Dynamic Contrast Sensitivity:

Methods and Measurements

by

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(ABSTRACT)

A portable device was constructed which presents moving, computer generated, sine-wave grating slide projections that range in spatial frequency from 0.4 to 20.5 cycles per degree. At each of two different testing sessions, the contrast sensitivities of 60 undergraduate psychology majors were measured at a static, 25 deg/sec, and 50 deg/sec target movement condition. The results indicate that as target velocity was increased, contrast sensitivity decreased at middle and high spatial frequencies but that contrast sensitivity was enhanced at very low spatial frequencies by target movement. Also, the area of peak sensitivity shifted toward lower spatial frequencies as target velocity increased. In addition, test, re-test reliability was demonstrated. The results are consistent with previous Dynamic Visual Acuity (DVA) research which has shown that the ability to resolve fine detail decreases as target velocities increase, presumedly due to limitations in eye movement control. The testing device, which was designed and constructed for the present study, has

proven to be a reliable means for measuring dynamic contrast sensitivity (DCS) and has some distinct advantages over existing methods for measuring both DVA and DCS and, as such, will be valuable in future DVA and DCS research.

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INTRODUCTION

So ubiquitous is the role of visual ability in everyday functioning that its importance is difficult to overstate. With regard to specific tasks such as driving and flying, for example, good visual ability is essential. For this reason standardized vision testing is normal practice for both automotive and aviation licensing agencies as well as for the selection and evaluation of pilots in the armed services. The standardized vision tests that are commonly used include Snellen and Sloane letters, Landolt C's, Tumbling E's and checkerboard patterns. Typically these tests employ stationary, high contrast targets where vision is assessed in terms of the smallest detail of the target (optotype) that an observer is capable of resolving (Committee on Vision, 1984). Acuity tests such as these have proven extremely effective in determining the correction for refractive errors of the eyes. However, if one stops to consider the variety of ways in which visual ability guides both everyday activities and specialized tasks such as driving and flying, it becomes evident that static, high contrast vision tests assess only a small proportion of overall visual ability (Leibowitz, Post, & Ginsburg, 1980).

The present study focused on two types of visual ability which typically are not assessed through standardized vision tests: dynamic visual acuity (DVA) and contrast sensitivity. Dynamic visual acuity is defined as the ability to resolve detail when there is relative motion between an object and an observer

(Cline, Hofstetter, & Griffin, 1980). Such a situation describes a large portion of everyday visually guided activity and is always present during walking, driving, and flying.

Contrast sensitivity, as it is commonly measured, refers to an individual's ability to perceive sign wave gratings across a range of spatial frequencies and contrasts. This information is summarized conveniently in a contrast sensitivity function (CSF) which displays an individual's contrast thresholds across a range of spatial frequencies. The spatial frequency of the gratings relates to the size of conventional objects. Sensitivity to high spatial frequencies corresponds to one's ability to perceive small objects or fine detail. Sensitivity to low spatial frequencies corresponds to one's ability to perceive large objects and the outlines of objects (Ginsburg, 1981; Sekuler, 1974). Compared to traditional vision tests which primarily measure sensitivity to high spatial frequencies, the CSF has the potential to provide more information about one's visual functioning because it measures sensitivity across a range of spatial frequencies and contrasts (Committee on Vision, 1984).

The goal of the present research was to combine aspects of dynamic visual acuity and contrast sensitivity into a single test of dynamic contrast sensitivity. Dynamic contrast sensitivity was measured using sine wave gratings across a wide range of spatial frequencies and at two target velocities, the purpose of which was to determine the effect of target movement on contrast sensitivity

This effort is consonant with the Committee on Vision (1984) report Emergent Techniques of Visual Assessment which recommended that such an investigation be undertaken. The committee report cites a number of research articles concerning both DVA and contrast sensitivity which point out their superiority over existing standardized vision tests with regard to their ability to predict performance on some real-world visually guided tasks. Both the Committee on Vision and the present writer feel that dynamic contrast sensitivity may prove to be a powerful way to measure visual ability because of its potential to predict performance on real-world visually guided tasks. Both DVA and contrast sensitivity are discussed in more detail below. In doing so, the limitations of current standardized visual acuity measures are pointed out both in terms of their adequacy in assessing general visual ability and in their utility in predicting performance on real-world visually guided tasks.

Dynamic Visual Acuity

A programmatic investigation of DVA began with the classic work of Ludvigh and Miller in the late 1940's and early 1950's (see Miller & Ludvigh, 1962 for a review). Since this time, there has been general agreement that the relationship between target angular velocity and the size of the smallest resolvable detail of a target is a positively accelerating function. Ludvigh and Miller (1954) have determined that the shape of this function is described best by the equation $y = a+bx^3$, where y = visual angle in minutes of arc, x = target angular velocity in degrees/second, a = the individual's predicted static visual acuity (SVA) level, and b = a dynamic acuity component. In general, target angular velocities of up to 40^o/sec. have relatively little effect on acuity; however, at speeds of 50^o/sec. and higher acuity becomes markedly impaired (Miller & Ludvigh, 1962; Morrison, 1980).

The above relationship was determined using horizontal target movement. However, vertical movement, circular movement, and movement of observers relative to stationary targets also have been examined. These studies were reviewed in Miller & Ludvigh (1962) and in Morrison (1980). The deterioration of DVA with increasing target angular velocity occurs least rapidly with vertical target movement and most rapidly with circular movement, yet the general shape of the function relating target angular velocity and the smallest resolvable detail of the target is similar for all three types of target motion. The rate of deterioration of visual acuity that results from observer movement relative to a fixed target is not significantly different from that which results from target movement relative to a fixed observer.

A number of studies also have compared DVA performance for different types of movement (horizontal, vertical, and circular) using a within subjects design (e.g. Miller, 1956, 1958; Miller and Ludvigh, 1953). These studies indicate that individuals who demonstrate superior DVA performance with one type of motion also show superior performance for other types of motion. It has been argued that this finding demonstrates that DVA is dependent upon the entire oculomotor pursuit mechanism rather than on specific extraocular muscles (Miller, 1958; Miller & Ludvigh, 1962).

As pointed out by Morrison (1980), three tentative hypotheses as to the cause of the progressive deterioration of visual acuity with increasing target angular velocity were proposed by Miller & Ludvigh (1962). The first hypothesis is that acuity deteriorates during visual pursuit because of an inability of the eye to move fast enough to track the moving target. This hypothesis was discounted by Miller and Ludvigh on the grounds that eye movement velocities previously had been recorded by the authors in excess of 500 deg./sec. As noted above, a marked decrease in DVA occurs with target angular velocities of just 50^{o}/sec.

Miller & Ludvigh's second hypothesis was that the deterioration in acuity may result from the target stimulating an extrafoveal retinal position during visual pursuit even though the pursuit mechanism keeps the image in a stable location on the retina. This hypothesis also was discounted because an earlier experiment by Ludvigh (1949) showed that acuity for targets moving in a circular path 2^{o} concentric to the eye fixation point resulted in far worse acuity than that for a stationary target positioned 2^{o} from the point of fixation. In light of the first two rejected hypotheses, Miller & Ludvigh offered a third explanation: that visual acuity deteriorated during visual pursuit because of erratic eye movements which cause movement of the image on the retina.

