attributed to the main effect of Eccentricity was 32.4 %. 


**Fixed/Random (F/R) Presentation Mode.** Figure 16 and Table 6 represent the main effect of F/R Direction of presentation on mean threshold visual acuities collapsed across all of the other factors (Eccentricity, Task Difficulty, and Target Velocity). The main effect of Target Direction of presentation means were significantly different ($F(1, 45) = 17.66; \ p < .001$), thereby supporting the notion of Research Question 2a, that there would be a difference between the values obtained for the F/R Target Direction of presentation case. The random direction of Target Direction would be expected to be more difficult to see based upon the literature review than the fixed Target Direction case. The mean acuity obtained for the random Target Direction of presentation (27.85 mins) is greater than the mean acuity found (25.93 mins) for the fixed Target Direction of presentation case. The percentage of the total variance that can be attributed the main effect of Target Direction presentation was 0.8 %.

Table 5.

<table>
<thead>
<tr>
<th>Visual Eccentricity (in deg)</th>
<th>Mean Acuity</th>
<th>N</th>
<th>S.E</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>17.56</td>
<td>320</td>
<td>0.27</td>
</tr>
<tr>
<td>35</td>
<td>24.75</td>
<td>320</td>
<td>0.44</td>
</tr>
<tr>
<td>45</td>
<td>26.57</td>
<td>320</td>
<td>0.49</td>
</tr>
<tr>
<td>50</td>
<td>29.62</td>
<td>320</td>
<td>0.58</td>
</tr>
<tr>
<td>55</td>
<td>35.89</td>
<td>320</td>
<td>0.58</td>
</tr>
</tbody>
</table>

Notes: All means shown are significantly different from each other using the Fisher LSD test at $p < .01$; and the Tukey HSD test at $p < .049$ individual error rate.
Figure 15. Main Effect of Eccentricity on peripheral Dynamic Visual Acuity (in mins). Error bars indicate ± 1 SE of the mean.
Table 6.
Comparison of Mean Threshold Visual Acuity (in min) as a Function of Fixed (horizontal) or Random (Random: “>” pattern) Target Direction of Presentation.

<table>
<thead>
<tr>
<th>Direction of Presentation</th>
<th>Mean Acuity</th>
<th>N</th>
<th>S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed</td>
<td>25.93</td>
<td>800</td>
<td>0.736</td>
</tr>
<tr>
<td>Random</td>
<td>27.85</td>
<td>800</td>
<td>0.724</td>
</tr>
</tbody>
</table>

Note: The random Target Direction of presentation mean is significantly different from the fixed Target Direction of presentation means at p < .001.

Figure 16. Main Effect of Target Direction of Presentation on peripheral Dynamic Visual Acuity (in mins). Error bars indicate ± 1 SE of the mean.
**Tracking Task Difficulty Level.** The main effect of Tracking Task Difficulty is shown by Figure 17. When collapsed across all of the other factors (Eccentricity, Target Direction, Velocity), Tracking Difficulty is a statistically significant ($F(3, 135) = 315; p < .027$) effect on mean threshold peripheral visual acuities. Table 7A contains the means and standard errors for each of these levels.

Table 7B highlights the pairwise comparisons among the four Tracking Task Difficulty levels. The Sidak test reveals a significant difference on the acuity values obtained between the monitoring state (0) and the most difficult level (3) of Tracking Task Difficulty ($p < .035$). Multiple pairwise comparisons with the more liberal Least Significant Difference (LSD) test result in significant differences between Tracking Task Difficulty levels at not only 0 and 3 ($p < .006$), but also between the Tracking Task levels 1 and 3 ($p < .033$).

A multiple regression was performed on the Tracking Task data and the lowest-order best fit was a linear function that increased monotonically across all of the Tracking Task Difficulty levels ($F(1, 1598) = 4.68; p < .031$). These results taken all together indicate support for Research Question 3a-- that increasing Tracking Task Difficulty under these experimental conditions resulted in an increase for mean visual acuity values (i.e. result in decreased visual acuity performance). The Tracking Task contributed 0.3 % to the total experimental variance.

Table 7 contains a widely used reporting format throughout the rest of this dissertation. The (I)TRKL refers to the listed “Ith” Tracking Task Difficulty level, while the (J)TRKL refers to the “Jth” level that the “Ith” level is being compared with in the multiple comparisons tests. Note that a comparison of 0, 3 is the same as 3, 0-- except for the sign in front of the difference value obtained due to the subtraction of one mean from the other. This gives an indication as to which value is larger. If the LSD test highlighted any significant differences between means that the Sidak test did not, these are noted in the text below the tables, or if the differences were extensive, a separate table of values was created. Values that are boldfaced in the tables are significantly different from one another, according to the MC test used with the level of significance (“p values”) stated in the tables. Boldfacing these significant differences helps to highlight the values among the rest of the comparisons that may not be different.

To assess if participants actually were able to perceive differences between the various Tracking Task levels, they were asked to rate the “Estimated Difficulty” of completing the
Tracking Tasks assigned while simultaneously attending to the visual periphery. Figure 18 presents these results graphically with “Estimated Difficulty” plotted as a function of actual Tracking Task Difficulty level from 0-3 (monitor only, thru the hardest Tracking Task Difficulty level). Collapsed across all secondary peripheral task conditions, the participants as a group were able to discern all of the different Tracking Task Difficulties from a subjective estimation standpoint. These subjective results are very similar to Arnegard and Comstock’s (1991) previously published results of their participants’ subjective estimate of Tracking Task Difficulties.

Figure 17. Main Effect of Tracking Task Difficulty on peripheral dynamic visual acuity (in mins). Error bars indicate ± 1 SE of the mean.
Table 7.
A. Comparison of Mean Threshold Visual Acuity (in min) as a Function of Tracking Level.

<table>
<thead>
<tr>
<th>Tracking Level (Difficulty)</th>
<th>Mean Acuity</th>
<th>N</th>
<th>S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitor (0)</td>
<td>26.21</td>
<td>400</td>
<td>0.678</td>
</tr>
<tr>
<td>Easiest (1)</td>
<td>26.44</td>
<td>400</td>
<td>0.824</td>
</tr>
<tr>
<td>Moderate (2)</td>
<td>27.26</td>
<td>400</td>
<td>0.770</td>
</tr>
<tr>
<td>Hardest (3)</td>
<td>27.64</td>
<td>400</td>
<td>0.789</td>
</tr>
</tbody>
</table>

B. Pairwise Comparisons of the Main Effect of Tracking Level Difficulty on Acuity with the Sidak test.

<table>
<thead>
<tr>
<th>Levels</th>
<th>Mean Acuity</th>
<th>Difference (I-J)</th>
<th>S.E.</th>
<th>Significance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>(I)TRKL</td>
<td>(J)TRKL</td>
<td>S.E.</td>
<td>Significance Level</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>-.227</td>
<td>.589</td>
<td>.999</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-1.045</td>
<td>.551</td>
<td>.328</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>-1.428*</td>
<td>.494</td>
<td>.035</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>.227</td>
<td>.589</td>
<td>.999</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-.818</td>
<td>.556</td>
<td>.618</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>-1.201</td>
<td>.547</td>
<td>.184</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1.045</td>
<td>.551</td>
<td>.328</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>.818</td>
<td>.556</td>
<td>.618</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>-.383</td>
<td>.474</td>
<td>.963</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>1.428*</td>
<td>.494</td>
<td>.035</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1.201</td>
<td>.547</td>
<td>.184</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>.383</td>
<td>.474</td>
<td>.963</td>
</tr>
</tbody>
</table>

Notes: *The mean differences highlighted are significant (p < .05) using the Sidak test for multiple comparisons. Furthermore, the Least Significant Difference test reveals meaningful differences between the Tracking Task levels represented not only at the 0 and 3 (p < 0.006) levels, but additionally between the 1 and 3 levels as well (p < 0.033).
Figure 18. Participants’ estimates of Tracking Task Difficulty as a function of actual Tracking Difficulty level. Error bars denote ± 1 SE of the mean. All pairwise comparisons are significantly different from one another using the Tukey test (p < .05 individual error rate) and LSD test (p < .01).
**Velocity.** Figure 19 highlights the main effect of Target Velocity collapsed across the other factors (Eccentricity, F/R, and Tracking Task Difficulty). The main effect of Target Velocity across the four levels tested was found to be significant (F (3, 135) = 68.53; p < .001). There was a general trend of increasing mean visual acuity thresholds with increasing velocity, with the notable exception of the velocity at 4.88 deg/s. This general trend partially supports Research Question 4b, that increasing target velocity results in more difficult-to-see targets in the periphery. For these data, this is particularly true for Target Velocities of 4.88 deg/s and higher. A multiple regression analysis revealed that the best fit to a curve of this form is a quadratic function \( F (2, 1597) = 43.65; p < .001 \). Appendix B (Part C) contains the multiple regression results.

Examination of the pairwise comparisons (see Table 8) reveals several significant \( (p < .001) \) differences using the Sidak adjustment for multiple comparisons. Additionally, the Least Significant Difference test of these same pairs reveals nearly the same results, except that the comparison of the 0 deg/s and 14.62 deg/s case is also significantly different (where it was not by the Sidak test), with all pairwise differences reported at the \( p < .01 \) level of significance. The one pairwise comparison not found to be significantly different by either the Sidak or LSD test was at the velocities of 0 deg/s and 4.88 deg/s, thereby not supporting the Research Question 4a posed earlier, that acuities might in fact be better at the slower 4.88 deg/s velocity. Note however, that the best-fit multiple regression curve to these Target Velocity main effect data is not a monotonically increasing line, but rather a quadratic function that decreases just a bit in the slower velocity region (thereby mitigating this last comment somewhat with respect to not seeing a slow velocity effect from a regression perspective).

The variance attributable to the Target Velocity effect represented 5.2 % of the total variance expressed in the dataset.

All of the main effects just described should be considered in terms of the higher order interactions discussed next.
Figure 19. Main Effect of Target Velocity on mean threshold acuity (in min).
Table 8.
Threshold Visual Acuity (in min) as a Function of the Velocity of the Landolt C Target.

A. Threshold Visual Acuity (in min) as a Function of the Velocity of the Landolt C target.

<table>
<thead>
<tr>
<th>Velocity</th>
<th>Mean Acuity</th>
<th>N</th>
<th>S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00 deg/s</td>
<td>25.40</td>
<td>400</td>
<td>.751</td>
</tr>
<tr>
<td>4.88 deg/s</td>
<td>24.62</td>
<td>400</td>
<td>.691</td>
</tr>
<tr>
<td>14.62 deg/s</td>
<td>26.69</td>
<td>400</td>
<td>.820</td>
</tr>
<tr>
<td>24.40 deg/s</td>
<td>30.86</td>
<td>400</td>
<td>.739</td>
</tr>
</tbody>
</table>

B. Pairwise Comparisons of the Main Effect of Velocity on Acuity.

<table>
<thead>
<tr>
<th>Levels</th>
<th>Mean Acuity</th>
<th>Difference (I-J)</th>
<th>S.E.</th>
<th>Significance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>(I)VEL</td>
<td>(J)VEL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0 deg/s</td>
<td>4.88</td>
<td>.783</td>
<td>.440</td>
<td>.400</td>
</tr>
<tr>
<td></td>
<td>14.62</td>
<td>-1.289</td>
<td>.488</td>
<td>.066</td>
</tr>
<tr>
<td></td>
<td>24.40</td>
<td>-5.462*</td>
<td>.490</td>
<td>.001</td>
</tr>
<tr>
<td>4.88 deg/s</td>
<td>0.0</td>
<td>-7.83</td>
<td>.440</td>
<td>.400</td>
</tr>
<tr>
<td></td>
<td>14.62</td>
<td>-2.072*</td>
<td>.487</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>24.40</td>
<td>-6.245*</td>
<td>.497</td>
<td>.001</td>
</tr>
<tr>
<td>14.62 deg/s</td>
<td>0.0</td>
<td>1.289</td>
<td>.488</td>
<td>.066</td>
</tr>
<tr>
<td></td>
<td>4.88</td>
<td>2.072*</td>
<td>.487</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>24.40</td>
<td>4.173*</td>
<td>.447</td>
<td>.001</td>
</tr>
<tr>
<td>24.40 deg/s</td>
<td>0.0</td>
<td>5.462*</td>
<td>.490</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>4.88</td>
<td>6.245*</td>
<td>.497</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>14.62</td>
<td>4.173*</td>
<td>.447</td>
<td>.001</td>
</tr>
</tbody>
</table>

Notes: *The mean differences shown are significant using the Sidak adjustment for multiple comparisons. The Least Significant Difference Test reveals meaningful differences between all of the various velocity levels shown above (p < .01) EXCEPT between 0 deg/s and 4.88 deg/s.
Two-Way Interactions

Figure 20 represents the two-way interaction between Velocity and F/R Target Direction of Landolt C presentation. This Target Velocity x F/R Target Direction of presentation interaction provides support for Research Question 4c, that Target Velocity and Target Direction of presentation would exhibit an interaction. As the Target Velocity increases, random Directions of target presentation make the targets harder to see, resulting in higher mean threshold peripheral acuity values as compared to fixed Target Directions of presentation. Simple effects tests with either the Sidak or LSD test (Table 9) at each of the velocities reveal that only at the highest two velocities of 14.62 deg/s and 24.40 deg/s are the fixed and random Directions of presentation significantly different from one another-- at the \( p < .026 \) and \( p < .001 \) levels, respectively.

---

Figure 20. Two-way interaction between Target Velocity and F/R Target Direction of presentation on peripheral Dynamic Visual Acuity. Error bars denote \( \pm 1 \) SE at the means shown.
Table 9.
Threshold Visual Acuity (in mins) as a Function of Target Velocity with the Interaction of Target Presentation Direction (Fixed or Random) at Each Velocity Level.