In an extension of this line of inquiry, a number of researchers have provided detailed measurements of eye movements in response to moving targets (e.g. Barmack, 1970; Brown, 1972a, 1972b; Reading, 1972). Taken together, the results of the studies cited above converge to give an account of a characteristic pattern of eye movements which vary as a function of the angular velocity of the targets. At lower target velocities (up to 40^{o}/sec.), the eye exhibits an initial latency period of about 200ms. followed by a high velocity saccade which fixates the retinal image of the moving target on the fovea. This is followed by a smooth pursuit movement which serves to track the target and stabilize its' retinal image. Crawford (1960) has shown that resolution of moving targets takes place during smooth pursuit movements. At a higher target velocity (90^{o}/sec), Brown (1972b) found that the initial eye movement latency period before the first saccade decreased to 145 msec. compared to 200 msec. for target speeds of 20^{o}/sec. Also, the velocity of the pursuit movement of the eye lagged behind the velocity of the target, and pursuit movements were supplemented with more rapid, saccadic movements in order to keep the retinal image of the target at or near the fovea (Barmack 1970; Brown 1972b; Reading 1972). Brown (1972b) showed that although the velocity of the eye consistently lagged behind the velocity of the target during smooth pursuit movements, the pursuit velocity increased following each of the supplemental saccades, such that the eye/target velocity mismatch error was progressively reduced.

For example, Brown (1972b), using a target speed of 90^{o}/sec. found that following the first saccade, the first pursuit movement had a mean velocity of 40^{o}/sec. After the second and third saccades the mean pursuit velocities reached 50^{o}/sec. and 60^{o}/sec. respectively, but never matched the speed of the target. However, even though the mean eye/target pursuit velocity mismatch for a given target speed progressively became smaller following each saccade, the mean eye/target velocity mismatch still increased overall as target speeds increased, with the eye velocity consistently lagging behind that of the target.

Given the above results, it can be seen that movement of the target image on the retina during visual pursuit increases as target angular velocities increase. This supports Miller & Ludvigh's contention that the degradation of visual acuity with increasing target speeds results from movement of the retinal image on the retina.

While the above discussion answers some questions concerning the mechanisms responsible for the degradation in acuity with increasing target angular velocity, it also can serve as a point of disparity between SVA and DVA. SVA is determined primarily by the resolving power of the eye (Hoffman, Rouse,

& Ryan, 1981). The oculomotor abilities involved include fixating on a stimulus and maintaining that fixation long enough for resolution to take place. In contrast, DVA involves the integration of high velocity saccadic eye movements and smooth pursuit movements in an effort to maintain a stable retinal image of a moving target. Reading (1972) contends that the information necessary for accurate target tracking is obtained during two separate states; that of fixation and during pursuit movements themselves. During the state of fixation (prior to the first saccadic eye movement in response to the moving stimulus) information regarding the angular velocity of the stimulus is obtained. During pursuit movements, information concerning the difference between the angular velocities of the target and the eye is obtained. Feedback from these two information sources is necessary to bring the retinal image of the moving target onto the fovea and to make the appropriate eye movement corrections to maintain a foveal position.

Reading also provides evidence that the execution of smooth pursuit movements at velocities greater than 30^{o}/sec. may be dependent upon feedback regarding contour sharpness. Previous research had shown the maximum velocity for smooth pursuit eye movements to be approximately 30^{o}/sec. (Westheimer, 1954), yet numerous researchers have recorded smooth pursuit movement velocities at upwards of 100^{o}/sec. (e.g. Atkin, 1967, 1969; Barmack, 1970; Brown, 1972b; Reading, 1972). Atkin (1969) suggested that the reason for the different results between his research and that of Westheimer's may be that Westheimer used spots of light whereas Atkin used targets which required the resolution of detail. All of the studies cited above which found pursuit eye movement velocities far in excess of 30^{o}/sec. used targets which required resolution of detail. Reading (1972) suggests that the degree of contour sharpness in the moving image provides additional information regarding the degree of eye/target velocity mismatch and that the pursuit control system uses this feedback for optimal performance.

It can be seen that during a DVA task the demands placed on the oculomotor system are considerable compared to that of a task involving only SVA. It is not only the case that DVA is dependent upon the entire oculomotor system whereas SVA is chiefly determined by the resolving power of the eye. Oftentimes, real-world DVA tasks require that the oculomotor system operate at a high degree of proficiency. For example, an automobile traveling at the relatively slow speed of 30 miles per hour, passing perpendicular to a line of sight 30 ft. away produces a peak angular velocity of 84^{o}/sec. (Hoffman et. al., 1981). Successful resolution of objects moving at this velocity may require smooth pursuit movements at velocities that approach the upper limits of oculomotor capability. Hoffman contends that many real-world tasks that require visual resolution involve a relative velocity between target and observer of 100^{o}/sec. or more.

In addition to the coordination of effective eye movement patterns, there are a number of other observer attributes which contribute to DVA ability that play no role in SVA. Elkin (1962), for example, demonstrated that by allowing free head movement and by providing an anticipatory tracking time, DVA could be significantly increased. Elkin's subjects were allowed to track the motion of the acuity targets prior to their actual exposure. Thus, the probability of the eye being on target during its' exposure was increased. Elkin's study demonstrates that anticipatory factors play a role in DVA.

In summary, it is noted that many real-world tasks involve DVA and that there are a number of abilities involved in DVA which play no role in SVA. These include the ability to anticipate the location, speed, and direction of targets, the coordination of head and eye movements, and, according to Hoffman et.al. (1981), attentional ability and peripheral awareness. Clearly, vision tests which assess only SVA do not take into account a variety of visual abilities which play an important part in real-world daily visual functioning and which may be especially important in specific tasks such as driving and flying.

In a recent study, Long and Penn (1987) argued for an increased role of DVA testing in visual assessment, especially when the assessment is used as a screening device for such things as the licensing of drivers and pilots. In this study, Long and Penn identified two basic findings in the DVA literature which underscore the practical utility of DVA assessment.

First, they cited the fact that numerous studies have shown that for a given individual, SVA is not a good predictor of DVA. The work of Miller and Ludvigh, which used U.S. Naval aviation cadets who all had 20/20 or better SVA, clearly demonstrated that individuals who are matched on SVA vary dramatically with regard to DVA (see Miller & Ludvigh, 1962). Miller & Ludvigh found that their subjects could be roughly sorted into two categories, velocity resistant and velocity susceptible. As target velocities increase, velocity susceptible individuals showed greater degradation in acuity than velocity resistant individuals.

Second, Long and Penn have noted that a number of studies have demonstrated that DVA is superior to SVA in the prediction of performance on some real world visually guided tasks. For example, Burg (1971), who examined the relationship between visual ability and driving record (i.e. accidents and convictions for traffic citations), reported that out of a battery of seven different types of vision tests DVA was by far the best single predictor of driving record. The test battery included measures of DVA, SVA, lateral visual field, lateral phoria, low illumination vision, and glare. In another study (Henderson & Burg, 1973), DVA was found to be significantly related to accident record for truck and bus drivers. With regard to flying ability, it has been reported that DVA is more highly correlated than is SVA with in-flight measures of instrument reading, night flying, and formation flying (deKlerk, Eernest, & Hoogerheide, 1964). With regard to athletic performance, DVA has been found to be positively correlated with shooting accuracy in basketball players (Beals, Mayyasi, Templeton, & Johnson, 1971), batting average in little league baseball players (Falkowitz & Mendel, 1977), and ball catching ability (Sanderson & Whiting, 1978).

As Long and Penn have pointed out, the two basic findings cited above (i.e. that SVA is not a good predictor of DVA for a given individual and that DVA has been shown to be a better predictor of performance on some real world tasks than SVA) indicate that current standardized vision testing may be inadequate when used as a screening device for tasks which involve DVA. This argument is applicable to the present research effort which seeks to establish a methods for the measurement of DCS because future research will examine the predictive utility of the DCS with regard to performance on real-world tasks.

Contrast Sensitivity

In recent years, a method of visual assessment known as contrast sensitivity has been developed from research in spatial vision (Campbell & Robson, 1968). This method provides a way to measure spatial resolution across the entire range of human ability. In comparison, standardized vision tests, which are based on one's ability to resolve fine detail, primarily assess sensitivity to high spatial frequencies (Leibowitz, Post, & Ginsburg, 1980). Contrast sensitivity typically is measured using sine wave grating patterns which vary in terms of their spatial frequency, contrast, phase, and orientation. The term sine wave grating is used because transitions in intensity from light bars to dark bars are regular and gradual.

The spatial frequency of a sine wave grating is a measure of the number of repetitions of light and dark cycles per one degree of visual angle. The human observer is capable of detecting spatial frequencies within a range of approximately .1 to 60 cycles per degree (cpd) (Committee on Vision, 1984), with a peak sensitivity between 2 and 4 cpd (Sekuler, 1974).

Contrast is a measure based on the ratio of the maximum luminance to the minimum luminance of a grating. This value is conventionally obtained by dividing the difference between the maximum and minimum luminance of the grating by the sum of the maximum and minimum luminance. This value may range from 0.0 to 1.0. The minimum contrast value at which a sine wave pattern can be distinguished from a uniform gray field is referred to as the contrast threshold. The inverse of the contrast threshold is called contrast sensitivity. A contrast sensitivity function is constructed by selecting a range of spatial frequencies and determining the contrast sensitivity for each (Committee on Vision, 1984).

The phase of a sine wave grating refers to its position relative to some land mark . Thus, a grating target which begins with a dark bar would have an opposite phase to a grating which begins with a light bar (Sekuler & Blake, 1985). The orientation of a sine-wave grating refers to the positioning of the bars in a vertical, horizontal, or diagonal plane.

The human contrast sensitivity function is, in essence, a graphic representation of the filter characteristics of the visual system with regard to spatial information (Ginsburg, 1981; Sekuler, 1974). In other words, it represents the range of spatial information that the human visual system is capable of passing on for further processing. As Ginsburg (1981) has pointed out, the filter characteristics of any information processing system may be determined through the use of simple test patterns where the ability of the system to represent such patterns is indicative of how well the system will be able to represent more complex combinations of information.

For example, the audio-engineer may be interested in assessing the sound processing capability of a music recording device. This could be accomplished by determining how faithfully the device is able to record a series of simple test patterns (i.e. a range of pure tones). In this example, pure tones are used as test patterns because complex sounds can be broken down into a collection of pure tones. Likewise, a combination of pure tones can be used to construct more complex sounds.

Similarly, vision researchers have adopted the sine wave grating as a type of simple test pattern for assessing the information processing capability of the human visual system. Sine wave gratings are the patterns of choice because, through the process of Fourier analysis, any complex scene can be represented as sine wave patterns which vary in terms of their spatial frequency, contrast, orientation, and phase. Likewise, any complex scene can, though Fourier synthes is be approximated by the appropriate combination of sine wave patterns (Campbell & Robson, 1968; Ginsburg, 1981; Sekuler, 1974).

The use of sine wave grating patterns in vision research and the development of the contrast sensitivity function as a means of visual assessment has proceeded hand in hand with the development of the multi-channel model of form perception. Campbell and Robson (1968) proposed that the human visual system contains functionally separate mechanisms or "channels," each of which is tuned to respond maximally to stimulation that is within a particular range of spatial frequencies. Thus, the contrast sensitivity function which describes the entire range of spatial frequencies to which the human observer is sensitive, actually is comprised of a number of separate functions each of which describes the sensitivity of a different spatial frequency channel.

Selective adaptation studies using sine wave grating patterns as stimuli have supported this theoretical view. For example, Blakemore and Campbell (1969) found that when subjects adapted to a grating of a given spatial frequency, a threshold increase occurred within a range of spatial frequencies centered at the adapted frequency, but that more remote frequencies were unaffected. When plotted, the adapted channel appeared as a depression or "notch" in the contrast sensitivity function. In general, the multi-channel model of form perception has received considerable support in the literature (see Bodis-Wolner & Diamond, 1976; Sekuler, Wilson, & Owsley, 1984; Wilson & Bergen, 1979).

Consistent with the multi-channel model of form perception, the testing of spatial visual ability using contrast sensitivity has been likened to the testing of auditory ability using an audiogram (Evans & Ginsburg, 1985; Ginsburg, 1981). Just as a limited range of pure tones stimulates a specific set of receptive cells in the auditory system, simple sine wave gratings of various spatial frequencies excite different channels (sets of simple cells) in the visual system. In the case of the audiogram, sensitivity to a specific tone is determined by presenting it at various decibel levels to determine a threshold. With the contrast sensitivity function, sensitivity to sine wave gratings of different spatial frequencies is determined by presenting them at various levels of contrast. As Ginsburg (1981) has pointed out, the testing of visual sensitivity using high contrast optotypes, such as those employed in standardized vision tests, is like measuring hearing sensitivity using a single high decibel level across all sound frequencies. Clearly, neither of these scenarios represents an optimum method of determining perceptual sensitivity.

Ginsburg (1981) contends that, compared to the contrast sensitivity function, standardized visual acuity tests provide little information about visual sensitivity. Normal Snellen acuity assesses sensitivity to spatial frequencies in the range of approximately 18 to 30 cpd, yet even within this range the relative sensitivities regarding specific spatial frequencies cannot be determined. Furthermore, sensitivity to all spatial frequencies which fall outside this range cannot be assessed. This includes the entire peak range of sensitivity which is from 2 to 4 cpd. Ginsburg has been clear to point out that standardized vision tests should not be abandoned. They are an efficient method for determining refractive errors of the eyes and prescribing corrective lenses, However, compared to Contrast Sensitivity they provide little information regarding visual problems associated with such things as cortical damage or disorders of the nervous system.

For example, Bodis Wollner and Diamond (1976) used contrast sensitivity to assess the visual capability of patients with cerebral lesions who, although they showed normal 20/20 Snellen acuity, complained of blurred vision. They found that such patients had abnormal contrast sensitivity functions. Some patients exhibited an overall reduction in contrast sensitivity while others showed a decreased sensitivity only at a specific range of spatial frequencies.

Regan, Raymond, Ginsburg, and Murray (1981) obtained similar results from patients with multiple sclerosis. Twenty out of 48 patients tested exhibited contrast sensitivity losses which could not be predicted by standardized acuity tests.

Both of these studies support the multi-channel model of form perception since numerous cases with both cerebral lesions and multiple sclerosis seem to have visual impairments which were confined to specific spatial frequency channels. These studies also point out that standardized acuity tests cannot be used to predict an individual's contrast sensitivity. The Committee on Vision (1984) refers to this as a dissociation of acuity and contrast sensitivity.

The contrast sensitivity function provides information about an individual's visual sensitivity that cannot be provided by standardized measures of visual acuity. As a number of recent studies have demonstrated, this additional information may be used to predict performance on complex, real-world tasks. Ginsburg, Evans, Sekuler, and Harp (1981) found that contrast sensitivity predicted simulated air-to-ground target detection in pilots. Traditional acuity measures, on the other hand, were not significantly correlated with this ability. In this study pilots were required to land simulated aircraft, but on randomly selected trials the runway was occupied by another aircraft. Pilots were required to detect this aircraft so that it could be successfully avoided during landing. The distance at which the aircraft was detected was recorded.

Significant correlations were found between several of the low and middle spatial frequency measures of contrast sensitivity and the distance at which the target was detected (slant range). The strongest correlation was between the peak range of scotopic contrast sensitivity and the slant detection range.