A. Mean Threshold Visual Acuities for the two-way interaction between Target Velocity and Target Direction of Presentation (Fixed/Random).

<table>
<thead>
<tr>
<th>Levels</th>
<th>FR</th>
<th>Mean Acuity</th>
<th>S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 deg/s</td>
<td>1</td>
<td>25.50</td>
<td>.911</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>25.29</td>
<td>.743</td>
</tr>
<tr>
<td>4.88 deg/s</td>
<td>1</td>
<td>24.250</td>
<td>.692</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>24.980</td>
<td>.786</td>
</tr>
<tr>
<td>14.62 deg/s</td>
<td>1</td>
<td>25.850</td>
<td>.860</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>27.523</td>
<td>.934</td>
</tr>
<tr>
<td>24.40 deg/s</td>
<td>1</td>
<td>28.111</td>
<td>.902</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>33.608</td>
<td>.803</td>
</tr>
</tbody>
</table>

B. Pairwise Comparisons of the Interaction between Target Velocity and Target Direction of Presentation (F/R).

<table>
<thead>
<tr>
<th>Levels</th>
<th>Mean Acuity</th>
<th>S.E.</th>
<th>Significance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>VEL</td>
<td>(I)FR (J)FR</td>
<td>Difference (I-J)</td>
<td></td>
</tr>
<tr>
<td>0.0 deg/s</td>
<td>1 2</td>
<td>.208</td>
<td>.714</td>
</tr>
<tr>
<td>4.88 deg/s</td>
<td>1 2</td>
<td>.730</td>
<td>.530</td>
</tr>
<tr>
<td>14.62 deg/s</td>
<td>1 2</td>
<td>1.674*</td>
<td>.728</td>
</tr>
<tr>
<td>24.40 deg/s</td>
<td>1 2</td>
<td>5.497*</td>
<td>.855</td>
</tr>
</tbody>
</table>

Notes:  *The mean differences shown are significant using the Sidak adjustment for multiple comparisons. Multiple comparisons with the Least Significant Difference test does not alter these results for any comparison at p < 0.05.
The interaction between Target Velocity and Tracking Task Difficulty is presented by Figure 21. This interaction was significant (p < .028) and supports the notion contained in Research Question 4d that increasing Target Velocity will result in an interaction with Tracking Task Difficulty. This says that the resulting mean threshold acuities change with Tracking Task Difficulty as a parameter across the various levels of Velocity. As Figure 21 illustrates, this interaction (apparently) has some unexpected aspects to it at the moderate level (purple colored line) of Tracking Task Difficulty.

Figure 21. Two-Way interaction between Target Velocity and Tracking Task Difficulty level. Error bars denote ± 1 SE at the means shown.
An analysis of the simple effects tests for Tracking Task Difficulty differences across each of the Target Velocities by the Sidak test reveals statistically significant differences (p < .001) only at a Velocity of 4.88 deg/s between the Tracking Task Difficulty levels of 0 and 2 (see Table 10b). Apparently, there is some facilitative effect with regard to improved acuity at the slow target speed of 4.88 deg/s when comparing the monitor only (easiest) and moderately difficult level of Tracking Task Difficulty given the results of the Sidak MC test.

A further analysis of this interaction with the more liberal LSD test is summarized by Table 10c for each level of Target Velocity and compared with all of the various levels of Tracking Task Difficulties, thereby revealing a few additional significant differences. In this analysis, there are significant simple effects test mean differences not only at this same Target Velocity (4.88 deg/s) and Tracking Task Difficulties (0, 2) as before (p < .001), but additional significant simple effects differences between acuity means using the LSD test which appear at several Tracking Task Difficulty levels of: 0, 3 (p < .026); 1, 2 (p < .017); and 2, 3 (p < .042; Refer again to Table 10c for these simple effects tests using the LSD test). Thus, there is evidence when using the LSD test that there is a definite facilitative effect of easier Tracking Tasking on peripheral visual acuity across many levels of Tracking Task Difficulty at this slow (4.88 deg/s) Target Velocity.

The LDS test, but not the Sidak test, also highlights statistically significant simple effects differences among sample means at the 24.40 deg/s velocity condition. At this Target Velocity, there appear to be simple effects differences among the means for the Tracking Task Difficulties between the following levels: 1,3 (p < 0.25) and 2,3 (p < 0.030). Noting this LSD test result at the highest Target Velocity (24.40 deg/s) shows that there is a tendency for the most difficult level of Tracking Task Difficulty to result in worse peripheral DVAs as compared with the easiest and moderate levels of Tracking Task Difficulty at this Target Velocity.
Table 10a.

Threshold Visual Acuity (in mins) as a Function of Velocity with the Interaction of Tracking Level at Each Velocity Level.

A. Mean Threshold Visual Acuities for the Velocity by Tracking Level Interaction Levels

<table>
<thead>
<tr>
<th>VEL</th>
<th>TRKL</th>
<th>Mean Acuity</th>
<th>S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 deg/s</td>
<td>0</td>
<td>25.64</td>
<td>.791</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>24.81</td>
<td>.894</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>24.88</td>
<td>.987</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>26.27</td>
<td>.979</td>
</tr>
<tr>
<td>4.88 deg/s</td>
<td>0</td>
<td>23.00</td>
<td>.752</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>24.04</td>
<td>.892</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>26.62</td>
<td>.967</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>24.81</td>
<td>.897</td>
</tr>
<tr>
<td>14.62 deg/s</td>
<td>0</td>
<td>25.71</td>
<td>.985</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>26.69</td>
<td>.897</td>
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<tr>
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<td>2</td>
<td>27.31</td>
<td>.933</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>27.04</td>
<td>1.031</td>
</tr>
<tr>
<td>24.40 deg/s</td>
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<td>30.51</td>
<td>.955</td>
</tr>
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<td></td>
<td>1</td>
<td>30.23</td>
<td>1.079</td>
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<tr>
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<td>2</td>
<td>30.23</td>
<td>.911</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>32.46</td>
<td>.971</td>
</tr>
</tbody>
</table>
### Table 10b.

Threshold Visual Acuity (in mins) as a Function of Velocity with the Interaction of Tracking Level at Each Velocity Level (Sidak test for Simple Effects evaluation)

#### B. Pairwise Comparisons of the Interaction Between Velocity and Tracking Level.

<table>
<thead>
<tr>
<th>VEL</th>
<th>(I)TRKL</th>
<th>(J)TRKL</th>
<th>Difference (I-J)</th>
<th>S.E.</th>
<th>Significance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0</td>
<td>1</td>
<td>.830</td>
<td>.737</td>
<td>.844</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>.763</td>
<td>.863</td>
<td>.944</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>.628</td>
<td>1.048</td>
<td>.992</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>-.830</td>
<td>.737</td>
<td>.844</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>-.67</td>
<td>.742</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-.148</td>
<td>.861</td>
<td>.459</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>-.763</td>
<td>.863</td>
<td>.944</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-.067</td>
<td>.742</td>
<td>1.000</td>
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</tr>
<tr>
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<td>-.1391</td>
<td>.854</td>
<td>.504</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.88</td>
<td>0</td>
<td>1</td>
<td>-1.043</td>
<td>.833</td>
<td>.770</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-3.620*</td>
<td>.797</td>
<td>.001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>-1.810</td>
<td>.787</td>
<td>.147</td>
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</tr>
<tr>
<td>1</td>
<td>1.043</td>
<td>.833</td>
<td>.770</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>-2.577</td>
<td>1.037</td>
<td>.096</td>
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</tr>
<tr>
<td></td>
<td>-1.768</td>
<td>.994</td>
<td>.970</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3.620*</td>
<td>.797</td>
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<td>3</td>
<td>1.810</td>
<td>.787</td>
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<td>.970</td>
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<tr>
<td></td>
<td>2</td>
<td>-1.810</td>
<td>.863</td>
<td>.225</td>
<td></td>
</tr>
</tbody>
</table>

*Statistically significant difference using the Sidak test at p < 0.001.
(Continued Table 10b—Sidak simple effects tests)

<table>
<thead>
<tr>
<th>Level</th>
<th>Mean Acuity</th>
<th>S.E.</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>VEL</td>
<td>(I)TRKL</td>
<td>(J)TRKL</td>
<td>Difference (I-J)</td>
</tr>
<tr>
<td>14.62</td>
<td>0</td>
<td>1</td>
<td>-.976</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>-1.603</td>
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<td>0</td>
<td>.976</td>
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<td>2</td>
<td></td>
<td>-.627</td>
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<td>0</td>
<td>1.325</td>
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<td>1</td>
<td></td>
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</tr>
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<td></td>
<td>2.227</td>
</tr>
</tbody>
</table>

Notes: An evaluation of this interaction is based upon the Sidak adjustment for multiple comparisons. Refer to Table 10c for additional analyses using the Least Significant Difference pairwise comparison test of these factors at the Target Velocity levels stated.
Table 10c.

Threshold Visual Acuity (in mins) as a Function of Velocity with the Interaction of Tracking Level at Each Velocity Level (LSD test for Simple Effects evaluation)

C. Pairwise Comparisons of the Interactions Between Velocity and Tracking Level.

<table>
<thead>
<tr>
<th>VEL</th>
<th>Level</th>
<th>Mean Acuity (I)TRKL</th>
<th>Mean Acuity (J)TRKL</th>
<th>Difference (I-J)</th>
<th>S.E.</th>
<th>Significance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 deg/sec</td>
<td>0</td>
<td>1</td>
<td>0.830</td>
<td>0.737</td>
<td>0.266</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.763</td>
<td>0.863</td>
<td>0.381</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>-0.628</td>
<td>1.048</td>
<td>0.552</td>
<td></td>
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<td>1</td>
<td>0</td>
<td>-0.830</td>
<td>0.737</td>
<td>0.266</td>
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</tr>
<tr>
<td>2</td>
<td>0</td>
<td>-0.763</td>
<td>0.863</td>
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<tr>
<td></td>
<td>1</td>
<td>-0.067</td>
<td>0.742</td>
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(Continued-Table 10c, LSD simple effects tests)

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Note: *The mean differences shown are significantly different at the level stated using the Least Significant Difference test for multiple comparisons. Note how this changes if the values are significantly different as compared to those pairwise comparisons found using the Sidak correction in Table 10b.
DISCUSSION

**Mixed Eccentricity/Velocity Commentary**

One of the research goals of this study was to explore peripheral DVA at a variety of moderate (25-55 deg) visual eccentricities. Reviewing the results of the main effect of eccentricity (F (4, 45) = 18.71; p < .001; see Figure 15) collapsed across all of the experimental conditions reveals a loss of acuity that increases rapidly from 25 deg to 35 deg, then decreases somewhat less rapidly from 35 to 45 deg, and next begins to accelerate more rapidly toward worsening peripheral visual acuities. Taken as a whole, the results found in this study follow the same general form of the curves from 35 deg of eccentricity on as the acuities found in the peripheral DVA curves presented by Hoogerheide (1964; refer to Figure 8) and static curves by Anstis (1974), with general parallels to other static acuity measures in the periphery already noted (Kerr, 1971; Weymouth, 1958; Williams and Coletta, 1987).

Collapsed across all other experimental conditions, the main effect of Eccentricity (Figure 15) on acuity was subjected to a multiple regression procedure resulting in the best fit to the data being a monotonically increasing cubic form of the regression equation with increasing Eccentricity. This result lends strong support to Research Question 1a, that DVA acuities would increase with increasing Eccentricity. The best-fit curve accounts for 32.4 % of the variance, which is virtually all of the variance contribution represented by the main effect of Eccentricity. The regression analyses revealed a very strong linear component to these Eccentricity data, which account for fully 30.0 % of the total variance attributed to this source. About 2 % of the variance in Eccentricity was due to the cubic component as is shown in Appendix B.

The results with regard to Research Question 1b that there would be some change in variances with increasing Eccentricity is not surprising given the literature review, and more specifically due to previous work from Low (1947a) on motion acuity in peripheral vision. On the whole, the pattern of somewhat changing variance with Eccentricity has been borne out by the results presented in Table 3A with Levene’s Test (p < .001), and supported with the results from Table 5. Due to the relatively benign ratio of the largest variance to the smallest (4.56) along the Eccentricity dimension, where values near 10 are considered troublesome for the violation ANOVA assumptions (Tabachnick and Fidell, 1996), it can be safely assumed that
the resulting data structure is amenable to ANOVA, and to reasonably “stable” multiple comparisons tests results if carefully chosen tests are used (as has been discussed earlier). The two closest values of acuity found across all Eccentricities were those at 35 deg (24.75 mins) and 45 deg (26.57 mins) where the Eccentricity curve “flattens out,” before accelerating upward again (refer to Figure 15). Despite the flattening of the response curve in this region, the more conservative Tukey test revealed significance differences between these means, as did the liberal LSD test. Interestingly, other researchers (Anstis, 1974; Weymouth, 1958) have found a grossly similar pattern of acuity decrement in this region, with an accelerating increase in worsening acuities at approximately 50 deg of Eccentricity.

“Tunnel vision” can be thought of in general terms as a visual acuity response that becomes “much worse-- and not simply worse-- since that is expected,” with increasing Eccentricity across different levels of some “tasking variable” as a review of Figure 11 (revisited) on the following page illustrates. As the discussion from the literature review on attention and peripheral visual processing highlighted, the “tasking variable” on visual processes might be along any dimension including: workload, tracking task difficulty, attentional issues, or perhaps even (indirectly) target velocity, as a few potential examples.

Along this line of thinking, an interesting non-significant interaction (p < .27) worth commentary in this particular section is that of Eccentricity by Target Velocity, which addressed Research Question 1e with regard to assessing this possible interaction. The results lead to the conclusion that under these experimental conditions there was no “tunnel vision” like effect (in the vein of that presented by Figure 11) where Target Velocity was the parameter of interest as the more eccentric regions of the retina were probed in this study. Figure 22 reveals this interaction graphically and shows that while all of the Velocity results tended to parallel each other across each of the Eccentricities shown, the fastest target speed of 24.40 deg/s was separable from the other three velocities, which tended to cluster together. If even faster velocities were to be tested, then it is possible that an interaction between Eccentricity and Velocity might occur, leading to a conclusion of some type of Velocity-related “tunnel vision” across the Eccentricities tested (i.e. a significant Eccentricity by Velocity interaction) showing up with respect to the higher velocities. But, for these data at the tested Velocities and
Figure 11. Peripheral visual acuity as a function of retinal eccentricity according to the General Interference Model (Top Panel), or the Tunnel Vision Model (Bottom Panel). The two solid lines represent the theoretical effect of two different levels of tasking as a parameter. The bottom line in each panel represents a lower level of tasking than does the upper line.
Eccentricities such is not the case, and the observation from a graphical perspective that is that
the data more closely exhibit a “general interference” type of relationship between Eccentricity
and Velocity. This evidence is graphical in nature only, since the statistical method of strong
inference has not been applied to these results.

**Relationship/Discussion to Past Peripheral DVA Research.** Recall Low’s (1943, 1947a) work in the 30-75 deg range for static (1943) and moving targets (1947a). His reported
acuities were so poor at 60-75 deg of eccentricity that he could not accurately measure
peripheral DVA in that retinal region with his target sizes. As noted by Low (1947a) in his
peripheral DVA study, there is quite a bit of variation in his data, particularly as eccentricity
increases. This to some extent also was the case with the data variances across Eccentricity
here (refer back to Table 3A).

Using targets moving at 15 deg/s for 1.0 s, Low (1947a; p. 126-127) commented:
A sharp drop in motion acuity was observed between the 30° and 60° measures, the latter being virtually unobtainable. At the 30° measures there was only one failure [inability to see a target at all] (consisting of failure on the largest test object) in a total of 200 such measures. At 60° there were 144 such failures, or 72 percent. At 45°, midway between these measures, there were 32 such failures, or 16 percent....Thus it must be said that, when a peripherally perceived object is moving toward or away from the line of vision, the innermost 5° of its excursion is the critical area for perception of its form.

As noted earlier, the threshold acuity values in this current research study also fell rapidly in the 25-55 deg of eccentricity range (except for the slight plateau at 35 –45 deg), paralleling Low’s “sharp drop” between the 30 and 60 deg of eccentricity.

Low’s 1947b results for Landolt C targets moving at 15 deg/s with a 1.0 s exposure duration yielded an average DVA acuity of 37 mins of visual angle at 30 deg of eccentricity. The same stationary target, with unlimited viewing time at 30 deg of eccentricity required only 17.9 mins of visual angle to be resolved (Low, 1943). Therefore, it appears from Low’s (1943, 1947a) data that adding target motion of 15 deg/s for 1s (thus covering 15 deg of arc), nearly doubled (worsened) the visual acuity values he found. In the present study, viewing times for all targets were limited to 0.5 s, and the moving target acuity values obtained were never twice what the stationary ones were for this study’s experimental conditions.

Interpolating from Hoogerheide’s (1964) data at 30 deg of eccentricity yields visual acuities that are approximately 28 mins of arc at a target velocity of 20 deg/s, and 18 mins of arc at 10 deg/s. Averaging these values at an interpolated velocity of 15 deg/s would result in an estimated DVA of approximately 23 mins of arc at 30 deg of eccentricity. This study’s nearest treatment to the condition of 15 deg/s and 30 deg Eccentricity may be found in Figure 22. The acuity derived from the velocity curve in Figure 22 from this study of 14.62 deg/s is not particularly close to Low’s (1947a) average acuity (37 mins) at a velocity of 15 deg/s. The acuity determined from the interpolated 15 deg/s value previously obtained by Hoogerheide (1964) would be approximately 23 mins as noted above. While referring to this study’s results from Figure 22, and reading the 14.62 deg/s velocity line at an interpolated 30 deg of eccentricity in that figure, a value of roughly 21.5 mins is obtained. This is in close agreement with the 23 mins that was estimated from Hoogerheide’s (1964) curves, but not quite as close as the “inswinging and outswinging” values Low (1947a) obtained at 30 deg of eccentricity.
The differences between Hoogerheide’s (1964) values, Low’s (1947a) results, and the acuity values obtained in this study might be explained by a myriad set of factors including: target presentation geometric effects, contrast issues, target polarity, room illumination, and target type, etc.

In sum, Target Eccentricity was the single largest source (32.4 %) of variation in this dataset, and this represents about 80 % of all of the variation in this experiment that can be attributed to the various experimental factors that were controlled for and tested.

**Tracking Level Main Effect Commentary/Results.**

*Tracking Task Results.* Interestingly, while the subjective “Estimated Tracking Difficulty” measure at each Tracking Task Difficulty level (Figure 18) was fairly distinct as the standard error of the mean bars indicate, the actual effect of an increasing Tracking Task Difficulty level on measured acuity performance (see Figure 17) was less than might have been expected. This is particularly true given the graphical presentation of Figure 17 where the dependent Estimated Total (Tracking ) Difficulty variable was plotted as a function of Tracking Task Difficulty. While the main effect of Tracking Task Difficulty was statistically significant with visual acuity as the dependent measure (see Figure 17), the effect is not quite as robust ($F (3, 135) = 3.15; p < 0.027$) as might have been expected with due consideration given to the results graphed in Figure 17 (compare Figures 17 versus 18).

A multiple regression on the independent variable of Tracking Task Difficulty revealed that the dependent acuity relationship to the Tracking Task Difficulty level is a monotonically increasing function one that accounts for most of the variance (0.3 %) associated with this main effect (refer to Table 2, or see Appendix B for statistical results). These results are in agreement with the notion contained in Research Question 3a, that increasing Tracking Task Difficulty will result in decreased DVA performance in the visual periphery. The addition of higher order terms into the regression equation does not improve the statistical regression in any meaningful way.

The implicit assumption is that as the “Estimated Total Difficulty” of the Tracking Task increases, one might logically assume that the visual acuity in the periphery might decrease based upon considerations noted extensively in the literature review (that increasing Tracking Task Difficulty levels leads to decreasing visual acuity peripheral performance,
presumably due to more attentional resources being devoted to the primary Tracking Task, with the drawn-down of reserve cognitive resources required to process this more difficult task environment).

Using the Sidak statistical test for post-hoc comparisons, significant visual acuity performance differences were only found between the levels of monitoring (0) the primary display and the most difficult level (3) of Tracking Task Difficulty. The Least Significant Difference test revealed that there was a significantly different outcome in terms of visual acuity measures not only at the 0 and 3 Tracking Task Difficulty levels, but also at the 1 (easiest) and 3 (most difficult) levels. Despite these slight disparities in some of the post-hoc MCs, Tracking Task Difficulty means analyses, the effect of Tracking Task level on DVA in the retinal periphery seems somewhat less impressive than might have been hinted at from the literature previously reviewed. This is likely explained by a limited “range effect” in the Tracking Task Difficulty main effect results for this experiment. Had the Tracking Task been quite a bit more difficult at the hardest levels of the Tracking Task, extra primary “attentional resources” probably would have been allocated to the successful completion of the Tracking Task, to the detriment of the secondary peripheral acuity task. However, as noted previously, the Tracking Task needed to be accomplished within a constrained area of the foveal visual field in order to have useful geometric control of the eccentric location of the target in the visual periphery. Similarly, if the Tracking Task had been much more difficult at the hardest level in this experiment, then determining the eye-target geometry for assessing visual eccentricity probably would have required the use of an eye tracking device.

**Further Tracking Task Commentary/Models.** Many justifiably consider the peripheral visual system as largely separate and semi-independent of the foveal visual system as noted previously. In many respects, the peripheral visual system can be thought of as a distinct “channel” (or perhaps even “modality”) of input into the brain (Wickens and Hollands, 2000). This other visual channel would therefore perhaps be less likely to be influenced by visualf (foveal)-visualp (peripheral) conflict from a shared resources model and perhaps even “coding” point of view. However, this approach is a simplification. As discussed in the previous literature, Williams (1982) varied cognitive load foveally and thereby affected the (static) functional field of view out to 11 deg of visual eccentricity. Williams (1988) also demonstrated that increasing foveal visual loads affects the functional field of view out to at
least 4.4 deg of visual angle (thus creating a foveal visual-peripheral visual “conflict”). Other authors have discussed this type of visual$_{f}$-visual$_{p}$ “conflict” in various incarnations as well (Holmes et al, 1977; Mackworth, 1965).

Taken at face value in this experiment, the “complexity” of the visual content presented to the foveal visual system does not change with increasing Tracking Task Difficulty levels, although from a foveal standpoint the eyes are in fact kept “busier” while working to keep the small target centered at the most difficult Tracking Task levels. At the hardest levels of Tracking Task Difficulty the eyes must track a more quickly moving foveal target. However, the motor-control aspect of performing the primary Tracking Task to criterion also increases with higher levels of Tracking Task Difficulty, such that separating the contributions of each of these two modalities (motor and visual) into an easily-measured workload (task loading) difficulty paradigm is somewhat problematic since these two modalities involved are working together in a confounded manner (Wierwille, Casali, Conner, and Rahimi, 1985; Wierwille and Eggemeier, 1993). To press the commentary perhaps a bit further, it is impossible to fully separate the cognitive/motor and foveal/visual components under these particular experimental conditions.

If the Tracking Task Difficulty level is proportional to task loading (and the subjective estimation of such task loading is carefully considered, Wierwille et al., 1985; Wierwille, personal communication), then the results of this study’s Eccentricity by Tracking Task Difficulty level interaction denoted by Figure 23 points away from the “tunnel vision” model of visual performance as reviewed earlier and presented conceptually by Figure 11 in this region of the periphery (Holmes, et al., 1977; Williams, 1995a,b).

A “tunnel vision” model in this sense of peripheral visual field performance would show an interaction of Eccentricity by Tracking Task Difficulty level where Tracking Task Difficulty represents task loading, and is proportional to the general concept of workload (see Arnegard and Comstock’s 1991 paper for a mini-validation of the task levels and estimated difficulty of accomplishing the tracking task with the original software, and the workload/task loading results using the NASA TLX workload rating scale; Peres, et al. , 2000). Such an interaction was not observed for these data, resulting in an implication that under these experimental conditions, a “general interference” type of model would be a better place to begin to explain results such as these across the various Eccentricity levels tested.
This study is the first known attempt to assess the “tunnel vision” models of peripheral vision function in this region of the periphery under dynamic viewing conditions. It should be recognized, however, that neither the tunnel vision nor general interference models as shown in Figure 11, strictly interpreted, really describe how this data set behaves, although the results are more graphically relatable to a “general interference” type of interpretation versus the tunnel vision paradigm. Interestingly, the non-significant interaction of Eccentricity and Target Velocity (Figure 22) comes the closest to a “general interference” type of decrement in acuity performance with increasing Eccentricity, where increasing Target Velocities are the parameter of interest instead of increasing task loading. (A few thoughts to consider: faster velocity targets might be conceptualized as requiring more of the reserve cognitive effort to attend to in terms of orientation discrimination in the retinal periphery. So, the discrimination...
of Landolt C target orientations at the higher target speeds in the retinal periphery could be thought of as an indirect proxy for task loading along some dimension that “taps into” the reserve attentional resources).

**Multiple Resource Model.** Few studies in this domain would be complete without mention of the multiple resource theory proposed by Wickens (1976, 1980, 1991). Specifically, Wickens (1980) has postulated that the composition of information processing resources could be conceptualized by three dimensions: stages of processing (perceptual/cognitive and response stages), codes of processing (spatial and verbal), and modalities of processing (auditory and visual). Within this resource model, two tasks are thought to interfere with each other when they compete successfully for overlapping resources, or resource pools. Here, put simplistically, increasing the motor/cognitive aspects of Tracking Difficulty level would be postulated, at face value, not to substantially interfere with a secondary peripheral Dynamic Visual Acuity task. In other words-- we can sometimes divide attention between the eye and the ear better (two different modalities), than between two competing auditory, or two competing visual channels. Thus, bi-modal time-sharing is thought to be more efficient than intra-modal time-sharing, and there is a body of research that shows this to be true for many situations (Wickens, 1991). However, if consideration is given to the structure of attention resources, it could be said that when/if a foveal Tracking Task affects peripheral visual acuity this does not imply that a single resource pool is being “tapped” into by both, only that there is the suggestion of an absence of a complete independence of resources (Wickens, 1980), or non-orthogonality in terms of the structure of the resources being taxed.

Herein lies part of the quandary represented by the Tracking Task level results on peripheral DVA in this experiment. The primary motor system controlling the Tracking Task obviously contains a foveal visual element, while the secondary task of peripheral target orientation recognition contains a visual element as well, albeit a peripheral visual system one. While there are clearly “multiple resources” being tapped into by the observers in this experiment, the nature of the intramodal (visual$_v$-visual$_p$) interaction here makes for a more challenging, and less clear-cut application of this type of resource modeling approach for explaining these research results. Wickens (2000) has recently suggested that such an
intramodal interaction/conflict as mentioned here lies in the information processing “coding” domain along a certain dimension.