In a related study (Ginsburg, Easterly, & Evans, 1983), pilots were tested under actual field conditions for their ability to detect incoming aircraft. In this study, groups of about 10 pilots at a time who were separated by partitions were seated at the end of a runway. The distance at which each was able to detect an incoming aircraft was recorded. A total of 84 pilots was tested across 10 different sessions under a wide range of atmospheric conditions. Significant correlations between contrast sensitivity and slant range were found in 8 out of 10 testing sessions compared to 3 out of 10 for traditional measures of acuity.

Finally, Evans and Ginsburg (1985) showed that although a group of younger (19 to 30 yrs) and older (55 to 79 yrs) drivers both had the same Snellen acuity, the older drivers needed to be significantly closer to a road sign before it became legible. This was explained in terms of contrast sensitivity differences between the two groups. The contrast sensitivity of the older group was significantly lower than the younger group at 3, 6, and 12 cpd. Contrast sensitivity at 1.5 and 12 cpd was found to be positively correlated with discrimination distance. Thus, contrast sensitivity was found to be a good predictor of highway sign discriminability that could differentiate between the performance of younger and older drivers. In this study, the correlation between Snellen acuity and discrimination distance was not significant.

Dynamic Contrast Sensitivity

The preceding discussion has attempted to point out the need for a more comprehensive measure of visual ability than standardized vision testing currently provides. The assessment of visual acuity using static, high contrast test targets does not take into account important observer attributes which contribute to an individual's effectiveness with regard to complex, real-world, visually guided tasks. Two emergent methods of visual assessment that the Committee on Vision (1984) has found to be promising are DVA and Contrast Sensitivity. The argument which underlies the practical utility of each of these methods is similar. First, traditional acuity measures are not good predictors of either DVA or Contrast Sensitivity. Second, a number of studies have shown both DVA and Contrast Sensitivity to be better predictors than SVA with regard to performance on some complex, real-world visually guided tasks.

It should be pointed out, however, that a number of studies in the DVA literature have reported inconsistent correlations between DVA and various flight performance measures in Navy carrier based jet pilots (Prestrude, 1986). For example, Monaco and Hamilton (1984, as cited in Prestrude, 1986) found that DVA was not a good predictor of air-to-air target detection in terms of slant range. Morley and Monaco (1985, as cited in Prestrude, 1986) reported a moderate correlation of .24 between DVA at 50 deg./sec. and night carrier landing scores and that in a multiple prediction battery SVA was actually weighted more heavily than DVA.

Prestrude (1986) has noted that the inconsistent results that these studies present may have been due to unreliable performance measures such as subjective measures of night landing scores rather than an invalid predictor. Prestrude has also noted that the high contrast DVA test targets that were used (Landolt C's) might not be the best target for the measurement of DVA and has endorsed the Committee on Vision (1984) recommendation that DCSFs be determined at various angular velocities and that these be compared with Static CSFs in their relationship to predicting flying ability. The present study represents a necessary first step toward that end and opens up numerous other avenues of potential research.

The goal of the present research effort has been to design and construct a device which may be used to test dynamic contrast sensitivity. Such a test will take into account factors that contribute to one's ability to resolve moving targets across a wide range of spatial frequencies and contrasts. Because the dynamic contrast sensitivity function will be sensitive to these important real-world factors, it represents a far more comprehensive test of visual ability than current standardized vision tests and has the potential to be a powerful predictor of performance on real-world tasks that involve relative motion between observers and objects. As the preceding discussion points out, many real-world tasks involve relative movement between objects and observers and the objects themselves may vary a great deal in terms of their spatial frequency composition and contrast levels.

No studies to date have examined the effect of motion on contrast sensitivity using both a large range of different spatial frequency sine-wave gratings as test targets and a method of target presentation which is similar to that used in previous DVA research. Temporal modulation, which is a repetitive alternation of the phase of a grating, has been used to create apparent motion within a stationary field (e.g. Kulikowski & Tolhurst, 1973). However, given that temporal modulation occurs within a stationary field, it is unknown whether the patterns of eye movements employed in this situation are comparable to those which are used to track moving targets. It is also unclear how the rate of motion produced by temporal modulation, which is expressed in Herz, compares to the extant DVA literature which typically expresses the rate of target movement in terms of deg./sec. A recent study by Scialfa, Garvey, Gish, Deering, Leibowitz, and Goebel (1988) used dynamic projected images of sine wave gratings produced from slide transparencies of the Vistek Contrast

Sensitivity Test System (Ginsburg, 1984) as test targets. However, the range of spatial frequencies which they were able to use was very narrow (.93 to 3.72 cpd).

The design of the equipment used in the present experiment was based on that of Scialfa et. al. (1988); however, the test stimuli were slide transparencies of computer generated sine wave gratings that range from 0.4 to 20.5 cpd. This range of spatial frequencies represents a large portion of that which the human observer is capable of detecting. Thus, a significant contribution of the current research effort will be a means by which dynamic contrast sensitivity may be measured across a wide range of spatial frequencies. In addition, the dynamic contrast sensitivity device is portable allowing for testing to be carried out in the field.

The current study examined the effect of target movement on contrast sensitivity and assess the reliability of the dynamic contrast sensitivity test which was designed for the current study. In doing so, two target speeds were used. Since there is no literature currently available regarding the velocity at which contrast sensitivity becomes seriously impaired, the faster of the two target speeds was selected on the basis of subjective reports from pilot subjects which indicated that the task of detecting the gratings at this speed became difficult but not impossible. The slower of the two speeds was selected as an intermediate point between the static and fast conditions. The present study examined the overall shapes of the contrast sensitivity functions for static, slow, and fast target movements. The CSF for the static condition should be comparable to the existing contrast sensitivity literature both in terms of the range of spatial frequencies to which subjects are sensitive and the area of peak sensitivity.

With regard to the DCSFs, it was hypothesized that the area of peak sensitivity would shift toward lower spatial frequencies as target velocity increased and absolute sensitivity would be decreased. Such a finding would be consistent with that of Kulikowski and Tolhurst (1973) and Scialfa et.al. (1988), both of which reported such a sensitivity shift with non-stationary gratings. Based on the DVA literature which shows a marked decline in acuity as target speed increases, it is also hypothesized that sensitivity to high spatial frequencies will be reduced as target velocity increases.

METHODS

Subjects

Subjects were 60 undergraduate psychology majors from Virginia Polytechnic Institute and State University who participated for extra credit. Subjects were not selected on the basis of SVA scores. This research project has been approved by the Virginia Tech Human Subjects Research Committee and the Institutional Review Board.

Apparatus and Materials

Both near acuity and distance acuity for stationary targets was measured with a Bausch & Lomb Orthorater using plates N-1 and F-3, respectively. Static contrast sensitivity was determined at five spatial frequencies (1.5, 3.0, 6.0, 12.0, and 18.0 c/deg) using the Vistek Contrast Sensitivity Test System (Ginsburg, 1984) near chart at a distance of 18 in.

Dynamic contrast sensitivity and an additional measure of static contrast sensitivity was determined using sine wave grating patterns which were generated using a VAX 11-785 computer in conjunction with a Perceptics 9200 color image processor and photographed with a Matrix graphic image recorder camera. At a viewing distance of 63.5 cm the projected circular test targets subtended 3.5 degrees of visual angle. The spatial frequencies of the test targets were 0.4, 0.8, 1.0, 1.7, 2.3, 3.7, 5.7, 7.5, 11.4, 13.5, 16, 20.5 cpd.

The contrast values of the test targets were determined with a Gamma Scientific scanning photometer. Within each spatial frequency a range of test targets have been constructed which vary in terms of their contrast levels. The range of contrast levels within each spatial frequency was such that a contrast threshold could be determined for each.