**Possible Hypothetical Explanation: “Radar Beam” Framework Suggested.**

Succinctly put, after an experimental participant becomes fairly adept at accomplishing the Tracking Task, doing that task becomes partially “automatic” (see Hess, 1997 for various references on manual control feedback models). The recently-learned motor skills neural “programming” takes over, thereby allowing for a significant amount of the attentional resources to be devoted to monitoring the retinal periphery for the potential appearance of the Landolt C target. Edelman (1992) has crudely described what general pathways might be involved for creating focused attention where the already learned “motor programs” are concerned based upon his work in neuronal group theory. Furthermore, brain studies show that novel actions where choice by novices is required involve a pattern that might indicate more intense and diffuse brain activation, attention and “working memory,” as compared to routine or well-rehearsed tasks where there is a good “mental model” of the relevant task parameters (refer to Carter, 1998 for a brief summary of brain function, particularly based upon the latest neuro-imaging techniques; review the Peres et al. (2000) team’s extensive quotation in the Literature Review). This attentional/workload state would naturally lead to fewer attentional/cognitive resources being left over since attention has to be “spread” over a wider area in consciousness as Peres et al. have demonstrated in brain activation studies—almost like the zoom lens and spotlight models mentioned earlier for vision (refer to Figure 12). In this peripheral DVA study, participants did in fact report (refer to Figure 18) that they had to “concentrate on,” or attend to, the foveal tracking task in a more focused manner at the harder Tracking Task Difficulty levels. Thus, it appears that there was both a foveal visual and cognitive component to the Tracking Task results of this study (as would be expected).

Overall, it is possible that the Tracking Task Difficulty main effect results can be explained by a parallel processing/tasking approach. That is, while executing the Tracking Task, a recently-learned neural “program” in the visual-motor cortex is initiated that is partially automatic—much like driving a car. Yet, keeping that partially-automated neural “program” operating at the more difficult Tracking Task levels challenges the reserve of “attentional resources.” This is accomplished by allocating an increasing amount of the attentional/cognitive neural “controller” of the attentional “radar beam” to the visual-motor
domains involved in joystick control, thereby maintaining the desired level of performance output (much like driving or flying under more difficult conditions). A radar beam is a good analogy for a “controlling” attention mechanism since it has a finite “sweep time” around the region being controlled (areas of activation in the brain here are activated that subserve certain brain functions scattered throughout different regions that have temporal and bandwidth limitations); highlights targets/regions of interest (activates very specific areas of the brain that are involved in controlling specific functions based upon a “mental strategy” as the Peres et al. (2000) team put it); and can focus attentional resources as in a “sector scan” with high resolution in a given area to accomplish the desired strategy. As noted earlier, experts are far better at accomplishing a desired strategy than novices in the tasks at which they are practiced that involve cognitive/motor/visual resources presumably because experts can implement the strategy more efficiently with less attentional and working memory resources being “drained away” by the tasking. However, if a “sector scan” of focused attention occurs, then there is some sacrifice of a more global “picture” of what is going on all around on the other parts of the cognitive “screen” (other parts of perception/working memory, general situation awareness, etc), in order to achieve “focused attention” [Author’s note: credit for the “sector scan” idea as an aspect of the radar beam model must be shared with Professor (Col) P. T. Kemmerling as this was discussed and conceptually refined over several conversations about these areas in 1999 as this work was being revised]. This hypothetical “radar beam” notion of cognitive/attentional “sweep” throughout areas in the brain that control areas such as perception and working memory is an outgrowth of the already cited situation awareness literature, attention studies, neuronal group theory and very recent functional brain imaging studies that link attention and task actions to brain activity (refer again to Figure 12 and to Figure 24 on the following page for an example). Note that the “radar beam” approach to explaining aspects of this research relates to dividing attention in a more general sense while accomplishing multiple tasks that may involve peripheral vision. By comparison, the previously discussed “tunnel vision” and “general interference” models relate most directly to how the peripheral vision system more specifically performs on a given dimension across a variety of retinal eccentricities under certain conditions of task loading, or workload.
**Figure 24.** The same stimulus activates different brain areas according to whether the participant is paying attention to that stimulus or not. The computer-enhanced coronal plane scans show:

A. At left—the brain of a person who is hearing speech, but concentrating on their breathing.

B. At right—the same person actively listening to the words being spoken. Note how many more areas of the brain are now activated (from Carter, 1998).

Returning directly to commentary on how this attention-focusing radar beam analogy might be a partial explanation for the peripheral DVA results in this study, it could postulated that the attentional “radar beam” has to stay more focused on performing the Tracking Task adequately at the harder levels of Difficulty—thereby leaving a bit less cognitive reserve for “attending to” the visual periphery as the secondary task. The degrading effect, however, is observable but less than impressive as shown in Figure 17 until the fastest Velocities and/or the most difficult Tracking Task level is encountered (for example refer to Figure 21). Recall that the hardest level of Tracking Task Difficulty occurs in a region of perceived difficulty approaching a value of 7 on a “Total Estimated Tracking Difficulty” scale of 1-10. Presumably, as the attentional/cognitive “radar beam” has to focus more energy (attention) on the primary task with the foveal/motor neural control center, there are fewer attentional resources left over with which to attend to the visual acuity task in the periphery.
This touches upon the broader concept of general situation awareness where the limited attentional resource pool affects “working memory” components such as perception, interpretation, decision making and action guidance, among others (Endsley, 1995).

Terms such as “effective attentional field,” “attentional resource pools,” and “functional visual field” are used by researchers loosely, and often interchangeably. Edwards and Goolkasian (1974) have suggested that there may be several functional visual fields based upon task complexity, while other researchers (Ikeda and Takeuchi, 1975; Williams, 1995a, 1995b) have focused on the sensitivity of the functional field of vision (with static targets) to the overall higher level information processing demands. Interestingly, William James (in 1890) spoke of similar visual attention regions where there is a focus, margin, and fringe areas of the visual field (James, 1950). Such thinking about the functional visual field implies a functional visual gradient in which attentional/visual resources decrease from the attended-to area to other less resolved parts of the visual field. Summarizing the attention literature as related to visual performance, Eriksen and St. James (1986, p. 235) wrote:

In the introduction, we proposed a principle of optimal allocation of attentional resources. This principle recognizes that the level of task performance is not due solely to the amount of attentional resources directed to the task. Level of performance is significantly determined by sensory factors, motor factors, and processing mechanisms other than attention. In other words, there is an optimal level of attentional resources for a given task and further attentional resources devoted to the task will not result in an improvement in performance. Subjects have learned from experience to make good judgments as to the optimum amount of attention that will benefit a given task.

The attentional/cognitive “radar beam” model might be thought of conceptually as activating certain brain sub-regions responsible for integrating these disparate tasks. However, the activated areas in the brain involved in bringing peripherally presented acuity stimuli into consciousness apparently require a higher degree of attentional “radar beam” energy to stay “lit up” in our consciousness in order to accurately perform a peripheral acuity discrimination task. To use an electro-optic analogy, this postulated peripheral visual behavior is like the short-persistence phosphors that need the controlling electron beam (attention) to sweep over them more often to be seen on a visual display as compared with longer persistence ones.
In many respects this hypothetical model of cognitive/attentional behavior is a finely-tuned attribute of the nervous and visual systems. This is the case because if the brain regions activated involved in organizing information coming from the visual periphery were always in the “on” mode, the limited information processing capability of the brain’s visual system might quickly be overwhelmed since the foveal areas of vision are so predominant in our consciousness.

An example of a related experience is termed “vection.” A type of vection occurs when objects moving in the visual periphery “capture” our attention and give us a powerful temporary sensation of motion, yet no movement is in fact occurring. (A car next to yours backs out of the grocery lot, and you feel as though your car is moving forward for a moment—until the attentional “controller” gets readjusted and de-weights these sensations.)

The functional foveal/parafoveal visual region comprises only about + 4.5 deg of visual angle at most (depending upon the author), but processes much visual information due to the cone density in this region. From an information processing standpoint, it is hard to imagine adding another 70-some degrees of dense visual information to be processed efficiently and completely all of the time (even with less cone density), and still be able to function adequately foveally given that there are a finite amount of information processing resources available. If this is true, even much less reserve would be available under such conditions with additional verbal and cognitive intrusion(s) that add to the proposed attentional “radar beam’s” already high workloads (see related papers supporting some aspects of this intrusion notion by Webster and Haslerud, 1964; Williams 1982, 1988, 1995a,b).

The conceptually proposed attentional “radar beam” that illuminates areas in the consciousness during multi-tasking not only has a limited sweep speed (time-sharing capability), but also a finite amount of “energy” when it is focused to a given attentional area(s). The fact that some neuronal groups subserving certain cognitive-perceptual-motor functions are likely more easily activated, and more automatized, than others should come as no surprise (e.g., the neural “program” most people use to drive a vehicle is very quick, easily activated, and easy to use after it is well-learned). When the attentional “radar beam” is forced to attend to a wider area in the visual periphery in the case of a random Direction target, or when the primary Tracking Task being accomplished becomes moderately difficult, peripheral visual performance can suffer (this concept relates most directly to the “zoom lens” and
“spotlight” models discussed earlier—for a complete discussion refer to Eriksen and Yeh, 1985; Eriksen and St. James; 1986). How the postulated attentional radar beam carries out its functions can be linked to the Peres et al. (2000) concept of “mental strategy.”

Acuity as a Function of Target Presentation Direction

The Main Effect and Some Geometric Factors. The next significant main effect to be discussed is the Landolt C Fixed or Random (F/R) Directional Modality of Presentation test (F(3, 135) = 17.66; p < .001). Figure 16 graphically highlights these results, which are presented in Table 6. The 1.92 mins of arc difference found between the F/R levels is small, but significant (p < 0.01). This supports the notion of Research Question 2a, that the targets appearing from a random Direction of presentation would be harder to resolve than those beginning from a fixed Direction of presentation case.

In the fixed Direction case, the Landolt C target appeared on the left hand side of the screen and traveled to the right at the distances stated in Appendix F, Table F2. From the distances traveled in 0.5s, a velocity can be easily computed for either the 0.5s of exposure, or extrapolated to 1.0s as noted in Table F2. Most researchers report visual angle velocities in terms of deg per 1.0s as an unwritten convention, even if the target only appeared for 0.5s (as was the case in this experiment).

As previously discussed, to test the random direction of presentation case, a Landolt C target appeared at any one of four corners of an “>” pattern, then traveled either to the right and down, to the right and up, to the left and down, or to the left and up. Therefore, the slowest Landolt C target moving from the right to the left began its path from either of the right hand corners a bit closer to the left side of the screen than did the fastest Landolt C emanating from the right side. This ensures that the Landolt C targets always ended at the same two points on the left hand portion of the VDT screen during the random direction of presentation case. The Landolt C’s traveled the “>” track on the VDT screen at an angle ± 45 deg with respect to the horizon, as might be expected for a symmetric “>” travel path.

The two upper left hand corners of the “>” pattern that the C’s originated from was 7.62 cm directly above (or below) the position of the starting point for the horizontally traveling Landolt Cs (in the fixed direction case). Given that the geometry of the fixed versus random Direction of presentation was somewhat different, the possibility exists that such a difference
in geometry might possibly contribute significantly to the statistical F/R Direction of presentation results.

Computations based upon the changes in visual angle produced by the geometric differences between the fixed and random (F/R) Direction of presentation modes reveal that in the **worst-case scenario** (upper/lower left hand corner points for target geometry in the “>” random motion path) the visual angle change in Landolt C target gap due to this geometric effect was between approximately 0.11 mins of arc (for the smallest Landolt C gap) and 0.92 mins of arc (for the largest Landolt C gap) in apparent size difference. This apparent size change occurs because of a difference in the eye-screen distance of slightly more than 56 cm in the random Direction target starting position, as compared to the middle of the target track for the horizontal path at which the observer’s eye was positioned in the fixed Direction of presentation case.

This estimation was obtained by computing the extra geometric distance from the eye’s position, which is set in the middle of the 14.62 deg/s velocity track, to the most extreme position for the Landolt C random Direction of presentation target origination point in the upper/lower left hand corners of the “>” target pathway. Given that the targets in the random Direction case are moving to/from a very slightly less eccentric position during their travel (on average) as a result of the geometry just considered-- all other factors being equal-- it would be that the targets would therefore be easier to see than this worst case scenario from a target eccentricity standpoint (not withstanding the slight decrease in apparent size just noted). So, despite the random Direction of target presentation mode being very slightly less eccentric in the periphery due to simple geometry, the F/R target acuity results are still nearly 2 mins apart when collapsed across all Target Velocities, Tracking Task Difficulty levels, and Eccentricities. Even accounting for the slight geometric differences just highlighted that may add to, or take away from, the ability to accurately perceive a peripheral target, the other attentional factors previously discussed are more important in terms of the experimental results. In sum, these results show that the random Direction of presentation case is slightly more difficult to “see” than the (only) horizontal left-to-right across-the-screen movement of the “fixed” Direction of presentation case.
**Further F/R Direction of Presentation Commentary.** The interaction highlighted in this section is the significant Velocity by F/R Direction interaction (F (3,135) = 15.48; p < .001). This interaction is highlighted by Figure 20 with the Direction of target presentation as the parameter where Target Velocity is the other interacting term. The acuities needed to see a target for both the fixed or random Direction of presentation cases as a parameter generally increase, and diverge, with increasing Target Velocity. The reduction in visual acuity would be expected with faster targets appearing in the periphery from less predictable positions (the random case), as opposed to more predictable fixed Target Direction of presentation case. This conclusion therefore is in support of the concept contained in Research Question 4d.

The Sidak and Least Significant Difference multiple comparisons found significant differences in the two Directions of presentation cases at both the 14.62 deg/s and 24.4 deg/s velocity levels. Here, by the time the hypothesized attentional “radar beam” gets around to “paying attention” to a fast-moving randomly originating target in the visual periphery, it is nearly gone, as compared to the easier-to-see fixed modality of presentation case. Thus, there is (possibly) effectively less time to visually “attend to,” then peripherally process a faster moving target randomly presented Landolt C target. Attention has to be “spread out” over a larger area for the random Direction of presentation targets as compared with the fixed Direction case.

**Receptor Heterogeneity Factors.** The effect of receptor density heterogeneity must always be kept in mind when engaging in visual studies, particularly with regard to those being conducted in the retinal periphery. As was discussed earlier, the cone receptor density is not spherical across all meridians of the visual system. Generally, where receptor density changes, performance changes follow. This is demonstrated by threshold detection isograms by McCollgen (1960) for the detection of rotary movement across a variety of meridians in the visual periphery (refer to Figure 7).

Based upon these isograms, and other researchers’ stated similar concerns for such effects (notably Brown, 1972a), it is clear that at a given eccentricity in the right hemifield, any substantial target position change results in a heterogeneous population of receptors being activated. For a Landolt C moving over a path purely along the horizontal meridian it appears that a shorter distance must be traversed by the image on the retina to stimulate the same
gradient of receptors as compared to movement along a diagonal meridian, which moves across the changing densities of receptors less quickly. The relative lack of change of the receptor-bed density may be partially contributing to the reasonably good acuities seen in the random Direction of presentation case (general support for this comment can be found in Brown’s 1972a study).

**Velocity Effects**

**Discussion of the Main Effect.** The main effect of Velocity collapsed across Eccentricity and Target Direction of presentation was significant ($F(3,135) = 68.53; p < .001$). A multiple regression performed on Target Velocity revealed that a quadratic equation is the best fit to the curvilinear relation seen in Figure 19 between the two variables. The quadratic equation that resulted from the regression accounted for nearly all of the variance (0.051) that was attributable to the Velocity main effect (refer back to Table 2; Appendix B for statistical results).

The general quadratic trend of the main effect of Velocity as shown by Figure 19 had a value for visual acuity of 25.4 mins at 0.0 deg/s, then a better acuity of 24.62 min at 4.88 deg/s, followed by rapidly worsening acuities for increasing Velocity values at 14.62 deg/s and 24.4 deg/s. Neither the Sidak nor more liberal Least Significant Difference test revealed a significant difference between the 0.0 deg/s and 4.88 deg/s velocity conditions. Differences between the other levels on a multiple comparisons basis with both of these tests were either all significantly different (LSD Test), or very nearly so (Sidak Test) as Table 8 highlights.

Other authors have reported increased acuity in the visual periphery for slowly moving targets. Ercoles and Zoli (1968) used only two observers and oblique Landolt C targets that varied in size from 14-34 min of arc. They found that the maximum value of contrast sensitivity deepened and shifted to slightly higher velocities as the experiment moved from testing in the fovea, then out to 1 deg and 2 deg of visual eccentricity. The term “deepened” is used in this sense to mean that the contrast sensitivity curve is steeper around each optimal velocity. The displacement of the peak of one of the participant’s curves clearly moved from a target velocity of 2 deg/s for foveal fixation, to 3 deg/s at 1 deg of eccentricity, then to about 3.5 deg/s at 2 deg of eccentricity. Brown also (1972a) found that targets moving at 5 deg/s were significantly easier to see with the trend becoming more apparent as visual eccentricity
increased to 10 deg of visual angle (refer again to Figures 9, 10). The results from this study’s slowest moving velocity (4.88 deg/s) trend in the same direction of better acuity for a slower target. That is why the slowest velocity for this research project was chosen to be nearly 5.0 deg/s.

**Further Velocity Interactions/Commentary.** The interaction of Velocity by Tracking Task Difficulty level, was found to be significant (F (9, 405) = 2.11; p < 0.028) thereby providing support for the Research Question 4c, that increasing Target Velocity would have an interaction with the Target Direction of Presentation. As Table 10a and Figure 22 reveal when analyzing the simple effect of Tracking Task level across the various Target Velocity conditions, there seem to be a few trends worth noting. First, only the 0 (monitoring only) and 3 (hardest) Tracking Task levels of Difficulty were nearly parallel to each other across all of the Velocities tested. Neither the Least Significant Difference nor Sidak tests found any significant differences among the various Tracking Task Difficulties at the 0.0 deg/s velocity condition (refer to Table 10b, 10c). However, the results obtained for the Tracking levels appear to diverge quickly as the Target Velocity becomes 4.88 deg/s. The multiple comparisons tests at this Velocity condition from Table 10b, 10c reveal that there are likely significant differences between the moderate level (2) of Tracking Task Difficulty and the monitor (0), or easiest (1), levels of Tracking Task Difficulty. Some of these results are surprising and not easily explained. The trend that would be expected would be for the curve associated with a Tracking level of “2” to yield acuities somewhere between the values found for a Tracking level of “3” and “0,” or “1.” However, the moderate level of Tracking Difficulty (2) resulted in worse acuities than any of the others (3, 1, or 0). Furthermore, the Velocity condition of 4.88 deg/s for a Tracking level of “2” resulted in the only worsening acuity of the group as compared to generally improving visual acuity for the other Tracking levels. In sum, the results from Tracking level “2” at the 4.88 deg/s speed are largely inexplicable. Perhaps the eyes are tracking the foveal target at a non-optimal speed back and forth (over a short time) so that a less optimal number/geometry of peripheral receptors are stimulated for this Velocity (4.88 deg/s) as compared to the other Tracking Difficulty levels.

At the next highest Velocity level (14.62 deg/s), all of the tracking task level acuities begin to somewhat converge toward each other. The Sidak and Least Significant Difference
tests do not reveal any significant differences in acuities between the related Tracking Task Difficulty levels found at this Target Velocity condition.

At the fastest (24.4 deg/s) Target Velocity, the most difficult Tracking values once again begin to diverge and begin to yield worsening acuities as might be expected. The Least Significant Differences test for multiple comparisons reveals meaningful acuity differences between the Tracking Task levels of 3, 1 and 3, 2 at this velocity. The more stringent Sidak test highlighted no statistically significant differences at any of the Tracking Task Difficulty levels for this Target Velocity condition.

**A Spatiotemporal Peripheral Visual Integrating Hypothesis**

During the data collection phase of this experiment the participants consistently made errors of judgment with regard to the Landolt C orientation. Often the observers reported that they were “fairly certain” that a moving target was oriented in a particular direction when in fact it was oriented in a different direction. Recall that these observers were using binocular vision and were seeing moving targets that would theoretically lower the chance of an aliased signal from occurring (in the classical sense per the literature review). Based upon many thousands of reported observations, targets moving from the left to the right along the horizontal meridian were much more often confused if the Landolt C gap was open to the right or left, as opposed to the gap being open in the up or down position. Targets moving to the right, with the gap opened to the right, were most likely to be confused by being occasionally called “left.” Prestrude (1987) commented on somewhat similar Landolt C orientation choice errors in his foveal DVA work.

Landolt C targets with an up or down orientation were often misclassified with the opposite direction of gap orientation. Observers would report when questioned, “I do not know whether it was oriented up or down, but it was one or the other.” For the Landolt C targets traveling horizontally with the gap up/down, it was as if the observers were spatially integrating a light-intensity signal over a very short period of time, and then evaluating that “smeared” light signal to some extent for where the most lightness or darkness was in the peripheral vision path. Then, they based their orientation judgments on how that light/dark pattern affected the perceived shape of the Landolt C. In the up/down-oriented case, the “less lit (least light-smereed) area” was where the Landolt C gap was determined to exist. Similarly,
if a target was oriented with the gap opened to the left/right, a lightness/darkness pattern was also sought out at a given brief moment in time when the attentional resources were fully available for the peripheral system. However, in this left/right case the observers would often only be able to say that the target was not in the up/down position, but could not accurately judge whether the moving target was oriented to the left or right.

To the experimenter (this author), after noting that a repeating pattern of errors occurred in nearly every participant-- what appeared to be occurring in the peripheral visual system was a pattern where the eye-brain interaction functioned in a spatial signal integrating fashion over that small time interval in terms of lightness/darkness patterns. The pattern the visual system appeared to evaluate could be called an image “smear,” with the lightness/darkness image pattern smeared onto the retina as it moved spatially over a short time interval. The concept that visual signals could be integrated over space and time is not new for the foveal visual system (Heinen and Watamaniuk, 1998), but is rarely, if ever, discussed in the manner described here with regard to the peripheral visual system under dynamic target conditions. Authors such as Watson, Ahumada, and Farrell (1986) have described a foveal psychophysical “Windows of Visibility” based upon the frequency spectrum content of two-dimensional “spatio-temporal response surfaces,” but have not yet extended those analyses to the dynamic peripheral visual detection realm. It might be instructive to do so, based upon the following additional commentary about what was observed in the time-space domain during the data collection phase of this experiment.

Using a spatiotemporal integrating approach it is reasonable to speculate qualitatively on what the spatiotemporally-integrated perception pattern might be for a target moving in the “>” pattern (random Direction of presentation case) from the upper left hand corner to the lower right hand corner in a diagonal pathway. The prediction of target orientation from an integrating spatiotemporal lightness/darkness signal processing model standpoint would be in this case that a Landolt C target with its gap oriented to the right would appear “smeared” as a Landolt C with the gap facing upward. This is because the “least lightness smear” pattern for a Landolt C target oriented to the right in the periphery moving down and to the right in a diagonal fashion would be along the front and leading edge of the target as it traveled along the path. If this hypothesis is true, then that target would sometimes be mistaken as a target with the gap oriented upward, since the eye would perceive the least light energy over a short track
as being from the front leading edge of that target. Deciding then whether the target is oriented to the right, or up, is the key problem. Similarly, a Landolt C with the gap oriented to the left, but moving down and to the right would quite often be misperceived as a target with the open gap facing upward also. Likewise, a Landolt C target with a left gap opening traveling from the lower left hand corner to the upper right hand corner might occasionally appear as a downward-oriented percept.

This type of peripheral spatiotemporal integrating pattern is postulated to have occurred on many occasions and seemed most prominent at the higher velocities. After watching the participants’ “peripheral retinas” process months of moving Landolt C targets, this author has concluded that under these experimental conditions the peripheral retina acts as a very short-period, open-shutter camera, that takes blurry “snapshots” of lightness/darkness patterns, then after some fairly sophisticated post-receptor neuronal processing and/or peripheral spatial frequency domain analyses arrives at fairly well-defined percept output as a “best guess” of Landolt C target orientation (see for example comments on evaluating a Landolt C target from a frequency-domain point of view by Bondarko and Danilova, 1997; Galvin, O’Shea, Squire, and Govan, 1997). So, the visual system’s final determination of peripheral target orientation is a complex combination of simple receptor sampling in a signal processing sense, along with some sophisticated further neuronal level post-receptor processing, followed by a cognitive overlay that results in further processing of the stimulus depending upon a variety of attention-related factors. All of this yields an output based upon the observer’s perceived understanding of how to accomplish the defined task objectives (a “mental strategy”), given the task complexity and contextual visual and workload elements surrounding the task to be completed.

It would be interesting to design an experiment to test this spatiotemporal integrating hypothesis based upon the predictions contained in the previous text in order to test how the peripheral visual system “processes” moving targets.
ANECDOtal COMMENTARY ON DISTRACTION
AND THE MINI-INTRUSION STUDY

The Problem of Distraction. Participants in this experiment through many trials seemed very prone to having their peripheral processing capabilities compromised by any outside distracting influence. Such distractions appeared to upset the optimal function of the attentional/cognitive “radar beam” that was attempting to optimally sweep the neural areas controlling peripheral visual processing that were required to “get the peripheral visual job done.” In fact, it was repeatedly noticed also that a brief change in workload/task loading which caused the hypothesized attentional radar beam to momentarily switch focus often led to the comment (when the observer was asked in what direction the target was oriented), “What target? I wasn’t paying attention.” Anecdotally, this situation occurred quite often despite the Tracking Task Difficulty level, Eccentricity, Velocity, or the Target Direction of Presentation. Notably, however, this momentary refocusing of attentional radar beam energy did seem to be target velocity sensitive (presumably because there was less time for the attentional “radar beam” to fully access the peripheral visual center as the faster targets “flew” quickly by).

A loud voice in the hall, door slamming, surprise intrusion into the room, or unexpected movement by the experimenter, all seemed to literally reset the participant’s attentional/cognitive focus (attentional “radar beam” ?) momentarily. As attention was refocusing momentarily, this often resulted in a completely missed target trial. After a quick recovery the cognitive resources appeared to realign the attentional “radar beam” sweep function across the required neuronal areas, and optimal time-sharing of the various resources needed to accomplish the task resumed. More research into what attributes of such distracting factors cause decrements in peripheral DVA performance and the countermeasures to blunt them would be useful. It is possible that such research might have real-world safety implications (e.g. in driving, flying scenarios).

Intrusion. Aside from the brief distractions that momentarily reoriented the attentional/cognitive processes of the participants, another factor which might be termed verbal/cognitive intrusion was noticed to negatively impact the observer’s ability to adequately process peripheral stimuli under these experimental conditions. Verbal intrusion (another form of distraction perhaps ?) was noted to cause a decrement in peripheral performance when the
participants were asked a question with the Landolt C targets appearing in the visual periphery. This occurred from time to time during particular aspects of the pilot studies. Anecdotally, more difficult questions where some depth of cognitive thought was required seemed to have the most detrimental effect on the participants’ ability to process peripheral stimuli. Any such task that required an observer to mentally “picture” a problem scenario such as adding two numbers that required “carrying” a third number to achieve an answer while accomplishing the primary tracking task also substantially eroded peripheral visual performance. Webster and Haslerud (1964, p. 272) noted a somewhat similar trend and commented:

Another important finding of the experiment is that both foveal and auditory counting tasks had an equally adverse effect on peripheral visual perception. If only the foveal task had produced an adverse effect, it could have been argued that retinal peripheral inhibition was the cause. However, the mental counting task rather than the sense modality was responsible for the adverse effect….