The dynamic contrast sensitivity tests and the additional tests of static contrast sensitivity were carried out using a portable DVA testing device which was designed and built to be used in the present thesis and in future DVA research (see Fig. 1). The device consists of a Kodak 850 H slide projector which has been modified by the insertion of a thin aluminum sheet with a 1.3 cm diameter hole cut into it. The hole is centered in front of the projector bulb. This setup effectively reduces the size of the projected image while producing a circular test target. The test targets are projected through a right angle prism onto a front surface mirror which is positioned at a 45 deg angle to a ground glass screen and back projects the image to the screen. It was necessary to reduce the size of the projected image so that it would fit onto the face of the right angle prism.

The prism is mounted inside a rotating circular frame which is powered by a drive belt connected to a variable speed electric motor. The motor is controlled by a Marietta Kinetic Visual Display variable resistance potentiometer which allows for variable target velocities. The front surface mirror is attached to the rotating circular frame such that the mirror remains in the same position relative to the prism during rotation. The mirror is off-set a distance of 9.2 cm from the reflecting surface of the prism. This distance forms the radius of the circular path traveled by the moving test targets. The rotating prism/mirror assembly and motor are all mounted inside a 40 by 33 by 61 cm wooden box. A hole for the slide projector lens was cut into the back of the box. The front of the box consists of the ground glass screen with an adjustable circular aperture mounted in front of it to control target exposure duration. A filter to

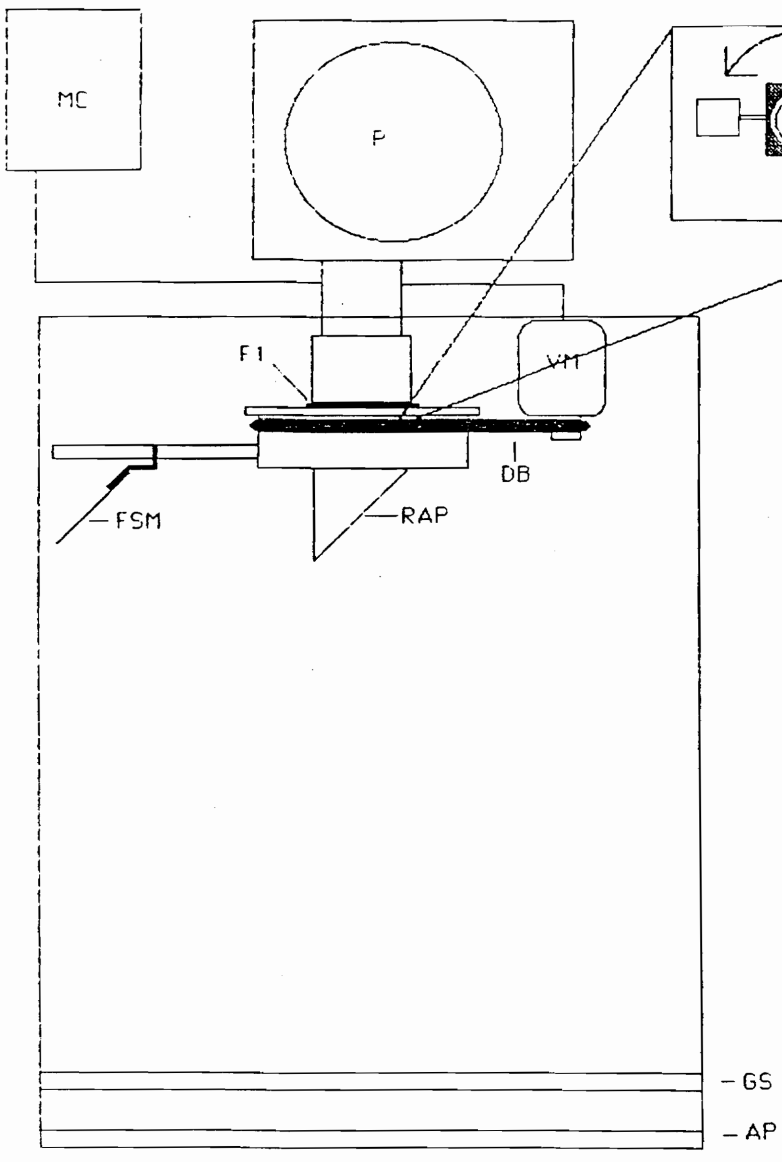

Figure 1. A schematic representation of the apparatus used to present moving targets: P=projector; RAP=rotating right-angle prism; FSM=front surface mirror; GS=ground glass screen; AP=adjustable aperture; F1=filter; VM=variable speed motor; MC=motor controller; DB=drive belt. The insert shows a front view of the belt-driven rotating prism and mirror

reduce glare was mounted in front of the projector lens.

Design and Procedure

All subjects were tested individually and all vision tests were carried out binocularly. Subjects who wore corrective lenses were instructed to wear them during all testing. Each subject participated in a series of two testing sessions both of which lasted approximately 50 minutes. At the start of the first session subjects completed the near acuity and the distance acuity tests using the Orthorater and the static contrast sensitivity test using the Vistek. The time required to complete these two tests was about five minutes.

Contrast sensitivity thresholds for both static and dynamic conditions using the dynamic contrast sensitivity (DCS) testing device were determined through a method of limits with a staircasing procedure. For each spatial frequency tested, the contrast was gradually reduced until the subject reported no longer being able to detect the sine wave grating. Contrast then was increased to the previous value, and, if detected, reduced again. Two "no" reports for a given contrast level was sufficient to terminate the run and the next highest contrast value was defined as the contrast threshold for that spatial frequency.

To obtain a measure of reliability with regard to the DCS apparatus and testing procedure all testing was repeated over the course of two testing sessions. The method used to assign subjects to experimental conditions was the same for both sessions. A testing session consisted of one static contrast sensitivity test and two tests of dynamic contrast sensitivity at two different target velocities (25 and 50 deg/sec). The order in which contrast thresholds were determined was randomized with regard to spatial frequency. Targets also were randomly divided into two sets (A and B), each containing six different spatial frequencies. All subjects completed the static testing condition first. This procedure allowed subjects to become familiar with the test stimuli prior to the dynamic contrast sensitivity testing. Subjects, then, were assigned randomly to two groups; one viewed the A set first, while the other viewed the B set first. Subjects also were assigned randomly to one of four DCS testing groups. Half of the subjects viewed the slower moving test targets first and the other half viewed the faster moving targets first. These two groups were further broken down by assigning subjects randomly to viewing either the A set first or the B set first.

In the static contrast sensitivity testing condition, the projector was set to change slides every five seconds until the first "no" response. The experimenter then proceeded with the staircasing procedure allowing approximately five seconds viewing time for each slide until a threshold was determined. For both of the DCS testing conditions target exposure time was held constant at 400ms. A 400ms exposure time is consistent with previous DVA work and allowed for an initial saccadic eye movement and a smooth pursuit movement (Miller &

Ludvigh, 1962). In the slower of the two DCS testing conditions, the targets were exposed over 54 degrees of arc and covered a linear extent of 11.4 cm. In the faster condition, the targets were exposed over 108 degrees of arc and covered a linear extent of 22.8 cm.

At the start of the testing session, subjects were seated in front of the DCS testing device with head stabilized by a chinrest. The testing device was at eye level with the subject. The overhead fluorescent lights were turned off and a red incandescent bulb was turned on. Such a situation served to maximize the visibility of the projected test targets while permitting the experimenter to record subject responses on a data sheet. A 5.7 cpd sample, high contrast sine-wave grating test pattern was projected onto the viewing screen of the testing device and was referred to during subject instructions.