Since it is the peripheral task that suffers deterioration when competing with a foveal or auditory task, the validity measurements within peripheral limits needs reconsideration. The results of this experiment make it impossible to assume that an object located inside the peripheral limit is necessarily perceived by an individual involved in some other task. Rather it is necessary, whenever the peripheral region is being utilized to determine the specific effect on peripheral perception of the presence of a second task. In such areas as driving, athletics, and flying, where peripheral vision is important there are definite practical limitations.

**The Mini-Intrusion Study.** The notion of intrusion was tested in a subset of participants if there was any time left during the experimental session. These participants accomplishing the exact same tasks as before, except that they were asked “intrusive” questions in a completely randomized fashion across all Velocities, Eccentricities, and Directions of Target Presentation, and asked to answer the question as quickly as possible. The asking of the question was timed such that as the participant was thinking of an answer, the Landolt C target appeared. Questions asked were those where a memory search was required, but not too difficult, and included the following:
What was the first concert you went to without your parents present?
Name one friend who was with you at that concert?
What was your best friend’s middle name in High School?
What was the first pet you had (or its name)?
What is your mother’s favorite food?
What was your favorite song (or band) your senior year of High School?
etc. (with additional questions of similar difficulty).

These data were analyzed in a 2 x 2 Contingency Table for whether or not verbal intrusion was present, and for whether or not the participant made a correct Landolt C response. An “incorrect response” with “verbal intrusion” cell count was assigned where the Landolt target orientation was missed with verbal intrusion present. The rules to permit assignment in the intrusion/incorrect contingency cell were that participant had previously made a correct response for that same treatment condition in the “regular” portion of the experiment of at least two gap widths smaller than the target being labeled as a “miss” in the intrusion mini-study case. Thus, the criteria for a “miss” were easily analyzed and fairly conservative since the “basement” of possible allowable Contingency Table entry responses was set at two gap widths above their comparable acuity performance in the “regular” study. Occasionally, a participant would miss a target when there was no verbal intrusion during the intrusion mini-study, just as they did in the “regular” data collection phase of this study. This was counted in the Contingency Table as an incorrect response with “no intrusion” (refer to Figure 25). The basement for the correct response with no intrusion was again set at two gap widths above the participant’s previous (“regular study”) same treatment condition acuity performance to be consistent. This was because near threshold, target orientation determination errors began to occur as per the protocols discussed earlier.

The Kappa statistic was used to measure the degree of agreement along the diagonal, i.e. no intrusion/correct responses and intrusion/incorrect responses. The amount of agreement was compared for the two slowest velocities, and for the two fastest velocities, collapsed across all of the rest of the experimental conditions. Table 11 contains the individual cell counts in the Contingency Table for this Mini-Study. As Figure 25 and Table 11 show, the two slowest velocities and two fastest velocities both had a reasonable degree of agreement along the
diagonal, meaning that the no intrusion/correct responses and verbal intrusion/incorrect response outcomes were somewhat associated with each other along the diagonal (Agresti, 1990).

The Kappa statistic measures the degree of agreement on a scale from zero to one. When two responses tend to agree, then most of the counts will fall along the diagonal. A Kappa of zero indicates that the responses are no more diagonal than expected from chance alone from independent responses. As noted in Figure 25, a Kappa of 0.40 – 0.75 represents good agreement along the diagonal. Both the two slowest and two highest velocities showed “good agreement” for intrusion being associated with missing Landolt C targets. Interestingly, the higher of the two velocities had a larger association of agreement (Kappa) along the diagonal than did the lower two velocities. This suggests that there is a possibility that higher velocities were more affected by intrusion and/or distracting influences. This idea will hopefully be more fully tested in a future study under similar conditions as have been presented in this peripheral DVA study.

Future studies such as these have the reasonable possibility that they will at least partially answer why people driving with car cell phones appear to have higher accident rates, and why pilots that are involved in a large majority of serious accidents are often “distracted,” and exhibit “channelized attention” according to formal military accident reports. The loss of some performance capability by the peripheral visual system may be underlying a portion of these accidents under intrusive or distracting circumstances.
Kappa Statistic Results for Intrusion
Mini-Study Contingency Table

Verbal Intrusion

<table>
<thead>
<tr>
<th>Response</th>
<th>No Intrusion</th>
<th>Intrusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct Response</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incorrect Response</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Kappa Statistic = K
Measures the degree of agreement along the diagonal

\[ K = \frac{Po - Pc}{1 - Pc} \]

Po = the sum of the observed proportions in the diagonal cells
Pc = the sum of the expected proportions in the same cells

Slowest 2 Velocities: KAPPA = 0.53 Std Err 0.04
Fastest 2 Velocities: KAPPA = 0.63 Std Err 0.04

KAPPA values meaning: < 0.4 poor agreement; 0.4 - 0.75 good agreement; > 0.7 excellent agreement.

Figure 25. Kappa Statistic computations and how the values obtained relate to agreement across the contingency cell diagonal.
Table 11.
Chi-Square Cell Counts and Computations for the Kappa Statistic Along the Contingency Table Diagonal.

### A. Kappa Statistic for the Two Lowest Velocity Conditions (0.0 and 4.88 deg/s) Combined.

<table>
<thead>
<tr>
<th>Cell count Expected count Cell Chi-square</th>
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<th>Intrusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct Response</td>
<td>455 398.33 8.06</td>
<td>75 131.67 24.39</td>
</tr>
<tr>
<td>Incorrect Response</td>
<td>26 82.67 38.85</td>
<td>84 27.33 117.52</td>
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</table>

Kappa = 0.53 ± 0.04; N = 640 total observations


<table>
<thead>
<tr>
<th>Cell count Expected count Cell Chi-square</th>
<th>No Intrusion</th>
<th>Intrusion</th>
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</thead>
<tbody>
<tr>
<td>Correct Response</td>
<td>443 368.98 14.85</td>
<td>50 124.02 44.18</td>
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<tr>
<td>Incorrect Response</td>
<td>36 110.02 49.80</td>
<td>111 36.98 148.16</td>
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</table>

Kappa = 0.63 ± 0.04; N = 640 total observations.
CONCLUSIONS

The results of this four factor experimental research design generally parallel those of previous peripheral DVA studies that were much more limited in scope for this region (25-55 deg Eccentricity) of the visual field. All of the main effects in this study of Eccentricity, Target Velocity, Direction of presentation and Tracking Task Difficulty levels were found to be statistically significant at $p < 0.05$. A set of research questions were evaluated based upon a review of the literature, and research goals were set forth with regard to accomplishing this study. Some of the additional results of this study indicate that under these experimental conditions, peripheral DVA tends not to follow a “tunnel vision” type of model for changes in peripheral visual performance with increasing Eccentricity under greater Tracking Task Difficulty levels.

The faster Velocity targets (14.62 and 24.40 deg/s) were all more difficult to accurately perceive in the visual periphery as compared to the slower (0.0 and 4.88 deg/s) ones. Targets emanating from more diverse positions in the periphery were more difficult to see, as would be expected from past literature related to anticipatory and peripheral vision attention factors. Similarly, as the difficulty level of a Tracking Task increased, visual acuities gradually worsened in the periphery, but not as quickly as might have been expected given the subjective “Total Estimated Difficulty” of the Tracking Task. This suggests that while a manual Tracking Task with foveal loading does affect peripheral visual performance at the velocities tested in a significant way, the effect is not quite as robust as one might expect given the literature review and perceived difficulty of accomplishing the task in this experiment. In a sense, the Tracking Task seems to become partially “automatic” after adequate practice trails. This relative lack of sensitivity to Tracking Task level in this experiment could be due to a range effect, since very difficult Tracking Task Difficulties could not be assigned and have the participants successfully achieve the criterion set up for completion of the primary Tracking Task trials.

There were two interesting two-way interactions of statistical importance highlighted. First, the interaction of Target Velocity by Target Direction of presentation revealed that as the Target Velocities increased, the randomly-appearing targets became more difficult to see than the fixed Direction targets. The implication of this result is that being able to better guess the position of a moving target appearing in the visual periphery seems to focus the attentional
resources to that area, resulting in better acuities for these targets, particularly as the target speeds increase. Interestingly, the other significant two-way interaction of Target Velocity by Tracking Difficulty level had a mixed result that was hard to explain (particularly at the level of the slowest moving target), except to comment that at the most difficult Tracking level and the highest Velocity, observers did not see the moving targets as well as they did at the lower levels of Tracking Task Difficulty.

The lack of a statistically significant interaction for Eccentricity by Tracking Task Difficulty may be interpreted as the lessening of evidence for a “tunnel vision” model of peripheral visual performance that has been often debated in the peripheral vision research literature. Stated simply, this means that there was a steady (not greater) reduction in peripheral visual performance while accomplishing the more difficult Tracking Tasks that did not appreciably change peripheral DVA values with respect to each other as visual eccentricity was increased (refer to Figure 11).

One aspect of this study that is difficult to quantify, and assess the implications of, is the question of motivation. Attention and motivation are inextricably linked. Highly motivated individuals are generally more stimulated from an overall nervous system/reticular activating system standpoint, and therefore generally perform better on tasks that require higher degrees of attention components to complete successfully. Participants in this study were told to “just do the best you can” on the study tasks. Other than credit toward a better class grade, or a small ($ 5.00 per hour) monetary reward, there were no real incentives built into the participants’ performance except to please the experimenter and accept the challenge of accomplishing the Tracking Task and reporting the targets seen in the periphery as best they could. Given that the performance on such tasks is quite related to attention (which is clearly affected to some degree by motivational issues), it would be interesting to create an experiment where greater extrinsic rewards are offered in order to test for “better” peripheral visual performance.

There is a hint in these data that motivational issues could have been a minor factor in the acuities recorded. The majority of the individuals that volunteered to participate in this experiment were female (32 of 50). Male participants were harder to recruit. The experimenter was a 37 year-old male for all of the sessions—whether the participant was male or female. Females exhibited a slightly better performance overall than males that was
The literature review suggested that for foveal DVA tasks, males generally have performed better in the past than females, perhaps due to better cross-training effects, more sports, etc. during the years in which those studies were conducted. However, in this experiment the females performed slightly better in a global sense for detecting moving targets in the periphery. Is it possible that the females were more motivated to perform better because of the male experimenter that was testing them? This motivational possibility cannot be ruled out, and it raises other interesting questions for future studies with regard to general motivational issues for peripheral vision performance. Again, in this experiment, participants were told to “Just do the best you can.”

There is very little data from previous peripheral DVA research in this region (25-55 deg) of the visual field, and none under systematically controlled levels of a Tracking Tasks, Target Velocities, and Directions of Target Presentation. The results of this study have implications for peripheral target detection, display design, and for some general assessment of how well people “see” static and moving targets in the retinal periphery under conditions of manual tracking and other task loading.

Other relevant implications and extensions of this research include potential applications with improving safety factors for aircraft pilots, controllers, or other vehicle operators that must attend to a variety of foveal and peripheral stimuli while they are exercising manual tracking control. These notions are in the realm of what might be termed “peripheral visual awareness” and are discussed briefly at the end this work.

What was found to be interesting, however, was the occasionally surprising sensitivity of the peripheral visual system to any distraction or intrusion. This intrusion could take the form of a sudden noise, door opening, or even movement by the experimenter. It is a possibility that the hypothesized attentional/cognitive focus (“radar beam” analogy in this study) quickly re-focused on the novel stimulus, redirecting the (shared) locus of attentional focus away from the periphery for just enough time to allow the participant to occasionally miss the peripheral target completely. These observations also led to further examination of previous studies of cognitive loading/intrusion issues that revealed an association between cognitive intrusion and degraded peripheral visual acuity. These concepts were tested in a “Mini-Study” in this experiment by a 2 x 2 Contingency Table. A positive association was found between no intrusion/correct responses, and intrusion/incorrect responses along the
Contingency Table diagonal using a Kappa Statistic. The higher velocities appeared to have a slightly stronger association, based upon the Kappa Statistic, than did the lower velocities. Hopefully, some of these ideas with regard to intrusion and/or distraction will be examined more fully in later research efforts.

Some of the “channelized” and “distracted” attentional states leading to a suggested decrement in “peripheral visual situation awareness” are next related together in a hypothesized framework of understanding where the interesting perceptual attributes and abilities of the peripheral visual system directly affect the safety and performance of human beings in visually and cognitively rich dynamic task environments. More research will be needed to explore the additional research questions raised by the results of this work with regard to the performance of the peripheral visual system under various states of task loading.

COMMENTARY, IMPLICATIONS, AND FUTURE RESEARCH

“Peripheral Visual Awareness” Issues

Other researchers have studied related areas that concern peripheral processing factors in vehicular environments that this study touches upon. One of these areas relates to the issue of car cellular-telephone calls and motor vehicle collisions (Redelmeier and Tibshirani, 1997). While the assessments of such accident data are a challenge to interpret (Maclure and Mittleman, 1997), there does appear to be evidence that there is an increased risk of an accident while driving and being cognitively involved (distracted) by a cellular phone conversation. At a basic level of analysis, driving a car is somewhat similar to accomplishing the Tracking Task in this study. Routine driving involves a nearly automatic visual/motor task until conditions either change abruptly, or become more difficult in general (e.g. heavy traffic, complex navigation in strange cities, etc.).

Drivers and pilots both foveate to obtain the majority of their information in order to make correct immediate/near-immediate decisions regarding their vehicular environment. Yet, drivers and pilots must also attend more carefully to the visual periphery under some conditions such as when changing lanes, negotiating heavy traffic, or for formation and low-altitude flying.
Vehicular operators only rarely collide with obstacles in their foveal field of view if they can be avoided no matter how task-saturated, since the data from central vision is directed so heavily into the forefront of consciousness in time to take corrective action. On the other hand, this author strongly believes that it is the targets in our visual periphery that are not attended to in time that occasionally result in an accident or collision. These targets from the visual periphery that end up “hitting us” may be the other vehicles around us, or the terrain “rising up” to meet the task-saturated low-altitude attack pilot. The question then becomes one of whether the hapless driver or pilot will become aware of the impending collision coming from the visual periphery in time to do something about it. This relates more broadly to the concept of situation awareness (see special edition of *Human Factors* on this topic; Gilson, 1995).

In general, the loss of “situation awareness” has been found to have several components useful for aircraft accident analyses including: channelized attention, distraction, and task oversaturation, among others (Lyons, Ercoline, Freeman, and Gillingham, 1994). “Channelized attention” has been discussed as becoming cognitively too focused to “see” the larger situation awareness environment (Sarter and Woods, 1991), leading to a host of potential problems (Hartman and Secrist, 1991), including accident and near-miss scenarios. Indeed, in a survey of F-16 Class A mishaps over a 10 year window in the 1980’s, Holland and Freeman (1995) found that 60% of the accidents were deemed to have “channelized attention” as a “definite contributor” to the mishap database. Fully 53% of the mishaps (of 59 total) occurred during low-level or maneuvering flight, thereby somewhat implicating the peripheral visual system from an attentional/cognitive “peripheral visual situation awareness” perspective.

Low-altitude high speed controlled flight into terrain due to the loss of situation awareness and spatial disorientation can be caused by a variety of sources, both physiological and cognitive, and thus has been one of the driving elements for the recent push toward automated Ground Collision Avoidance Systems (USAF GCAS/USN ANGEL systems) to protect the pilots from inadvertently flying “good” aircraft into the ground (Holland and Freeman, 1995; McCarthy, Demitry, Mapes, Albery and Holland, 1995).

Pilots and drivers alike may be trained to understand that as they become more cognitively task saturated, the likelihood of an accident will increase if they do not consciously alter their attentional focus (“radar beam”) to “pay more attention to” the targets/terrain in their
visual periphery that may hurt them. In other words, they need to learn to be able to enhance their “peripheral visual (situation) awareness” at the right times. Otherwise, in the absence of legislation to keep car drivers from cellular phone use in moving traffic, and state-of-the-art flight control systems for pilot protection, the major choice left is for more research into this problem with better education about how these perceptual processing issues that may be very safety-loaded for these populations.

Elements of this study with regard to manual tracking tasks, peripheral DVA, and intrusion have all been discussed with a wide variety of interesting possibilities for several lines of future research in this general area. Examples of such research would include: having a wider range of tracking/manual control difficulties represented, faster target velocities, and a host of distraction and intrusion studies to better tease apart what the most important components are for maintaining (or degrading) peripheral static and dynamic visual performance.

With the new capabilities for functional brain imaging as recently reported by Peres et al. (2000), it would be interesting to perform aspects of these highlighted suggested studies to try and assess what parts of the brain are involved in maintaining a high degree of peripheral visual performance (and under what conditions). Knowing these pieces of the puzzle may not only yield a better understanding of what makes the human brain be “attentive” to certain stimuli, but may also allow for interventions to be developed which my save lives in very high-performance, time-pressured dynamic visual environments from a human factors and safety engineering standpoint.
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Hueck, A.F. (1840). Von den grenzen des sehvermögens. Müller Archives fur Anatomie, Physiologie und Wissenschaftliche Medicin (pp. 76-81). (Absolute limits of the ability to see. Müller’s Archives of Anatomy, Psychology and Scientific Medicine, pp. 76-81).


APPENDIX A

Additional Factors That May Impact Foveal DVA Research Results

There are several topics of concern that researchers have highlighted in the foveal DVA research area that also can potentially impact DVA studies.

**Reliability of Target Types.** Miller and Ludvigh (1962) were concerned about the reliability of Landolt C targets for DVA tests. Miller and Ludvigh found that at even the highest velocity of 110 deg/s the result of the Pearson product-moment coefficient of correlation was 0.99 for DVA determinations using their experimental approach. They used eight orientations of Landolt C’s as the dependent measure for dynamic acuity.

Miller and Ludvigh (1962) were also interested in evaluating the original test/retest reliability of Landolt C targets after 10 months had passed. Using a group of 120 subjects the Pearson product-moment coefficients of correlation between the test/retest were computed, and the index of dynamic visual reliability was found to be 0.87 for the parameter “b” related to DVA measures (recall that acuity = a+bx^3 where x is a dependent measure of increasing velocity).

**Target Orientation Effects.** For SVA measures, certain Snellen letters are more easily seen than others and have different amounts of information in them (such as the comparison between a Snellen “F” and “O”). The Landolt C was thought to control for this by testing not letter content, but in which direction the open part of the Landolt C was oriented. However, spatial frequency domain analyses of Landolt C’s reveal that the lower frequency components not related to the width of the Landolt C gap may be used by some to determine the orientation of a Landolt C target. Thus, orientations may be discerned that reflect a higher acuity value than is being “seen” as the open part (gap) of the Landolt C target (Bondarko and Danilova, 1997).

There are other concerns raised by some authors for DVA studies where Landolt C targets are widely used. Erickson, Hemingway, Craig, and Wagner (1974) using the method of constant stimuli reported that Landolt C gaps on the left or right hand side are much more easily seen on a downward moving path, than if gap was in the upper or lower left- or right-hand corner of the Landolt C. These authors reported that, in general, the Landolt C gaps on the upper left-or right-hand side had the highest error rates for the smallest target gaps and highest downward speeds. Targets in this study never moved only downward, and did not have gaps in the upper or
lower corners. Targets in this study moved down and to the right, down and to the left, etc. Reviewing the work of Methling and Wernicke (1968), Brown (1972a, p. 294) stated for foveal DVA studies: “To achieve consistent results the target gaps were oriented in the four oblique meridians; horizontal target motion diminishes the visibility of targets with vertically oriented gaps more than it does those with horizontally oriented gaps.” Some of Brown’s targets moved only vertically, hence his need for the downward/upward moving targets to have obliquely-oriented gaps for better results. Somewhat similar arguments could be used regarding the visibility of Brown’s horizontally moving targets. Following Brown, some other researchers have followed this approach by utilizing oblique Landolt C’s as well (Long and Garvey, 1988; Long and Riggs, 1991; Long and Roarke, 1989).

Frank (1977) was also interested in exploring the question of orientation effects from Landolt C targets. Frank analyzed subjects’ Landolt C choice-of-direction response biases for all target orientations. Correlating the response bias scores and the threshold size scores resulted in the following comment from Frank (1977, p. 12), “…[participant] response bias contributes to the error in the measurement of psychophysically derived acuity thresholds.” Prestrude (1987) also considered the question of Landolt C target orientation for foveal DVA determinations with the percentage of correct orientations as a dependent variable. He found that as the Landolt C velocity for right-to-left horizontal motion increased, Landolt C targets with gaps oriented to the right were more often correctly detected than those with gaps oriented to the left. Landolt C’s with the gap oriented upward or to the left were of intermediate difficulty to see. As commented upon earlier, several other authors (Campbell, Kulikowski, and Levinson, 1966; Quinn and Lehmkuhle, 1983) investigating the foveal visual system have noticed consistently that sine-wave gratings are less visible when oriented obliquely than when oriented vertically or horizontally. This decrement in visual acuity response to oblique sine-wave gratings becomes more pronounced as the spatial frequency of the target increases. This has been described in the literature as the “oblique effect.”

**Fixed versus Free Head Viewing.** Crawford (1960) of the Royal Air Force found that DVA improved with free- versus fixed-head conditions viewing conditions. Crawford used four
subjects in his experiment at velocities of 50 deg/s to 125 deg/s and exposure times from 0.4 to 0.7 s. Crawford noted a more dramatic improvement in DVA for the free- versus fixed-head viewing conditions for the two highest velocities (100 deg/s, 125 deg/s) and exposure times (0.6 to 0.7 s).

Despite the performance advantage of free-head viewing yielding better DVA results, a freely moving head also makes for a more difficult assessment of the actual angular velocity of the target upon the retina. For this reason Burg and Hulbert (1961) used a bite board. Brown (1972 a,b,c) found the use of a headrest somewhat less intrusive than a bite-board. Burg and Hulbert had found higher correlations between SVA and “free-head DVA” than for SVA and “fixed-head DVA.” Long and Roarke (1989) in a training-effects DVA study used fixed-head viewing conditions. Shortly thereafter, Long and Riggs (1991) questioned if fixed-head viewing conditions might be contributing to the differences between DVA and SVA measures. Long and Riggs then repeated an earlier fixed-head study (Long and Roarke, 1989) and found that the free head movement experiment improved foveal DVA scores over the previous fixed-head experimental condition.

The question of free- versus fixed-head viewing is an important one from an ecological and construct validity standpoint where DVA measures are concerned. Active and passive head movements during ambulation and vehicular travel are the rule, not the exception, so free-head DVA measures from a human factors perspective (and not just a purely psychophysical one as fixed head measures assess) would be useful for real-world applications of foveal DVA research. Fixed-head measures are required, however, for most peripheral visual acuity studies since the geometry of the experimental investigation needs to be controlled well enough to make an assessment of where the target appears in the retinal periphery.

In daily life, retinal image dislocation (“slip”) would dramatically degrade DVA if it were not for two inputs to the oculomotor complex to stabilize the image onto the retina. The first of these compensatory mechanisms is the vestibulo-ocular reflex, which results in eye movements that correspond to the amount of head acceleration that is signaled to the oculomotor control center by the vestibular apparatus (Benson and Barnes, 1978; Westheimer and McKee, 1975).
Appendix A-4

The second compensatory mechanism is engaged when visually perceived motion produces optokinetic and pursuit eye movements that work in conjunction with the vestibular-ocular reflex to stabilize the moving retinal image, and produce what is known as the visual-vestibular interaction (Guedry, Lentz, and Jell, 1979).
Appendix B

A. Regression on Eccentricity

The regression equation is:
\[ Y = -106.171 + 9.81473X - 0.247215X^2 + 2.10E-03X^3 \]
R-Sq = 32.4 %

Analysis of Variance

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B. Regression on Tracking Task Difficulty

The regression equation is:
\[ y = 26.1 + 0.510 x \]
R-Sq = 0.3%

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Appendix B-2

C. Regression on Target Velocity

The regression equation is:

\[ Y = 25.2183 - 0.136263X + 1.52E-02X^2 \]

\[ R^2 = 5.2\% \]

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APPENDIX C

INTRODUCTION TO THE STUDY

The purpose of this study is to investigate Dynamic Visual Acuity (DVA) factors at various positions and velocities in the visual periphery. DVA, as opposed to static visual acuity, is the ability of an individual to accurately resolve a moving target versus the classic static (non-moving) target, such as letters or the orientation of certain objects. DVA factors will be investigated under several workload conditions. The study is being conducted under the supervision of Dr. Al Prestrude within the Psychology Department. The principal investigators are Dwight Holland, an ISE graduate student, and Dr. Prestrude.

In this study you will be asked to perform a variety of tasks to assess how well human beings see moving objects in the periphery under a variety of tracking task difficulty conditions. The various tasks that you will be asked to perform the visual task under are designed to evaluate how human beings in general see objects in the periphery, and therefore is not an evaluation of your abilities personally. Just try to relax and do the best that you can on the tasks presented by carefully following the instructions given.

You are being asked to spend approximately 1.5 hours in the Lab participating in this experiment. After reading this introduction, you will be asked to fill out an informed consent form. If you agree to participate, your vision will be tested to ensure that you have normal visual acuity, can accurately perceive objects in depth, and that you have normal color vision.

Before the actual experimental sessions begins, you will be given further instructions about the tasks and what is expected of you as an experimental participant. You will be given practice on the tracking task and DVA tests that you will perform so that you are comfortable with the experimental equipment and the tasks involved. After you have had an opportunity to practice the task several times and feel comfortable with the procedures, you will be asked to perform the same task several times while attending to objects as they are presented in the periphery.

If you pass the preliminary visual screening and participate in the study, you will be given extra credit for your course, or paid $ 5.00 per hour for your participation.
During the experiment, if for any reason you decide not to continue, you will be paid for the time that you actually participate in the study. Similarly, if the experiment is interrupted or must be discontinued because of software/hardware failure, you will be paid for the time spent up to the point of termination.

If you are still interested in being a participant in this study, then read and sign the informed consent form. Thank you very much for your interest and participation.
Title of Project:  Dynamic Visual Acuity in the Periphery Under Workload

Principal Investigator:  Dwight A Holland

I. THE PURPOSE OF THIS RESEARCH AND PROCEDURES USED

• You are invited to participate in this study whose purpose, description, and procedures are contained in the Introduction to the Study document, which you have already read.  There is a small chance that you will experience some very slight eyestrain from carefully attending to the primary tracking task.  It is not likely that you will experience these effects; however, if you experience any adverse symptoms, please notify the experimenter immediately.  Remember, you are free to withdraw from the study at any time.

II. THE BENEFITS OF THIS PROJECT

• While there are no direct benefits to you from participating in this study, other than the extra credit for your course or the payment, you may find the experiment challenging and interesting.

• No guarantee of benefits has been made to encourage you to participate.

• You may receive a synopsis or summary of this research when it is completed.  Please leave a self-addressed envelope or your electronic/regular mailing address with the experimenter if this is what you wish.
III. EXTENT OF ANONYMITY AND CONFIDENTIALITY

- Your anonymity will be strictly preserved. The information you provide will have your name removed from it, and only a subject number will identify you during analyses and any written reports of the research.

IV. COMPENSATION

- For participation in this project, you will receive extra credit, or $5.00 per hour. Payment will be made immediately following completion of the experiment.