Subjects were instructed that they will participate in a series of three different testing conditions to determine contrast thresholds for both stationary and moving sine-wave grating patterns across a range of spatial frequencies. A number of sample test patterns were presented to the subject. The samples included one low, one medium, and one high spatial frequency test pattern presented at decreasing contrast levels. Moving targets also were demonstrated. A sample threshold determination was carried out prior to actual testing. The demonstration procedures allowed approximately 5 minutes prior to actual testing during which subjects adapted to the lighting conditions of the test situation.

The optical power of the projected test targets was measured directly from the screen using a Jodon Engineering Associates, inc. Optical Power Meter, model 450-B. The test targets were found to have 0.1 milliwatts of optical power. Subjects were instructed that they should answer "yes" or "no" after each target presentation as to whether or not they were able to detect the presence of the grating pattern.

RESULTS

The effect of target velocity on contrast thresholds at each of the two testing sessions was assessed. Contrast thresholds were compared using a 3 x 12 x 2 (target velocity x spatial frequency x session) repeated measures, Analysis of Variance procedure. The test revealed a significant main effect for target velocity $\underline{F}$ (2,118)=55.43, $p<.0001$, a significant main effect for spatial frequency $\underline{F}$ (11,649)=118.14, $p<.0001$, and a significant target velocity by spatial frequency interaction $\underline{F}$ (22,1298)= 31.36, $p<.0001$. The Analysis of Variance procedure revealed no significant main effect for session and no significant interactions involving the factor of session. The contrast sensitivity functions for the static, slow, and fast conditions are plotted in Figure 2. Since there were no significant session effects, contrast thresholds have been

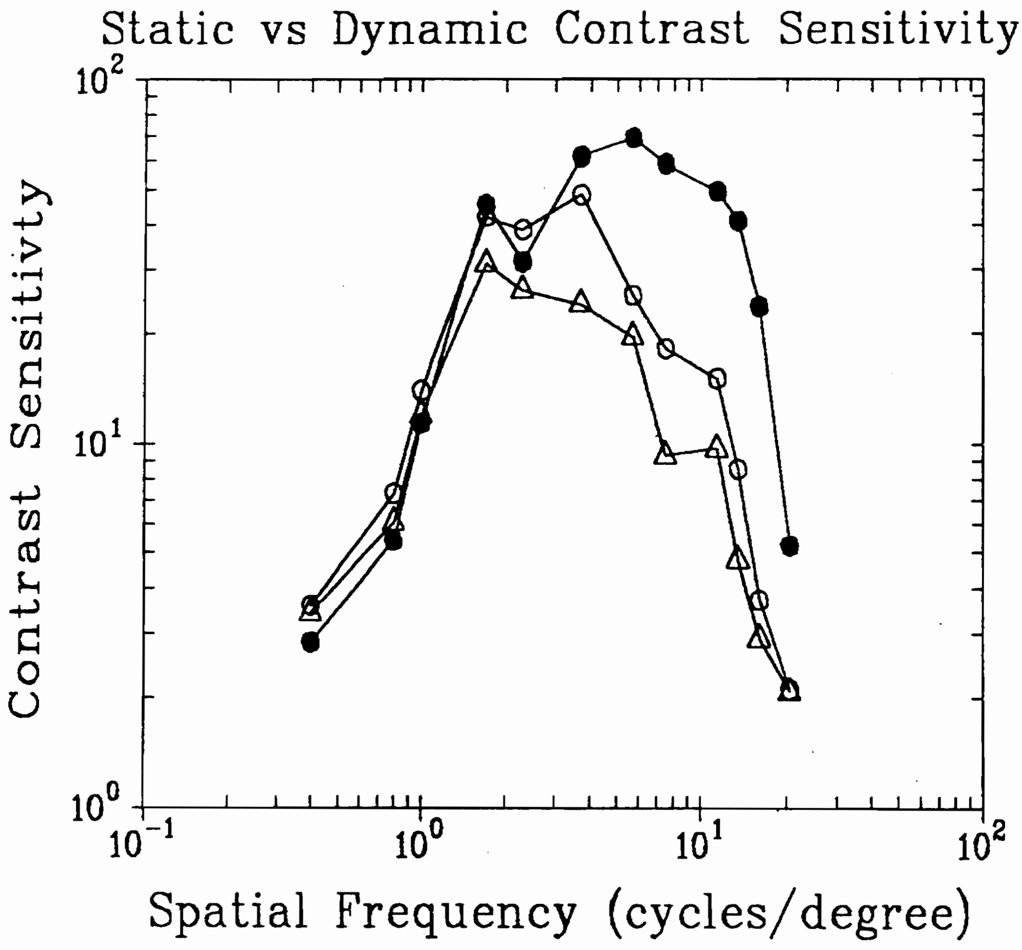

Figure 2. Static vs. dynamic contrast sensitivity: filled circles=static, open circles= 25 deg/sec movement, triangles = 50 deg/sec movement

averaged across testing sessions.

It can be seen that overall, contrast sensitivity tends to decrease with increasing target velocity. This is most apparent at the medium and high spatial frequencies. The mean contrast sensitivities across all 12 spatial frequencies for the static, slow, and fast conditions are 12.5, 7.69, and 6.32, respectively.

To examine the differences between the static, slow, and fast conditions more closely, a series of three contrasts were performed at each spatial frequency comparing contrast thresholds at each movement condition using an F test. The contrasts performed were static vs. slow, static vs. fast, and slow vs. fast. A Bonferroni procedure was employed to control for experiment-wise error such that the probability of committing a type-I error was held at 5% for the three contrasts performed within each spatial frequency. The degrees of freedom for each of these tests was 59. The results of these analyses are summarized in Table 1. For each spatial frequency tested, the mean contrast thresholds are given for each movement condition. Table 1 lists the F value and significance level for all pairs of means that were significantly different at the .05 level or less. For the sake of clarity, whenever a pair of means was found to be significantly different the direction of the difference is indicated with > and < signs. Reading from left to right, the signs positioned between the static and slow columns indicate the direction of the difference between the static and slow conditions and the static and fast conditions, respectively. The signs

Table 1

Statistically Significant Differences Between the Static, Slow, and Fast Movement Conditions at Each Spatial Frequency

Spatial Frequency (cpd)	Mean Contrast Threshold: Static		Slow		Fast	F-value and Probability level: St vs. Sl		St vs. Fst		Sl vs. Fst	
.4	.351	> >	.276		.291	30.5	.0001	15.3	.0002		
.8	.185	>	.137	<	264	32.4	.001			15.1	.0003
1	.088	>	.071	<	.083	26.8	.0001			9.00	.0039
1.7	.022	<	.023	<	.032			10.2	.0023	12.6	.0007
2.3	.031		.025	<	.038					21.8	.0001
3.7	.016	<	.020	<	.041			29.4	.0001	26.2	.0001
5.7	.014	< <	.039		.051	7.96	.006	33.3	.0001		
7.5	.017	< <	.055	<	.107	28.1	.0001	22.2	.0001	8.69	.0046
11.4	.020	< <	.066	<	.103	20.4	.0001	40.9	.0001	7.08	.01
13.5	.024	< <	.117	<	.209	27.9	.0001	38.1	.0001	23.7	.0001
16	.042	< <	.269		.343	38.9	.0001	150	.0001		
20.5	.191	< <	.473		.482	36.3	.0001	125	.0001		

Note. > and < signs indicate the direction of the difference. St = Static; Sl = Slow; Fst= Fast. cpd = cycles per degree.

which indicate the direction of the differences between the slow and fast conditions are positioned between the slow and fast columns. For example, Table 1 indicates that at the spatial frequency of 3.7 cpd the static condition did not differ from the slow condition but it was less than the fast condition. It also shows that the slow condition was less than the fast condition.