V. FREEDOM TO WITHDRAW

- You are free to withdraw from this study at any time without penalty. If you choose to withdraw, compensation will be prorated and you will be paid for the time you spent participating in this study. The same will be the case if for some reason the investigator terminates the experiment because of equipment failure.

VI. APPROVAL OF RESEARCH

- This research project has been approved, as required, by the Institutional Review Board for projects involving human subjects at Virginia Polytechnic Institute and State University.
VII. SUBJECT'S RESPONSIBILITIES AND PERMISSION

- I do not know of any reason that I should not participate in this study.
- I have read and understand the informed consent and conditions of this project. I have had all of my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.
- If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

Signature  ________________________________________

Date            ________________________________________

VIII. PARTICIPANT'S CONTACTS

- Should I have any questions about this research or its conduct, I will contact:

  Investigator:  Dwight Holland      Phone:  (540) 774-3465 (home, no office)
  Faculty Advisor:  Dr. Al Prestrude  Phone:  (540) 231-5673

  Chair, IRB Research Division:
          Dr. H. Tom Hurd Phone:  (540) 231-5281
APPENDIX E
PARTICIPANT INSTRUCTIONS

Your participation in this experiment will require careful attention to the tasks that you are asked to do, such that the data collected will be meaningful. You will be asked to perform a series of tracking tasks with a hand-held “joystick” that is often used for playing computer games. After a warm-up period, you will be asked to accomplish the tracking task on a small active-matrix Liquid Crystal Display (LCD) that is 2.5 inches wide. This is your primary task to accomplish, and should take precedence over all others. With the hand-held controller, you must attempt to keep the moving, circular target, on the crosshairs at the center of the screen. At a minimum, try to keep the target inside the small rectangular window on the screen that surrounds the crosshairs. You will note that there will be several levels of difficulty as you perform the tracking task. You will be given a chance to try each of the tracking task levels, not only to become familiar with the tracking task itself, but also to test your baseline performance at each level of the tracking task without any other secondary tasks to divide your attention. Do not become concerned if it may seem difficult to keep the target centered on the crosshairs since this is simply one aspect of the experiment. Just do the best you can.

After a warm-up (practice) period, while you are performing the tracking task, the VDT screen to your right will present several objects moving across the screen known as LANDOLT C’s. These C’s will be in one of four orientations with the open part on the C pointing to the right (as in a normal “C”), or with the open part of the C facing either up, down, or to the left. Before each of the C’s is presented to you, you will hear a tone approximately one second before the C is presented on the screen. The C will be moving at a variety of speeds and from several directions on the screen. You are to tell the experimenter in which direction the Landolt C was oriented. You must inform the experimenter if you are “unsure” (or “don’t know”) if you are not 95% sure of which direction the target was oriented. YOU ARE TO USE ONLY YOUR PERIPHERAL VISION TO TRY TO ASCERTAIN IN WHICH DIRECTION (UP, DOWN, LEFT, or RIGHT) THE C’S ARE ORIENTED. PLEASE DO NOT USE YOUR CENTRAL VISION BY MOMENTARILY GLANCING AT THE SCREEN THEN RETURNING BACK TO THE TRACKING TASK.
Appendix E-2

Always keep your eyes focused on the primary tracking task, but try to “see” the Landolt C orientation with your peripheral vision only. You will be given an ample number of practice trials to feel comfortable with the experiment. During the real trials, the experimenter will record your responses after you tell the experimenter in which direction the Landolt C was oriented. Keep performing the tracking task at all times during the experiment while the experimenter records the data and sets up the computer software for each trial.

You will receive 5 min rest breaks after 15, 30, and 45 mins of participation in this experiment.

Feel free to ask the experimenter any questions you have now or at any time during the experiment. Let the experimenter know when you are ready to begin.
APPENDIX F

Contents:

Table F1. PIXEL GAP SIZE (IN MINS) COMPUTATIONS

Table F2. LANDOLT C TARGET VELOCITY COMPUTATIONS

Table F3. SOME ASTVISION 7L VIDEO DISPLAY TERMINAL SPECIFICATIONS
Table F1.

Landolt C Critical Target Detail (gap width of open “C”) Visual Angle (G) in Minutes of Arc (mins).

<table>
<thead>
<tr>
<th>Average Landolt C Gap Size (s) in cm* (hortz + vert)/2</th>
<th>Number of Pixels to Create Gap</th>
<th>Gap (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.11345</td>
<td>2</td>
<td>6.965</td>
</tr>
<tr>
<td>0.22691</td>
<td>4</td>
<td>13.93</td>
</tr>
<tr>
<td>0.34036</td>
<td>6</td>
<td>20.89</td>
</tr>
<tr>
<td>0.45382</td>
<td>8</td>
<td>27.86</td>
</tr>
<tr>
<td>0.56727</td>
<td>10</td>
<td>34.82</td>
</tr>
<tr>
<td>0.68073</td>
<td>12</td>
<td>41.79</td>
</tr>
<tr>
<td>0.79418</td>
<td>14</td>
<td>48.75</td>
</tr>
<tr>
<td>0.90766</td>
<td>16</td>
<td>55.71</td>
</tr>
</tbody>
</table>

Computational Notes.

A derivation of the formula used by Schiffman (1990) to derive the Landolt C gap width in minutes of visual angle is \( G = \{ \arctan (s/d) \} \times 60 \). Here, \( s \) = size of the gap, \( d \) = viewing distance from right eye to the target, and 60 is a correction factor to convert degrees of visual angle into minutes of visual angle. The eye to screen distance (d) was 56 cm.

*Gap sizes in cm (s) were computed based upon CRT screen resolution measurements, and represents the mean of the vertical and horizontal pixel widths.
Table F2.

**Landolt C Target Velocity Computations.**

<table>
<thead>
<tr>
<th>Target Condition</th>
<th>Physical Distance (cm)</th>
<th>Velocity* (deg/0.5s)</th>
<th>Velocity (deg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Slowest Velocity</td>
<td>2.38</td>
<td>2.44</td>
<td>4.87</td>
</tr>
<tr>
<td>Middle Velocity</td>
<td>7.14</td>
<td>7.31</td>
<td>14.62</td>
</tr>
<tr>
<td>Fastest Velocity</td>
<td>11.90</td>
<td>12.20</td>
<td>24.40</td>
</tr>
</tbody>
</table>

Note: The viewing distance (d) from the right eye to the screen was maintained at d = 56 cm. The velocity across the screen in degrees of visual angle per 0.5s may be computed as:

\[
V = \text{Arcsin} \left[ \frac{0.5 \text{ s}}{d} \right]
\]

* where s is the distance (cm) actually traveled by the Landolt C target on the VDT Screen in 0.5s.

* All velocity computations reported in this study are derived from the actual path traversed in degrees/0.5s. Multiply by 2 to get Velocity in degrees per 1 second, which is the conventional measure used for studies with moving targets.
Table F3.

Technical Specification of the ASTVision 7L Video Display Terminal (only important ones provided).

________________________________________________________________________
(This VDT Manufactured by Samsung Corporation)
________________________________________________________________________

A. Picture Tube

- 43 cm (17”) full square type; 40 cm (15.7”) visual
- Flat Face, 90° Deflection
- 0.28 dot pitch
- Medium Short Persistence Phosphor

B. Unit Dimensions

- H x W x D: 420 x 428 x 439 (mm)
- Weight: 18.1 (kg)

C. Frequency Range

- Horizontal: 30-65 kHz
- Vertical: 50-120 Hz

D. Resolutions Supported (only best, most coarse listed)

I. Highest (Best) Resolution Mode

<table>
<thead>
<tr>
<th>Resolution</th>
<th>H-Sync</th>
<th>V-Sync</th>
<th>Interlaced</th>
</tr>
</thead>
<tbody>
<tr>
<td>1280 x 1024</td>
<td>63.7 kHz</td>
<td>60 Hz</td>
<td>Yes</td>
</tr>
</tbody>
</table>

II. *Lowest (most coarse) Resolution Mode

<table>
<thead>
<tr>
<th>Resolution</th>
<th>H-Sync</th>
<th>V-Sync</th>
<th>Interlaced</th>
</tr>
</thead>
<tbody>
<tr>
<td>640 x 480</td>
<td>46.8 kHz</td>
<td>85 Hz</td>
<td>No</td>
</tr>
</tbody>
</table>

*This was the resolution mode chosen for this research study.
Table F3-2

E. Maximum Pixel Clock

• 110 MHz

F. Computer Driving ASTVision 7L VDT

• AST Advantage! 824

• 133 MHz Intel Pentium Processor
  16 MB RAM; 1.6 GB Hard Drive
VITA

Dwight Holland was born in Roanoke, Virginia and attended Cave Spring High School where he served as the President of the Student Body his senior year. He graduated from Emory and Henry College with B.S. degrees in Mathematics and Physics. At Emory and Henry College he was one of a small number of students selected for induction into Blue Key, an honor society for academics, service and leadership. Dwight entered the Master’s program in Geophysics at Virginia Tech, and after completing his coursework took a leave-of-absence to participate in an Antarctic Research Program Expedition as a Geophysicist. He returned to Virginia Tech to write his Master’s thesis on Earth-Moon Tidal Gravity interactions and graduated with his Master’s degree in 1986. He was awarded the Antarctica Service Medal by the National Science Foundation for “…valuable contributions to exploration and science under the US Antarctic Research Program.” During this time at Virginia Tech he has served in many graduate student offices including: Editor of the Graduate Student Newsletter APEX, and as the Associate Chief Justice of the Graduate Honor System (appointment by the Dean of the Graduate School), among others.

Dwight then joined the Air Force Reserve and graduated from officer/pilot training and he was selected as an Honor Guard for graduation. At present he has approximately 2000 hours of flight time in 35 aircraft, military and civil combined, with the military rating of pilot, and civilian commercial and jet type ratings. He currently holds the rank of Captain in the USAF Reserve. His military reserve assignment from May, 2000 is as a Crew Systems/Human Factors Engineering Instructor attached to the Test Pilot School at the Naval Air Test Center in Patuxent River, Maryland. His next Air Force assignment combines this work with scientific program and grant review in the Air Force Office of Scientific Research (AFOSR).

Dwight worked for the General Electric Company in the late 1980’s/early 1990 as a Safety and Human Factors Engineer and co-designed the first Ergonomics Program that was used as a test-bed proof-of-concept (prototype) for the Company. During this time he returned to Virginia Tech and completed a Master’s degree in Systems Engineering in afternoon and evening study. His Master’s thesis in Systems Engineering entitled “Systems and Human Factors Concerns for Long-Duration Spaceflight” was completed in 1991, and eventually resulted in several presentations and publications.

In 1993, Dwight entered the Human Factors Engineering Program at Virginia Tech to pursue a doctorate. While completing the Ph.D. portion of his training at Virginia Tech, he was a recipient of the prestigious Cunningham Fellowship, and selected for several NASA fellowships, including serving as a NASA/Stanford Research Fellow-- where he received a Certificate of Recognition for his work in Aerospace Human Factors at the Ames Research Center.

During his academic studies, Dwight has been elected to several academic/leadership honor societies. Those at Virginia Tech include Phi Kappa Phi (across-discipline), Tau Beta Pi (engineering), Omicron Delta Kappa (academics/leadership), and Sigma Xi (research), among others. He has been chosen as one of the “Distinguished Lecture Series” speakers for the Virginia Tech Corps of Cadets (1996), and was chosen in 1995 from 140,000 living Virginia Tech Alumni to be featured for an “Alumni Profile” article in the Virginia Tech Magazine for his various contributions to Virginia Tech and the professional community at large. Dwight’s 1992 paper presented at the Annual Aerospace Medical Scientific Meeting in Miami, FL on Situation
Awareness and Spatial Disorientation in the USAF resulted in him being selected as a Finalist for the association-wide “Young Investigator Award” (top 3 of over 170 eligible papers).

In service to the professional community, Dwight is the currently elected Secretary/Treasurer for the International Association of Military Flight Surgeon-Pilots, and has recently served out a third term as the Academic Program Chair. He is also the elected Member-at-Large for the Aerospace Human Factors Association. He is an Associate Fellow of the Aerospace Medical Association (AsMA), and a member of several other professional organizations, including being a Senior Member of the American Institute of Aeronautics and Astronautics (AIAA). He has served in the past as the Program Chair of the Space Medicine Branch of the Aerospace Medical Association, and is currently serving on the Young Investigator Awards Committee. Dwight’s service to the professional community also includes being a member of several standing committees of AsMA, and a member of the Scientific Program Committee of AsMA. He was an invited participant in the first (1999) NASA Space Human Factors Workshop in Houston, TX for assessing the human factors issues on future long duration space missions, and is serving as a consultant on the medical standards board for astronaut physical requirements specification.

As he closes his academic career at Virginia Tech in May of 2001, Dwight Holland will have chaired 11 scientific sessions at a variety of medical and engineering meetings over a 10-year window, and has over 35 refereed abstracts, papers, conference proceedings, book chapter and other academic works to his credit— including co-editing a recent special edition of an international journal on virtual reality and medicine. He has served as a reviewer for three peer-reviewed journals, and as a reviewer for various Human Factors, Systems Engineering, and Aerospace Medicine Conferences.

He has been active throughout these years in a variety of community/youth service positions including: Youth Minister (1981, 1983), Angel Flight Volunteer Pilot (1982-1986), Bradley Free Clinic Volunteer (1984-85, and 89), Tennis Instructor for the Parks and Recreation (1983-86; 1988-89), FAA Aviation Safety Counselor (1998—present), and as a Congressional Intern (1989). He has also served on the Supervisory Committee of Member One Federal Credit Union for the past five years, which recently achieved the first “CAMEL 1” rating by the Federal Government in the 50-year history of this Credit Union.