Inspection of Table 1 shows that at the spatial frequencies of 0.4, 0.8, and 1.0 cpd slow movement served to lower contrast thresholds compared to the static condition. Fast movement at the spatial frequency of 0.4 cpd. also served to lower contrast thresholds. At the spatial frequencies of 0.8 and 1.0 cpd. slow movement lowered contrast thresholds but fast movement did not. For each of the spatial frequencies at which target movement lowered contrast thresholds (0.4, 0.8, and 1.0 cpd) fast motion did not result in further threshold reductions over slow motion and actually resulted in an increase in the contrast thresholds compared to the slow movement conditions at the spatial frequencies of 0.8 and 1.0 cpd.

Another general trend is the tendency for contrast thresholds to increase with increasing target velocity. This trend becomes more pronounced as the spatial frequency of the test targets increase. For example, at the spatial frequencies of 7.5, 11.4, 13.5, and 16.0, both slow and fast target movement resulted in higher thresholds than the static condition and fast movement resulted in consistently higher thresholds than slow movement.

The hypothesis that the peak sensitivity will shift toward the lower spatial frequencies with increasing target velocity also was tested. Tukey's HSD was used as a multiple range test to determine whether the mean peak sensitivity scores differed between the static, slow, and fast conditions. It was found that each of the mean peak sensitivity scores differed significantly from each other $HSD(3,118)=.37$, $p < .05$. The mean peak sensitivity scores for the static, slow and fast conditions are 5.93, 3.84, and 3.21 cpd respectively. It can be concluded that the area of peak sensitivity does shift toward the lower spatial frequencies as target velocities increase.

DISCUSSION

The research effort reported here has been undertaken with two main goals in mind. The first goal was to develop a reliable means by which dynamic contrast sensitivity may be measured across a wide range of spatial frequencies. The second goal was to examine the effects of various velocities of target movement on contrast sensitivity across a wide range of spatial frequencies. A recent report from the National Academy of Sciences' Committee on Vision (1984) has recommended that such an investigation be undertaken. The present research represents the first and only attempt to date toward accomplishing this objective.

The first step toward the completion of the above stated goals was to design and construct a device which may be used to present sine-wave grating patterns at various target velocities. The device was constructed in such a way that the traditional methods for measuring DVA could be employed in the measurement of DCS. This is desirable because it will allow for a more direct comparison to the existing body of research on DVA. As mentioned in the Introduction, numerous studies have used non-stationary sine-wave grating patterns as test stimuli, but this motion has, for the most part, been accomplished through temporal modulation which produces apparent motion within a stationary field. As such, it is unknown whether the pattern of eye movements employed in this situation is comparable to those which are used to track actual moving targets. For this reason, the apparatus that was designed for the current research presents actual moving targets. The DCS testing device also is capable of producing target velocities comparable to those which have been used in previous DVA research.

The main difference between the DCS testing device and those which have been employed in previous DVA research is that the type of motion produced is circular rather than horizontal, although circular movement has been used for DVA research in the past (Miller, 1956). It has been shown that individuals who demonstrate superior DVA performance with horizontal movement also show superior performance with circular movement. Scialfa et. al. (1988) point out that the extraocular musculature involved in rotary pursuit movements is different than that involved in linear pursuit and that rotary pursuit is probably more taxing on the pursuit system. This may be an advantage, however, when rotary motion is used to test visual ability because, as Scialfa et.al. point out, individual differences that may not be measurable with an easier task such as horizontal movement might surface when rotary motion is employed. As such, rotary movement may make for a more sensitive test of visual ability.

While the current study has attempted to create a testing method which is comparable to that of previous DVA research, the device which has been constructed for the present study has some distinct advantages over the more traditional DVA testing apparatus. The devices which have been used to present moving test stimuli in previous DVA research typically have been fixed-base projection systems where either a rotating projector, or a rotating mirror positioned in front of a projector, is used to project test targets on to a semi-circular screen. Such devices take up considerable space and cannot be transported. The DCS testing device, on the other hand, can be easily transported and very little testing space is needed. This will greatly facilitate the testing of diverse subject populations since individuals will not be required to come in to the lab for testing. Some subject populations which are of particular interest include children, the elderly, and military personnel.

Another advantage of the DCS testing device is that it has proven to be extremely reliable in that there have been no mechanical malfunctions throughout the course of subject testing for the current study or in all previous subject testing. The traditional DVA testing devices, on the other hand, have in the past been subject to frequent malfunctions which result in loss of data and wasted time (A. M. Prestrude, personal communication, April 28, 1992). Thus, an important aspect of the current research project has been to fulfill a need for a portable and mechanically reliable method for projecting dynamic stimuli.

Another major component in the development of the DCS testing device has been the production of sine-wave grating slide transparencies. Scialfa et.al. (1988) used test stimuli that were produced by making slide transparencies of the Vistek Contrast Sensitivity Test System test plates. They reported that through this method the targets that they produced could not be detected reliably at spatial frequencies greater than 3.72 cpd. when target velocities were as slow as 20 deg./sec. Scialfa et. al. state that the reason for this is that they were unable to achieve a high contrast in their test slides. The method of producing sine-wave grating slide transparencies that was used for the current study has produced high contrast sine-wave grating patterns that range from .4 to 20.5 cpd. Thus, the current method for producing sine-wave grating slide transparencies is a significant improvement over that used by Scialfa et.al. and may represent the best method to date for creating sine-wave grating slide transparencies.

As stated earlier, a main concern in the development of the DCS testing apparatus has been that the test be a reliable measure of this ability. Since the Analysis of Variance procedure revealed no significant session effects it can be concluded that subjects' responses to the test targets were consistent across the two testing sessions and that the test is a reliable measure of DCS.

The second goal of the present study was to examine the effects of target movement on contrast sensitivity when the type of movement is similar to that which has been used in previous DVA research. As mentioned earlier, numerous studies have examined the effects of non-stationary temporally modulated sine-wave gratings on contrast sensitivity but this type of motion takes place within a stationary field, and as such, probably does not require subjects to employ the same types of eye movements that are needed to track and resolve actual moving targets. It should be noted that most real-world tasks which involve the resolution of moving targets involve the type of tracking eye movements that are required in a DVA task.

The results of the current study show that there is an overall tendency for DCS to decline as target velocity increases but that this effect is dependent upon the spatial frequency of the test target (see figure 2 and table 1). In table 1 it can be seen that fast target movement resulted in higher contrast thresholds (i.e. lower sensitivity) compared to the static condition for the spatial frequencies of 1.7, 3.7, 5.7, 7.5, 11.4, 13.5, 16.0, and 20.5 cpd. In the slow movement condition the contrast thresholds at 5.7, 7.5, 11.4, 13.5, 16.0, and 20.5 cpd. are all significantly higher than in the static condition. When fast and slow movement are compared in relation to the static condition it can be seen that fast movement results in a decrease in contrast sensitivity beginning at a lower spatial frequency than in the slow condition; 1.7 compared to 5.7 cpd.

The above results are consistent with previous DVA research in that target movement decreases one's contrast sensitivity just as it does one's ability to resolve standard acuity targets and that this effect becomes more pronounced as target velocities increase. A likely explanation for the observed decrease in contrast sensitivity is that as target velocity increases the pursuit eye movements which track the moving stimulus become less accurate, resulting in movement of the retinal image on the retina (Brown, 1972b). Recall, a number of studies have demonstrated the importance of eye movement control in DVA (Barmack, 1970; Brown, 1972b; Reading, 1972). Since the type of target movement used in the present study is similar to that used in previous DVA research, eye movement control should be no less important in the determination of DCS than it is in the determination of DVA.

An unexpected result of the current study is that at the three lowest spatial frequencies (0.4, 0.8, and 1.0 cpd) movement resulted in decreased contrast thresholds. At the spatial frequency of 0.4 cpd contrast thresholds did not differ between the slow and fast conditions but both of these were lower than the static condition. At 0.8 and 1.0 cpd contrast thresholds in the slow condition were lower than the static condition, but the fast condition had higher thresholds than the slow condition and did not differ from the static condition. In summary, slow target movement (25 deg/sec) has been found to decrease contrast thresholds at very low spatial frequencies (0.4, 0.8, and 1.0 cpd). Fast movement (50 deg/sec) also resulted in a contrast threshold reduction but this occurred only at the lowest spatial frequency tested (0.4 cpd).

A number of studies have found that at low spatial frequencies, stimulus movement enhances contrast sensitivity (Arend, 1976; Flipse, Wildt, Rodenburg, Keemink, and Knol, 1988; Kelly, 1979). Flipse et.al. used drifting sine-wave gratings where a fixation point was superimposed on the grating and moved at the same velocity as the modulation of the grating. In this way, contrast sensitivity was measured during smooth pursuit eye movements. Flipse et.al. used a 0.5 cpd grating and found that contrast sensitivity was enhanced by motion. This enhancement reached a peak at a velocity of about 20 deg/sec for each of their two subjects. An examination of the plotted data in this study also shows that at a stimulus velocity of 50 deg/sec, contrast sensitivity for a 0.5 cpd grating was about the same as that for a stationary grating.

The current study, which used target velocities of 25 and 50 deg/sec and a range of low spatial frequency test targets, corroborates and adds to these findings. Target movement of 25 deg/sec was found to enhance contrast sensitivity for spatial frequencies ranging from 0.4 to 1.0 cpd. An enhancement of contrast sensitivity was also found for the spatial frequency of 0.4 cpd at a target velocity of 50 deg/sec. Since Flipse et.al. found no enhancement of contrast sensitivity for a 0.5 cpd grating at a velocity of 50 deg/sec, the results of the current study suggest that as spatial frequency decreases, the velocity at which contrast sensitivity enhancement is greatest may increase. the same reasoning also suggests that target movement may enhance contrast sensitivity for gratings above 1.0 cpd, but the velocities at which this would occur would be slower than 25 deg/sec. Future research should examine this enhancement effect across a range of low spatial frequencies to determine the velocity at which different spatial frequencies show the greatest enhancement. Future research should also determine the highest spatial frequency at which an enhancement of contrast sensitivity occurs with motion.

A final result of the current study is that as the velocity of the test targets increases, the peak contrast sensitivity occurs at a lower spatial frequency (see fig. 2). Such a finding is consistent with both psychophysical and neurophysiological data which indicate that the human visual system is comprised of two separate visual channels which have different sensitivities to the temporal and spatial characteristics of stimuli (e.g. Kulikowski & Tolhurst, 1973; Brietmeyer & Ganz, 1976). The "sustained" channel is thought to mediate pattern detection and has a high spatial resolution but a slow response time. The "transient" channel, on the other hand, is specialized for the detection of motion. It has a faster response time than the sustained channel and is more sensitive to low spatial frequency information. Thus, a likely explanation for the observed shift in peak sensitivity is that as target velocity increases the relative contributions of these two channels in the perception of the test targets shifts toward the transient channel.

In conclusion, it has been demonstrated that the DCS testing device can function in a mechanically reliable manner, that it is able to produce consistent results across testing sessions, and that it functions to measure DCS across a wide range of spatial frequencies. As such, the device should serve to open up a variety of future research possibilities. First of all, future research will seek to determine the validity of DCS as a predictor of real-world performance on tasks such as flying, driving, and sports. As was made clear in the introduction, DCS seems to have a great deal of potential in this area. Another promising research area is that of DCS in the peripheral visual field. The circular motion that the DCS testing device creates is ideally suited for such studies. With a center fixation point, the retinal eccentricity of the test targets can be easily manipulated as well as exposure duration and velocity. A limitation of the current DCS testing method is that when a grating pattern travels in a circle it may be argued that this results in differential retinal smear throughout the target excursion. For this reason, the target exposure area in the present study was centered at the top of the circular path so that the target movement was similar to horrizontal movement. This places a limit on the velocities at which DCS testing may take place, however, since in order to maintain a 400ms. exposure time at higher target velocities the aperture will need to be opened wider, resulting in an increase in differential retinal smear. Were it not for this limitation, a logical course of future research would be to test DCS at higher target velocities. Other potential research areas include training effects, transfer of training to other activities, and the collection of normative data for DCS across a large age range.

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B.A. in Psychology (December, 1988)	Buffalo State College Buffalo, NY

Professional and Other Experiences

- Worked as a Relief Program Instructor for Peoples Inc. (Buffalo, N.Y.) at a community residence for developmentally disabled adults (1987 - 1988)

- Graduate Research Assistant on a study which assessed EEG correlates of hypnosis and pain (Spring, 1989)

Teaching Experience

- Fall, 1988 -	Instructor for Sensation and Perception Lab
- Spring, 1989 -	Research Assistant/Graduate Teaching Assistant for Introductory Psychology
- Fall, 1989 -	Instructor for Cognitive Psychology Lab
- Spring, 1990 -	Graduate Teaching Assistant for Abnormal Psychology/Graduate Teaching Assistant for Introductory Psychology
- Fall, 1990 -	Instructor for Sensation and Perception Lab

Graduate Coursework

- Research Methods I
- Proseminar in Psyc I (Bio/Dev)
- Proseminar in Psyc II (Learning)
- Statistics for Psychologists I
- Advanced Topics in Applied (Hypnosis)
- Statistics for Psychologists II
- Proseminar in Psyc III (Soc./Pers.)
- Information Processing
- Sensory Processes

Other Skills

- Proficient in the administration of a number of different standardized Hypnotic Susceptibility Assessment Scales.

- Experienced in the use of the Electroencephalograph (EEG).

- Experienced in Computer word processing and statistical analyses.

- Experienced in Psyc-Lit and Med-line CD-ROM database searches.

Publications, Presentations, and Reports

Olesko, B.M. (1988). Recognition memory: An automatic process? Paper presented at Student Research Symposium sponsored by Sigma Xi Research Society, State College at Buffalo, Buffalo N.Y.

Olesko, B.M., Arany, C.B., and Crawford, H.J. (1989). Cold pressor pain in low and high hypnotizables: Hypnotic analgesia versus waking. Paper presented at the annual meeting of the American Psychological Society, Alexandria, VA.

Crawford, H.J., Kitner-Triolo, M., Clarke, S.W., and Olesko, B.M. (1990). Transient positive and negative experiences in stage hypnosis participants. International Journal of Clinical and Experimental Hypnosis, 37, 356.

Crawford, H.J., Kitner-Triolo, M., Clarke, S.W., and Olesko, B.M. (1990). Paper presented at the annual meeting of the society for Clinical and Experimental Hypnosis, St. Louis, MO.

Clarke, S.W., Crawford, H.J., Kitner-Triolo, M., and Olesko, B.M. (1990). EEG correlates of emotions: Moderated by hypnosis and hypnotic level. Paper presented at the annual meeting of the American Psychological Association, New Orleans, LA.

Prestrude, A.M. and Olesko, B.M. (1991). Dynamic contrast sensitivity. Paper presented at the International Symposium on Aviation Psychology, Columbus, OH.